# From Biological Revolution to Biotech Age: Plant Biotechnology in British Agriculture since 1950

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The candidate confirms that the work submitted is his own and that appropriate credit has been given when reference has been made to the work of others.

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# Abstract

The modern Biotech Age possesses a very particular set of characteristics: the use of recombinant DNA technology, a close relationship between academic science and industry and, in Britain, public hostility to genetically modified crops. Yet despite increasingly widespread recognition among historians of science that biotechnology has a long and multi-faceted history, there is no thorough account of the history of plant biotechnology in British agriculture. Harnessing previously unexamined archival sources at the National Institute of Agricultural Botany (NIAB), John Innes Centre (JIC) and the Science Museum, this thesis uncovers a number of largely unexamined plant biotechnologies and discusses their uptake in British agriculture since the mid-twentieth century. In doing so, it raises several new insights for historians. Chapters One and Two demonstrate how two commercially successful biotechnologies, industrial hybridization and mutation breeding, found agricultural applications by careful integration with existing industrial systems. Chapter Three shows how plant cell fusion became a genuine alternative to recombinant DNA technology during the 1960s and '70s. Chapter Four counters the standard narrative of a move from the morphological to the molecular in biological analysis with a case study of electrophoresis and other classificatory technologies. Chapter Five demonstrates the importance of Cold War ideology on the development of biotechnology with a case study of the graft hybrid in British horticulture. Finally, Chapter Six examines the GM controversy in Britain and considers what broader lessons about public attitudes to biotechnology can be taken from the debate. Taken together, this thesis demonstrates that a unique combination of plant biotechnologies emerged in mid-twentieth-century Britain. These biotechnologies succeeded or failed to influence British agriculture thanks to a combination of technological, economic and ideological factors. The Biotech Age could, at many points since 1950, have emerged in a very different way with very different characteristics.

# Table of Contents

# List of Figures

# List of Abbreviations

AFRC – Agricultural and Food Research Council

AGS – Atomic Gardening Society

ARC – Agricultural Research Council

BAAS – British Association for the Advancement of Science

BSE – Bovine Spongiform Encephalopathy

BSSRS – British Society for Social Responsibility in Science

CAP – Common Agricultural Policy

CHA – Chemical Hybridizing Agent

EEC – European Economic Community

ESRC – Economic and Social Research Council

GM – Genetically Modified

GMO – Genetically Modified Organism

IAEA – International Atomic Energy Agency

ISTA – International Seed Testing Association

JIC – John Innes Centre

JIHI – John Innes Horticultural Institute

MAFF – Ministry of Agriculture, Fisheries and Food

MRC – Medical Research Council

NFU – National Farmers' Union

NIAB – National Institute of Agricultural Botany

NIRS – Near-Infrared Spectroscopy

OSTS – Official Seed Testing Station

PAGE – Polyacrylamide Gel Electrophoresis

PBI – Plant Breeding Institute

RHS – Royal Horticultural Society

# Introduction

> Indeed, if it once should become possible to bring plants to mutate at our will and perhaps even in arbitrarily chosen directions, there is no limit to the power we may finally hope to gain over nature.
> – Hugo de Vries, *Species and Varieties: Their Origin by Mutation* (1905)[1]

> My greatest satisfaction is not in having power over people, but in having power over nature. There was a wonderful pleasure in understanding the rules of nature and, having understood them, making those rules work for me.
> – Howard Schneiderman, leading biologist at Monsanto (1989)[2]

'How does this potato differ from a potato?' asked a leaflet from the chemical giant turned biotech firm Monsanto in the late 1990s, at the height of the controversy over genetically modified (GM) crops in Britain (Figure 0.1). 'It looks like any other potato' the leaflet continued. 'It doesn't taste any different.' In fact the only difference between an ordinary potato and the Monsanto potato was that the latter had been altered using 'plant biotechnology' to require less chemical insecticide. Yet there was no need for consumers to worry. After all, plant biotechnology was only 'a new stage in the development of traditional cross-breeding.'[3] The history of plant breeding was presented by Monsanto as a linear, natural progression from traditional breeding to genetic modification. 'Farmers and plant breeders', the company announced in a promotional brochure, have long 'mixed and combined genetic information in new ways to create better hybrids. Though they didn't know it, they were applying genetic engineering.'[4] For a biotech firm keen to market its latest GM crop plants to a sceptical European public, portraying its activities as no different to those carried out by farmers since antiquity was a tactical move to improve floundering public relations.

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[1] De Vries (1905): 688.
[2] Avise (2004): 49.
[3] 'How does this potato differ from a potato?' Monsanto leaflet, Professor Joyce Tait collection of GM material [hereafter shortened to 'Tait papers'], Science Museum Library and Archives, Box 7.
[4] Monsanto, 'Genetic Engineering: A Natural Science', Colin Merritt collection of GM material [hereafter referred to as Merritt papers], Science Museum Library and Archives, Box 1.


Figure 0.1: 'How Does This Potato Differ From a Potato?' Monsanto leaflet, Tait papers, Science Museum Library and Archives, Box 7.

A completely different take could be found among anti-GM and environmentalist organisations (Figure 0.2). In protest against a public event held by the European Genetic Engineering Industry in June of 1997, Greenpeace described the 'release of transgenic organisms into the environment, particularly in large agricultural quantities' as 'an unprecedented experiment.'[5] Other campaign materials from Greenpeace described GM food as 'an experiment with nature.'[6] To those opposed to GM, the genetic engineering carried out by firms like Monsanto was something radically different from all that had gone before. It certainly had no valid parallels with traditional breeding techniques, namely the selection or crossing of promising crop varieties. Monsanto and Greenpeace not only hold wildly divergent views on the merits of GM crops, but also on the history of human attempts to manipulate crop plants. Is genetic engineering of crop plants using recombinant DNA technology really just another step in the development of plant breeding? Are GM crops completely different from all that has gone before?

A growing literature on the history of plant biotechnology indicates that a simple divide between traditional breeding and GM has never been representative of reality. Historians of biotechnology and agriculture have instead uncovered numerous and sophisticated techniques used in the manipulation of crop plants over the course of the twentieth century: hybridization, hormone treatment and irradiation among others. Yet there remain significant gaps in the current literature. Firstly, some important forms of biotechnology, notably cell fusion, have received less attention than they deserve from historians of science. Secondly, a great deal of attention has been paid to histories of plant breeding, when the scope of plant biotechnology extends far beyond this single activity. Finally, the majority of studies of plant biotechnology prior to the advent of recombinant DNA technology and genetic engineering have focused on the United States. These absences suggest that a great deal can be gained through the historical examination of lesser known techniques in plant biotechnology prior to GM, including those not directly involved with breeding.

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[5] Greenpeace International letter, Tait papers, Science Museum Library and Archives, Box 2.
[6] Greenpeace, 'Genetically Engineered Food: An Experiment with Nature', Tait papers, Science Museum Library and Archives, Box 2.

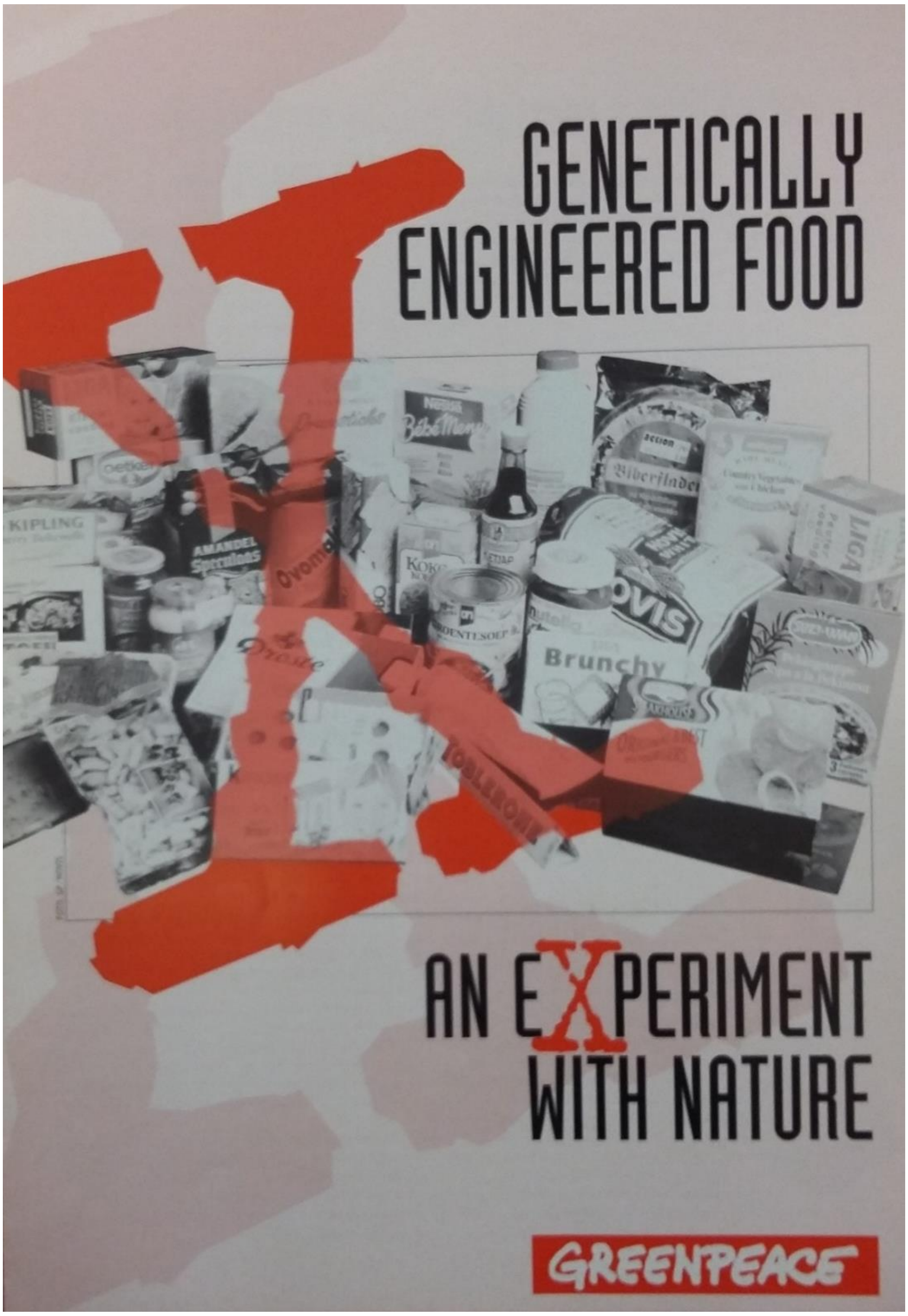


Figure 0.2: 'Genetically Engineered Food: An Experiment with Nature', Tait papers, Science Museum Library and Archives, Box 2.

This thesis addresses these gaps in our understanding with a ground-breaking study of plant biotechnology in Britain since 1950. A number of unique archives are held at agricultural institutions, plant breeding stations and rural museums in Britain. Foremost among these is the National Institute of Agricultural Botany (NIAB), the history of which from 1919-1969 has provided the basis of an earlier PhD thesis at the University of Leeds.[7] The archives of the NIAB and interviews with its staff are particularly important to this thesis, as the Institute has long been charged with testing crop varieties produced by plant breeders and recommending promising varieties to farmers: traditionally the final stage in the uptake of a plant biotechnology in British agriculture. Focusing on the United Kingdom is historically beneficial in a number of ways. The development of British plant biotechnology and its application to agriculture during the latter half of the twentieth century has remained largely unexamined by historians. This untold history is all the more promising for our understanding of biotechnology and twentieth-century science more broadly, given the post-war drive to modernise British agriculture, the looming shadow of the Cold War and the remarkable controversy over the arrival of GM crops in Britain. Given the largely unknown state of the history of plant biotechnology in Britain, this thesis poses three fundamental questions:

1) Which forms of plant biotechnology have been applied to British agriculture since 1950?
2) Why did some forms of plant biotechnology find a place in British agriculture, while others did not?
3) What role have Cold War divisions played in the development and uptake of plant biotechnology in Britain?

The remainder of the Introduction to this thesis will chart our current grasp of the history of plant biotechnology: from the technology used to manipulate crop plants, from how these technologies have developed, to their public reception and use in agriculture. The first of four sections in this Introduction covers the long history of biotechnology, where a flourishing historical literature has demonstrated that

[7] Berry (2014). The NIAB has also appeared in an earlier PhD thesis on Mendelism in Britain. Charnley (2011).

"biotechnology" is by no means a recent invention or buzzword. In fact a whole range of techniques fall under the banner of biotechnology, while attempts to manipulate life for human purposes have occurred throughout the twentieth century. The second section of the Introduction examines the recent literature on 'industrialized organisms', which casts plants, animals and microbes as biological components of industrial systems. This perspective provides fresh insights on how biotechnologically-altered crop plants can successfully become part of agriculture and related industries, such as brewing and food processing. Thirdly, a sizeable body of literature on the history of plant breeding is analysed, with particular attention paid to political influence. The twentieth century has seen different approaches to plant breeding align along Cold War divisions. Some plant breeders have defended their biotechnological productions on political grounds and ideology, while other forms of biotechnology have been neglected or abandoned on the same grounds. The final section of the Introduction maps out the structure of this thesis and presents some of its highlights and methodology.

## 1. State of the Historiography: The Long History of Biotechnology, in Britain and Beyond

In the February 1969 issue of *The Atlantic* magazine, Harvard historian Donald Fleming announced that the previous fifteen years had seen the occurrence of 'a veritable Biological Revolution', an event 'likely to be as decisive for the history of the next 150 years as the Industrial Revolution has been for the period since 1750.'[8] The mid-twentieth century had seen dozens of developments in biology, some of which are well known and celebrated: the discovery of the structure of DNA by Watson and Crick and the successful use of organ transplants in medicine. Others appear somewhat alien to the modern reader, for instance the creation of artificial hybrid cells via the fusion of different species. Our unfamiliarity with such forms of biotechnology is highly suggestive that we are somehow missing a trick. Our own 'Biotech Age' has instead seen plant biotechnology seemingly dominated by recombinant DNA technology and, more recently, genome editing. Is a straightforward leap from traditional breeding to the dominance of GM really representative of the whole history of plant biotechnology?

[8] Fleming (1969): 64-65.

Fleming's article would seem to indicate that this is not the case. More recent historiography has moved to back the claim that biotechnology has a long and complex history.

Writing in 1983, historian Edward Yoxen defined biotechnology as 'the engineering of life processes for commercial ends'.[9] His broad definition of biotechnology was fairly typical; both of its time and how the term is used today. The best known definition is that produced by the Organization for Economic Co-Operation and Development (OECD): 'Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services.'[10] Biotechnology can therefore be said to encompass many human practices: all the way from traditional breeding to fermentation, cloning and genome editing. Not only is biotechnology an all-encompassing term, but the word itself has a long history. Robert Bud has traced the etymological origins of biotechnology back to the early-twentieth century. Hungarian pig farmer Karl Ereky (1878-1952) coined the term 'biotechnologie' to describe his use of intensive factory farms at the beginning of the First World War, which were intended to efficiently fattening pigs on sugar beet.[11] Former editor of *New Scientist* Bernard Dixon noted that a Bureau of Biotechnology was established in Leeds back in 1920 to investigate the use of microorganisms for industrial purposes: brewing, sterilisation and the control of fungal and insect pests.[12]

Over the following decades, biotechnology took on many new meanings in different contexts and national settings. The twentieth century also saw the emergence of grand technological ambitions to control the basic processes of life. Luis Campos has described how a 'synthetic engineering-based approach to life' has been 'a prominent and reoccurring theme in the history of biology of the twentieth century.'[13] There are numerous examples of this theme: founded in 1904, the Carnegie Institution's Station for Experimental Evolution at Cold Spring Harbor sought to understand and direct the process of evolution to manufacture organisms best suited to human requirements of

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[9] Yoxen (1983): 14.
[10] Bud (1993): 1.
[11] Bud (1993): 32-24.
[12] Dixon (1985): 38.
[13] Campos (2009): 6.

beauty and utility.[14] Physiologist Jacques Loeb (1859–1924) tampered with artificial parthenogenesis, while in 1905 the physicist John Butler Burke claimed to have created artificial cells.[15] These examples and attempts from agriculturally-minded breeders to improve livestock and crops, claims Campos, have all ‘contributed in their own way to the development of an explicitly engineering-based approach to life.’[16] In one form or another, biotechnology has been a defining feature of the twentieth century.

Human attempts to tinker with life have a long history, emerging as what we would today recognise as biotechnology by the early years of the twentieth century. Hannah Landecker has shown how a growing realisation of the plasticity of life and its susceptibility to human manipulation, even on the cellular level, emerged during this period. From 1907-1910, embryologist Ross Harrison (1870-1959) was able to demonstrably cultivate nerve fibres outside the body, creating a newfound ‘sense of possibility’ among biologists.[17] A series of joint-authored papers emerged from Alexis Carrel (1873-1944) and Montrose Burrows (1884-1947) of the Rockefeller Institute for Medical Research in 1910, which introduced the biological and medical worlds to tissue culture: a technique for the nurturing and multiplication of cells which was applied to plants by the 1930s.[18] Tissue culture opened up new avenues for the manipulation of plant life, including the development of herbicides based on plant hormones during the 1940s.[19] Tissue culture, like many other biotechnological techniques, crossed seemingly established boundaries between biological disciplines with ease. Microbiologists, zoologists and plant physiologists alike were surprised by the ability of cultured cells to exchange genetic material, causing widespread interest among biologists of all stripes in the possibilities of cell fusion from the 1960s.[20] By the mid-twentieth century, at the origin of the Biological Revolution, it would be no great leap to believe that biotechnology could offer control over the most fundamental processes of life.

A rich and expanding literature has uncovered myriad attempts to apply this ambition to the breeding and growing of crop plants. Nicolas Rasmussen has argued

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[14] Campos (2009): 6-7.
[15] Campos (2009): 9-10. On Loeb, see Pauly (1987).
[16] Campos (2009): 12.
[17] Landecker (2002): 682.
[18] Landecker (2007): 153.
[19] Rasmussen (2001).
[20] Landecker (2007): 181-182; Holmes (2018).

that the features of our modern recombinant-DNA based biotech industry – a partnership between research biologists and industry and collaboration between projects in pharmaceuticals, chemistry and agriculture – are not new.[21] During the 1930s the development of plant hormones to promote crop growth was in part driven by collaboration between the California Institute of Technology and the Merck pharmaceutical company.[22] This attempt to harness 'biomolecules to manipulate crop plant growth' is in Rasmussen's view, 'strikingly modern'.[23] The desire to use what we would now term plant biotechnology to revolutionise agriculture is a longstanding ambition. In a series of publications and a recent monograph, Helen Curry has charted how twentieth-century technological ambitions manifested themselves in American plant breeding through attempts to accelerate evolution. Since the 1920s, American plant breeders had resorted to the use of unconventional tools to induce beneficial mutations in ornamental and economic plants: what is now termed mutation breeding.[24] X-rays and chemicals were harnessed in a quest which was more often than not unsuccessful. Yet such efforts were representative of a 'new conception of the plasticity of living organisms in response to a technological intervention.'[25] The practice and ethos of plant biology has long been subject to technological ambition.

Late-twentieth-century innovations offered breeders new means of intervening in the breeding of crop plants. One offshoot of atomic energy development in the United States during the post-war era was the use of radioactive isotopes to investigate plant breeding and biology at institutions like the Brookhaven National Laboratory. Curry portrays this trend as an integration of technological systems: namely atomic energy and plant breeding. Much has been made of the political aspects of this research. Both Curry and Rasmussen have recognised that, in the United States, an emergent atomic energy industry required positive publicity. This could potentially be achieved through the improvement of crop plants, at home or abroad. The politics behind mutation breeding have been recognised in other contexts. Karin Zachmann has described how the application of atomic tools to plant breeding developed in different

[21] Rasmussen (1999): 245.
[22] Rasmussen (1999): 251-255.
[23] Rasmussen (1999): 259.
[24] For a concise overview of milestones in mutation breeding, see Curry (2015).
[25] Curry (2013): 747.

ways in East and West Germany, while Jacob Darwin Hamblin has explained how atomic age technological ambition and the need to promote the atom overrode all other considerations during the International Atomic Energy Agency's (IAEA) attempts to improve agriculture in the developing world.[26] The controversy surrounding atomic age biotechnology can be viewed as a foreshadowing of the later debates around recombinant DNA technology. Curry presents 'mutagenic techniques as an early precursor to contemporary genetic engineering'.[27]

The literature on the long history of biotechnology presents us with two historiographical takeaway lessons for this thesis. Firstly, it is clear that the development of different forms of biotechnology and their application to agriculture have not been a simple matter. Collaboration and crosstalk, whether between different scientific disciplines or science and industry are common. Jean-Paul Gaudillière has argued that special attention should be paid to these connections by historians of science, as the relationship between 'biochemical [and] genetic research in the post-war period' and 'technological development and industrial production' is important to understand the 'dynamics of knowledge production.'[28] In other words, if we are to understand why biotechnologies developed in certain ways, it pays to grasp the competing pressures driving their production: scientific, industrial and commercial. A second lesson is that what Nik Brown has termed 'bio-hype' – the association of biotech with 'stratospherically high expectations of immanent and revolutionary change' – is a reoccurring feature of the twentieth century.[29] On the one hand, bio-hype represents an obstacle for those who wish to understand the practical implications of plant biotechnology in agriculture and the wider environment. Yet bio-hype reflects major themes in the history of biotechnology, including the tendency of biologists and the wider public to 'completely overestimate the practical capabilities of technologies', including their potential risks.[30]

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[26] Zachmann (2015); Hamblin (2009); Hamblin (2015).
[27] Curry (2016): 12, 223. Curry does not go so far as to suggest that modern forms of genetic engineering have historical precedents.
[28] Gaudillière (2009): 21.
[29] Brown (2003): 4. 'Bio-hype' was also used by Jack Ralph Kloppenburg to describe a period of wild claims and promises following new innovations in genetic biotechnology (recombinant DNA technology and cell fusion) during the 1970s. See Kloppenburg (1988): 200.
[30] Brown (2003): 4-5.

Despite the expanding scope and scale of the literature on the long history of biotechnology, we lack any kind of comprehensive account of plant biotechnology in Britain. This omission is problematic, as it leaves our historical understanding of British agriculture and, by extension, the history of British science, economy and society, sorely lacking. As we have seen, plant biotechnology and its application to agriculture are revelatory of much wider historical processes: futuristic imaginings, industrial systems and the public image of science. Traditional breeding and genetic engineering are not the only two techniques ever deployed by plant breeders, nor has there been a smooth and uninterrupted transition from one to the other. This problem lead us to the first of the three research questions tackled by this thesis: which forms of plant biotechnology have been applied to British agriculture since 1950? Answering this question reveals that a far broader array of plant biotechnologies have played a role in British history than previously thought.

## 2. State of the Historiography: The Long History of Envirotechnology, in Britain and Beyond

As this thesis progresses, it will become clear that a myriad of different plant biotechnologies were applied – or at least were attempted to be applied – to British agriculture. This leaves us with the complex question of why certain plant biotechnologies were more successfully integrated into agriculture than others. A useful tool for approaching this question is provided by an 'enviro-tech' literature on the relationship between organisms and industrial processes, including agriculture. Historians of technology, notes Edmund Russell, have already done the hard work of developing 'sophisticated ideas about (1) why and how humans have shaped machines the way they have, and (2) how those changes have in turn shaped human society.'[31] For Russell, there is no reason not to simply apply these established ideas to the human manipulation of organisms, including microbes, animals and plants.[32] A number of important suggestions come from adopting such insights, among them the view that the traditional divide between plant and animal should be rethought. As historians

[31] Russell (2004): 4.
[32] Russell (2004): 4.

approach the Biotech Age, it makes less and less sense to stick to classificatory schemes when genes have been so regularly swapped between diverse species.[33]

The traditional boundaries between industrial raw materials and crop plants have also been placed under scrutiny. Mark J. Smith has shown how sugar corporations sought to 'integrate the agricultural landscape with modern technology', thereby placing a common crop plant at the centre of an 'agroindustrial enterprise.'[34] Sugarcane was seen as a raw material by industrialists, which could be transformed into a commodity using technology.[35] Smith's approach suggests that the commercial uptake of organisms – in both farms and factories – is to an extent dependent upon their compatibility with technological systems. This compatibility can either be achieved through the development of machinery and industrial processes, or by the alteration of the organism. Ann G. Greene provides one instance of the latter with her study of horses during the American Civil War. Breeding systems played a key role as horses were bred to fit certain criteria of size, strength and stamina. These new standards meant that the animals could be smoothly integrated with the demands of industrialised warfare: standardised horses could be 'used interchangeably' and equipment like harnesses could be of a standard size.[36] Even in the nineteenth century, humans actively interfered in the biology of organisms to meet industrial requirements. If anything, we should expect to see this trend exacerbated in the mid-twentieth century thanks to a wider array of breeding techniques and the realisation of the plasticity of life on the cellular level.[37]

Enviro-tech studies of twentieth-century American agriculture have reinforced our image of technological and biological innovation working hand-in-hand. A review of the literature in this field by Mark Finlay further highlights a growing consensus among historians that the boundaries between technology, agriculture, and the environment are at the very least blurred, if not non-existent. One notable example given by Alan L. Olmstead and Paul W. Rhodes is the breeding of new varieties of cotton by American farmers in the twentieth century. Farmers not only bred cotton for characteristics like

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[33] Russell (2004): 11-12.
[34] Smith (2004): 86.
[35] Smith (2004): 104.
[36] Greene (2004): 150. For a more detailed treatment, see Greene (2007).
[37] Landecker (2007).

hardiness and yield, but also attempted to breed varieties best suited to new mechanical technology.[38] Yet similar studies have also brought the complexities of the relationship between biotechnologically altered plants and industrial systems to the fore. J. L. Anderson's history of post-war Iowa places great emphasis on the agency of farmers who, rather than acting as passive receivers of new technology, 'carefully assessed each step in the technological revolution and chose the options that best fit their own circumstances.' Although most Iowans eventually adopted the new agricultural technologies developed during between the Second World War and the 1970s – herbicides, pesticides, hormones, antibiotics and machinery – at no point was this result 'inevitable or predetermined.'[39] It pays to be wary of technological determinism at all times, but especially in the history of twentieth-century biotechnology. The translation of a biological technique or principle into an established agricultural technology is rife with possible setbacks, while the possibility of outright failure is ever present.

Bert Theunissen has similarly shown how such ambiguities have surrounded the uptake of biological innovations among livestock breeders in the Netherlands since the 1970s. During this time, a major transition occurred in Dutch farming as the traditional Friesian cattle were phased out in favour of the Holstein variety. Existing narratives had pitched this transition as the result of breeders finally accepting the recommendations of scientists to adopt a form of breeding based on quantitative genetics: this capitulation was in turn cast as a triumph for a programme of state-driven modernisation. To use a familiar phrase among agricultural scientists of that era, 'breeding was finally evolving from an art into a science'.[40] Yet Theunissen demonstrates that it was not that Dutch breeders refused to accept the findings of quantitative genetics: rather, their priorities were different from that of geneticists. Breeders were not just interested in milk yield, but the outward appearance of their cattle: 'In their view, a good bull, like a good cow, was an animal that won prizes for conformation at cattle shows.' These qualities reflected the inner quality of the animal,

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[38] Olmstead and Rhodes (2007); Finlay (2010): 481-482.
[39] Anderson (2008); Finlay (2010): 482-483.
[40] Theunissen (2012): 279.

in terms of hardiness and constitution.[41] The eventual shift to Holstein cattle was 'neither an intended nor an inevitable outcome of the modernization project in Dutch agriculture', demonstrating that agricultural innovation 'cannot be planned.'[42] Transforming an organism into an integral component of a modern industrial system is not simply a matter of engineering or economics: prevailing beliefs and ideology must also be taken into account.

Broader sweeps of the enviro-tech literature confirm that the integration of living things into technological systems is very much a social, or cultural, process. For instance, Sidney Mintz has argued that the uptake of sugar among the British working class – while providing benefits in terms of additional intake of calories – was driven by mercantilists and industrialists, who portrayed consumption of sugar as 'natural and beneficial to workers', thereby reinforcing their own social power over the lower classes.[43] David Nye has emphasised that America's 'sociotechnical energy systems' are the result of specific choices made on cultural grounds.[44] How energy is created and delivered could conceivably look very different given a shift in cultural norms and attitudes. Given this insight, the role played by the imagination – of how a new environment might be constructed, or new sources of power unlocked – also features in such enviro-tech studies as Elliott West's account of changes to the American Midwest during the nineteenth century.[45] If we apply these conclusions to the history of twentieth-century plant biotechnology, it soon becomes clear that even the simplest and least controversial forms of biotechnology in agriculture today are hybrid entities: at once the result of technical proficiency and resilience twinned with a favourable cultural reception. There is scope for historians of biotechnology to further engage with the role of technological imagination and ambition.

If we step back from the international scene to focus on British-orientated literature, similar themes emerge on the relationship between organisms and

[41] Theunissen (2012): 286.
[42] Theunissen (2012): 309.
[43] Russell, et al. (2011): 250.
[44] Russell, et al. (2011): 250-251. For more on Russell's vision for a new approach to human history based 'on the evolutionary trajectories of non-human species' and his intellectual predecessors, see Radick (2013): 350.
[45] Russell, et al. (2011): 254.

technological systems.[46] Daniel Schneider, for instance, has portrayed nineteenth-century sewage systems as 'industrial ecosystems' comprised of building materials, organic waste and microbes.[47] Back in the world of agriculture, Abigail Woods's recent account of twentieth-century British pig production has given us two takeaway lessons. First, Woods demonstrated that what we would commonly assume to be the modern face of pig production – factory farming – was already in place in Britain by the 1930s. Furthermore, factory farming did not inexorably sweep away all other practices. Outdoor methods of pig production continued and were deemed both modern and efficient. We should be aware that terms such as modernity, efficiency and productivism are situated in a particular historical context.[48] Second, both farmers and agricultural experts were not obsessed with improving yields or efficiency at all costs. Instead, many were 'keen to develop what they considered to be natural methods that met the pig's natural needs and desires.'[49] A romanticised view of pig farming was therefore an integral part of modern agriculture. The moral beliefs and attitudes of farmers played a fundamental role in shaping the pig as an industrial organism and pig farming as an industrial system.

The expansive enviro-tech literature provides three lessons and a valuable tool for this thesis. The first lesson is that biotechnological manipulation of organisms should be considered in the context of industrial systems. It would be impossible to fully understand horse breeding in the American Civil War, for instance, without reference to the mass production of standardised harnesses and artillery. Similarly the direction of American cotton breeding is only fully explained by reference to new mechanical technologies used in its harvesting. This lesson has been increasingly taken up by scholars with interests in the history of twentieth-century plant biotechnology prior to recombinant DNA technology: for example, revived interest in mutation breeding from the mid-twentieth century was intimately tied up with the expansion of atomic energy. The second lesson is not to underestimate the role of cultural or beliefs and attitudes

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[46] The enviro-tech literature on Britain is sparser and some studies containing enviro-tech themes do not necessarily identity themselves as part of that field. An account of the existing literature on Britain by Jon Agar will appear in a forthcoming collection edited by Jon Agar and Jacob Ward, *Technology, Environment and Modern Britain* (2017).
[47] Schneider (1995).
[48] Woods (2012): 190.
[49] Woods (2012): 168.

within certain communities in shaping how and when biotechnology becomes part of an industrial system. Take the example of post-war Iowa farmers, who adopted new hormones and antibodies on their own terms. Or that of Dutch cattle breeders, who prior to the 1970s rejected quantitative genetics in favour of their own breeding systems which best met industry standards. Technological systems have also included a human element. Our third and final lesson has been articulated by Edmund Russell, who has dismissed the usual division made between animal and plant histories in light of recombinant DNA technology. Yet as we will explore in greater depth, this division also makes little sense in the decades prior to the modern Biotech Age: biotechnological visions and techniques have long moved between zoology, botany, microbiology and even medicine with surprising ease.

Enviro-technology is a useful conceptual tool with which to interrogate the development and uptake of plant biotechnology in British agriculture. By viewing common crops as industrial plants we can, like Mark J. Smith, see how such crop plants have become part of much wider industrial systems: whether in agriculture or food processes. We can also use this perspective to ask what characteristics possessed by these crop plants, or attributed to them, have encouraged their uptake in agriculture. As this thesis investigates means of altering the genetics of these crop plants, we can also see how biotechnology has been used to facilitate this uptake. The insight of enviro-tech scholars leads us to the second major research question of this thesis: why did some forms of plant biotechnology find a place in British agriculture, while others did not? This is perhaps an old question, but one which can now be answered in a new light. Biotechnology is an attempt to produce industrial plants to meet economic and social needs.

## 3. State of the Historiography: The Politics of Post-War Plant Breeding, in Britain and Beyond

Only a few years before the start date of Fleming's Biological Revolution, a colossal edifice of concrete and steel began to emerge from the South Bank district of London. By the summer of 1951 construction was complete and the Festival of Britain opened its doors to the public. A series of sites detailed Britain's contributions to the arts, science and technology. To find living things among a mass of exhibits, visitors travelled to London's South Bank and the Agricultural and Country Pavilion. Here, fruit trees, cereals, berries and hops were grown in a specially-designed greenhouse by representatives of various universities and plant breeding stations.[50] The British landscape was lauded for its highly-efficient farms, while 'Mechanization and science were linked with the breeding of plants and livestock.'[51] The Festival was both a celebration of Britain's victory in the Second World War and a symbol of national recovery.[52] One lesson for us to take away from the Festival is that plant breeding, like other forms of science and technology, was a highly politicised practice. Creating successful crop plants was perceived as a demonstration of national superiority. Within the charged atmosphere of the Cold War, portraying a favoured biotechnology and its botanical productions as conducive to Western power and ideology could pay dividends.

The close relationship between plant breeding and the state emerged at an early date and on an international scale. Olga Elina, Susanne Heim and Nils Roll-Hansen have charted the close relationship between states and plant breeding since the late-nineteenth century. Faced with growing urban populations and industry, it was imperative for nations to ensure agriculture could meet increasing demands for food and raw materials. In the United States, land grant universities and agricultural experimental stations were founded. A similar combination of academic institutions and agricultural stations devoted to plant breeding were developed in Northern Europe, with leading facilities established in Scandinavia, Germany and Russia by the early twentieth century.[53] Following the First World War and economic depression of the 1920s, the majority of industrialised nations pursued a policy of agricultural self-sufficiency as a means of freeing themselves from 'the destabilizing influence of the global market.'[54] Agricultural research was closely managed by the state for the national

[50] Banham and Hillier (1976): 106-107.
[51] Atkinson (2012): 85. Intriguingly, perhaps revealingly, the Pavilion was completely separate from the 'Exhibition of Science' based at the Science Museum in South Kensington. A guide for the latter was produced by Jacob Bronowski (1908-1974). Part of the Exhibition was devoted to 'The Structure of Living Things' which, Bronowski explained, demonstrated how plants and animals are 'shaped jointly by heredity and the environment'. See Banham and Hillier (1976): 144-146.
[52] Conekin (2003): 4.
[53] Elina, et al. (2005): 161-162.
[54] Elina, et al. (2005): 162.

interest. This maxim held true in early twentieth-century Britain, where state-funded agricultural research stations and breeding institutes produced improved crop varieties and supplied farmers with seed.[55] Ensuring that the nation possessed a plentiful supply of food was clearly a priority for Western governments. Yet how and why did the very act of plant breeding become political?

Under Stalin, the Soviet Union underwent a drastic transformation in industry, society and science. Out of the chaos of the Terror of the 1930s rose Trofim Denisovich Lysenko, a peasant farmer turned agronomist. After the Second World War, with the personal support of Stalin, Lysenko rose to the highest echelons of Soviet agricultural science.[56] Lysenko's views on biology were completely at odds with those of Western biologists, at a time of heightened tension and confrontation between the West and the Soviet Union. Lysenko opposed Mendelian and Morganist genetics, denied the central role of the chromosome in heredity and supported the inheritance of acquired characters. Understandably enough, Lysenkoist doctrine was not received with much enthusiasm by the majority of biologists in the West. Nikolai Krementsov has described how Western geneticists sought to support their embattled Russian colleagues, including producing an English translation and review of Lysenko's *Heredity and Its Variability*. Many articles in the West were highly critical of Lysenko and the suppression of genetics in the Soviet Union, although American reviewers of *Heredity and Its Variability* were careful to avoid provocative political comments and critiqued Lysenko on 'scientific matters.'[57] Krementsov further suggests that such activities did eventually have a significant effect as the Communist Party leadership was more concerned with 'the current priorities of foreign and domestic policies' than 'esoteric scientific questions.' Scientific opposition between East and West was not simply ideological, but closely aligned with international relations.[58]

'The Cold War', declare John McNeill and Corinna Unger, 'was a contest for the hearts and minds of millions around the world, but it could not have been won without

[55] Palladino (1996): 116. Founded in 1919, the NIAB was one example of such an institution.
[56] On the rise of Lysenko, see Roll-Hansen (2005).
[57] Krementsov (1996): 240-242.
[58] Krementsov (1996): 240-242. On the reception of Lysenko among British scientists attracted to Soviet Marxism, see Paul (1983).

successfully filling stomachs.'[59] Concerned by the possibility that hunger in Latin America and Asia could spark Communist sympathy, American authorities embarked upon the Green Revolution: supplying countries such as Mexico and India with high-yielding crop varieties, agricultural chemicals and machinery.[60] Crop plants, supposedly bred with the aid of Western genetics, were a strategic tool in the global battle against Communism. Although 'agronomy, water management, and botany may not have been at the forefront of strategists' minds at Potsdam in 1945', it soon became apparent that the global and 'politico-ideological' characteristics of the Cold War required that such factors be harnessed to win it.[61] John Perkins portrays American plant breeding in the post-war era as 'critically shaped by the development of the Cold War', including theories which linked 'overpopulation, resource exhaustion, hunger, political instability, communist insurrection, and danger to vital American national interests.'[62] Wheat breeding, for instance, 'acquired ideological dimensions' as such practices entered the global 'battle for freedom.'[63] More broadly, plant breeding in the West had become more than a source of national pride or security. The Cold War produced new ideological restrictions and incentives for plant breeders. In the midst of the Biological Revolution, plant biotechnology was faced with the duel challenge of producing successful crop plants and supporting Western genetics.

Due to this political context, some historical interpretations of plant breeding have been driven by their authors' ideological standpoint. One of the most blatant examples of this tendency comes from the history of hybrid corn in the United States. Hybrid corn was once held up as an example of practical benefits of Mendelian genetics and as counterpoint to the disastrous results of Lysenko's attempts to breed new crop varieties.[64] Left-leaning scholars with Marxist tendencies have sought to undermine this example: biologists Richard Levins and Richard Lewontin have argued that the success of hybrid corn was limited to the American Corn Belt, while agricultural production in the Soviet Union did not fall behind that of the United States.[65] Marxist sociologist Jack

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[59] McNeill and Unger (2010): 6.
[60] McNeill and Unger (2010): 6.
[61] McNeill and Unger (2010): 15.
[62] Perkins (1997): 119.
[63] Perkins (1997): 141.
[64] Graham (1998): 19.
[65] Levins and Lewontin (1985): 172.

Ralph Kloppenburg has portrayed the development of hybrid corn as stealing financial support from public plant breeding stations and granting private corporations intellectual property control over seeds.[66] Not only has plant breeding been a highly political act for much of the twentieth century, but its history has been subject to politicised interpretations. The Cold War and ideological divisions between East and West have had lasting repercussions in the historiography of plant breeding and biotechnology.

Marxist interpretations of the history of plant breeding continue to exercise considerable influence. Gregory Radick has shown one instance of the historiographical influence of the Marxian canon in action, drawing upon the example of leading British Mendelian William Bateson. In 1921 Bateson was called as an expert witness in a London court battle over the identity of peas. Despite plunging his hands into the messy world of intellectual property controversies in agricultural botany, Bateson has come to be remembered as an exemplar of pure science. His insistence on the practical utility of Mendelism and his open admiration for cooperation between science and private industries was, for a time, all but forgotten. Radick explains this contradiction as the result of Marxist-influenced interpretations of Bateson, beginning with an overtly Lysenkoist interpretation in J.G. Crowther's 1952 *British Scientists of the Twentieth Century*. Crowther cast Bateson as a member of the bourgeoisie: conducting middle-class science concerned with theoretical questions. In Crowther's eyes, when contrasted with the practical concerns of Lysenko, Bateson performed poorly when it came to applying his scientific insights to plant and animal breeding.[67] The Marxist interpretation of Bateson, at least until recent years, has won out.

Other scholars are more sceptical of the role of ideology within the agricultural and the plant sciences. Elina, Heim and Roll-Hansen have argued that, in the case German, Soviet, and Norwegian scientists during the Second World War, 'ideological attitudes or political convictions did not necessarily determine their acts.' Instead, these scientists were able to 'refer to the unquestionably positive role of scientific work to justify whatever they did, whether confiscation or collaboration.'[68] Did this side-lining of

[66] Kloppenburg (1988). For an overview of the hybrid corn debate, see Radick (2005).
[67] Radick (2013a).
[68] Elina, et al. (2005): 178-179.

politics and ideology also occur when it came to deciding which forms of plant biotechnology to pursue? Although Elina, Heim and Roll-Hansen do not argue that it did, there are some hints that plant biotechnology could be carried out regardless of ideological climate. Lysenko felt able to accommodate mutation breeding within his vision of Soviet agriculture, although the technology was elsewhere understood as a means of altering chromosomes to induce heritable mutations.[69] Yet such accommodation was grudging and was likely in part the result of Lysenko's reliance on practical agriculture and popular belief over theory.[70] Given the stark ideological divisions over biology during the Cold War, combined with the long tradition of associating successful crop varieties with science, it seems highly likely that Cold War ideology did have a significant effect on the development of plant biotechnology in Britain.

The politicisation of plant breeding during the mid-twentieth century and the historiography of plant breeding in the Cold War leaves us with three reflections to take into our study of plant biotechnology in British agriculture. Firstly, it is clear that plant breeding became of increasing concern to national governments during the war-torn years of the twentieth century. Crop plants were not only vital to the security of the state, but were held up as a source of national pride: a connection evident in the Agricultural and Country Pavilion at the Festival of Britain. Crops possessed a political life. Secondly, we might expect that Cold War ideology did play a role in the development of British breeding. It is likely that one immediate implication of Lysenko's doctrine for British breeders was that any form of plant biotechnology which seemed to suggest alternative mechanisms of heredity beyond the chromosome were immediately suspect. It is equally likely that forms of biotechnology which chimed with an 'orthodox' understanding of genetics were not only acceptable but would be actively promoted to refute Lysenko. Finally, we should be alert to the influence of Marxism in existing histories of plant biotechnology. Both plant breeding and its history have been practiced within a highly politicised context. We should not expect this association, nor the influence of Marxist history and biology, to have ended with the fall of the Berlin Wall.

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[69] Lysenko (1954): 548.
[70] Deichmann (2014): 69-70.

When we consider the ideological clash which occurred between East and West over the basic mechanisms of heredity following the Second World War, it seems likely that British plant breeders would be influenced by these opposing ideologies in one way or another. We should pay, where possible, close attention to the farmers who bred or received crop plants in the context of the Cold War. Just as hybrid corn in the United States was used to demonstrate the falsehood of Lysenko's theories of heredity, so British plant breeding programmes were interpreted as practical refutations of Soviet doctrine. These reflections lead us to the third and final research question of this thesis: what role have Cold War divisions played in the development and uptake of plant biotechnology in Britain? The history of British plant biotechnology demonstrates that the Cold War played an integral role in shaping which forms of biotechnology have been developed and used in agriculture.

## 4. Overview of the Thesis

This thesis is organised around six case studies of plant biotechnology developed for, or applied to, British agriculture since 1950. A number of these plant biotechnologies are largely unknown to historians of science, or have not been thoroughly examined in the British context. A broad range of institutions and actors are examined during the course of this thesis. The bulk of archival material harnessed in this thesis comes from the NIAB. Based in Cambridge, the Institute was founded in 1919 in response to calls from the farming community to improve the quality and reliability of British seeds, following food shortages during the First World War.[71] As a regulator and distributor of new plant varieties, the NIAB received the end products of various biotechnologies over the decades, including hybrid seeds and mutation-bred varieties. Much of the NIAB's archive, particularly material from the latter half of the twentieth century, has remained unexamined by historians. A number of other unexamined archival collections are also used in this thesis, including the papers of prominent British breeder George Douglas Hutton Bell, former Director of the Plant Breeding Institute (PBI), now held at the John Innes Centre. Seed catalogues from the Milns Seeds and Marsters Seeds firms, held at

[71] For the pre-1970 institutional history of the NIAB, see Silvey and Wellington (1997) and Berry (2014).

the Gressenhall Farm and Workhouse Museum, are used to retrace the development of mutation breeding. Material from the GM Archive at the Science Museum informs the unique take of the thesis on the GM debate.[72] Oral history interviews, from members of the NIAB, biotech firms and university departments, form a small but important resource for this thesis.[73]

Chapter 1 introduces us to 'industrial hybridization', a term this thesis uses to denote the mass crossing of crop plants to meet pre-specified demands from industry. The term not only reflects changing techniques and approaches to hybridization in the twentieth century, but also reflects the newfound role of hybrid crop plants as a fundamental facet of industrialised agriculture. Until now, historical studies of hybrid crop plants have largely confined themselves to hybrid corn in the United States. The use of industrial hybridization in Britain to create new barley varieties from the 1950s is not only a new story for historians, but offers us fresh insights on mid-twentieth-century fears and ambitions. This chapter first outlines the development of an exemplary hybrid barley variety, 'Proctor barley', at the PBI. This breeding programme, modelled upon and directed by the needs of the brewing industry, was the first instance of industrial hybridization to occur in Britain. The chapter then moves on to discuss why hybrids, including Proctor barley, were taken up with such enthusiasm in British agriculture. One dimension of this uptake was economic in nature, with Proctor barley bred along a pre-ordained template best suited for brewers. Yet another dimension of hybrids' popularity was more irrational and unpredictable. During the Cold War, hybrid crops were held up as proof of the truth of Western science and values. Breeding high-yielding crops was also seen as a survivalist tactic, countering Malthusian fears of a hungry future. Hybrids were also viewed as solutions to Britain's economic problems: 'declinism' and competition from the European Economic Community (EEC). The final part of the chapter discusses the long-term consequences of hybrid monocultures in Britain, including the rise of new crop diseases. Such unintended consequences in turn drove the development and uptake of other forms of plant biotechnology.

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[72] See Moses (2016).

[73] A significant number of the institutions mentioned in this thesis, including plant breeding stations, government laboratories and universities, have received funding from the Agricultural Research Council (ARC). On the origins of the ARC, see DeJager (1993).

Chapter 2 also explores a reinvented form of plant biotechnology: mutation breeding. With the invention of the X-ray and use of powerful chemicals, it became possible to artificially induce mutations in plants. In Britain, this practice became part of a call for a new science of 'chromosome breakage'. The launch of this new science was held at the John Innes Centre (JIC) in 1952, under the auspices of its director Cyril Darlington. One of the contributions of this chapter is to situate British mutation breeding within the broader science of chromosome breakage, which encompassed everything from plant breeding to cancer research. This chapter places mutation breeding within the context of the Cold War and Lysenko's denial of the role of the chromosome in heredity. The chapter then moves on to describe an atomic age mutation breeding programme, which has only formerly existed in the history of science canon as rumour. During the late 1950s a private breeding firm named Milns Seeds exposed barley varieties to gamma radiation. Mutants resulting from this bombardment went on to form the basis of highly successful and widely-grown barley varieties throughout the 1960s and '70s. Yet their wide uptake was not so much due to their superior genetics as good all-round characteristics and detailed information provided to farmers on how to grow them. At the same time that Milns were busy creating mutagenic barley, experiments on mutation breeding were also being conducted at the state-funded Radiobiological Laboratory at Wantage. Here a far more pessimistic take on the relationship between the atom and agriculture emerged, as the Laboratory conducted a series of experiments designed to uncover the impact of nuclear fallout on agriculture. By the 1970s, mutation breeding had run up against serious competition from a new generation of genetic biotechnologies.

Chapter 3 examines the turbulent history of plant cell fusion, a topic which – until now – has not been brought to the attention of historians of science in a comprehensive manner. Although plant cell fusion had been observed since the early-twentieth century, its heyday did not emerge until the 1960s. By this time, ambitious and technologically-minded plant physiologists had positioned their discipline as the best qualified to investigate the inner workings of the cell. This chapter recounts how, in 1960, plant physiologist Edward C. Cocking first used a chemical enzyme to strip away the walls of plant cells. This technique, although hampered by a lack of commercially available enzymes, made large numbers of highly malleable plant cells – called protoplasts – available to researchers. Artificial fusion of plant cell nuclei, or somatic hybridization, was first used by a team at the Brookhaven Laboratory in the United States to grow a whole plant in 1972. By then, plant physiologists, pathologist and geneticists had all become involved in cell fusion. Somatic hybridization was held up as the plant biotechnology of the future, capable of overcoming world hunger, crop disease and the reliance of modern farming on chemical fertilisers. Yet numerous obstacles upset attempts to apply somatic hybridization to agriculture. This chapter explains how somatic hybridization fell behind recombinant DNA technology thanks to a combination of supply problems and technical difficulties. The final section of this chapter introduces another plant biotechnology stemming from cell fusion: cytoplasmic hybridization. Used to transfer cytoplasm from one cell to another, this biotechnology was developed in the 1980s. Its advocates sought, ultimately unsuccessfully, to align cytoplasmic hybridization with recombinant DNA technology. Although plant cell fusion did not achieve anything like the ubiquity of other plant biotechnologies in British agriculture, the technique continues to be of great interest to plant breeders.

Chapter 4 temporarily moves the thesis away from the world of plant breeding to consider the role of plant biotechnology in late-twentieth-century crop classification. During the 1980s, the NIAB found itself struggling to fulfil one of its fundamental tasks as a technical organisation: identifying and classifying crop varieties submitted by British breeders for testing and trials. This task had traditionally been fulfilled by detailed morphological observation and measurement. Yet government cutbacks to agricultural institutions forced the Institute to explore other means of classifying crop varieties. This chapter shows how the NIAB turned to a biochemical method of analysing crop plants on the molecular level: electrophoresis. The technology, which operates by tearing apart cells to reveal their constituent proteins, promised great strides in speed, reliability and savings. Yet electrophoresis was not the only classificatory technology available to the NIAB. Spectroscopy and machine vision systems also offered automated means of analysing and classifying crops varieties. Furthermore, some plant breeders were unhappy about the Institute's use of electrophoresis. They feared that electrophoresis did not accurately represent the all-important phenotypic characteristics of plants, or that results could be faked by saboteurs or rivals. Machine vision systems, which used cameras and a computer database to distinguish between crop varieties, were more attractive to those who favoured the old morphological methods. Today the NIAB uses a combination of techniques for its classificatory work. This chapter uses the history of the Institute during the 1980s and early 1990s to demonstrate that a turn to the molecular, or even a biotechnological solution, was by no means inevitable in British agricultural botany.

Chapter 5 returns this thesis to the world of plant breeding, in order to discuss one of the most controversial and long-running disputes in biology: the existence of graft hybrids. This chapter begins by giving a potted history of the graft hybrid controversy prior to the Cold War, beginning with Charles Darwin's investigations into graft hybridization. Darwin thought that a graft hybrid – the hybrid offspring which supposedly occurred when one plant was grafted onto another – would provide valuable support for his theory of pangenesis. While this did not occur, belief in graft hybrids persisted well into the twentieth century. What seemed like a fatal blow to advocates of graft hybridization in the West was dealt by Lysenko's support of the theory and his false claims to have created graft hybrids. This chapter argues that this was not actually the case: bastions of support for Lysenko and the graft hybrid could be found across Britain during the 1950s and early 1960s. These included members of the University of Edinburgh and the East Malling Research Station in Kent. This chapter also recounts how the British horticultural community nurtured long-held beliefs sympathetic to graft hybridization, while British fruit breeder Ben Tompsett was hugely impressed by the state of horticulture in the Soviet Union during a visit in 1967. This chapter concludes by looking at the modern re-emergence of graft hybridization as both a valid scientific phenomenon and possible biotechnological tool. Molecular studies have recently vindicated supporters of the graft hybrid by showing that genetic exchange, and even cell fusion, can occur between grafted plants. The graft hybrid has once again become a political tool, used either to support Marxist interpretations of biology or to argue that current opposition to GM crops on grounds of unnaturalness is nonsensical.

With the chapter on graft hybridization, the sequence of case studies of plant biotechnology engaged in this thesis concludes. But the thesis itself does not. Throughout this thesis, hints of public anxiety at new forms of biotechnology and their creations sporadically emerge. In Chapter 2 we will see a degree of relief that experiments on the application of radiation to crop plants were confined to the relative safety of the Wantage laboratories.[74] In Chapter 3 we will observe the emergence of plant cell fusion against a documented background of public fear and revulsion at the crossing of human and animal cells.[75] It is appropriate that these attitudes are examined in their own right. This thesis will therefore move to examine public attitudes to biotechnology in agriculture through a case study of the GM controversy in Britain. This move is a way of examining what has, until now, been an incipient yet underdeveloped aspect of the thesis.

Chapter 6 finally brings us to the Biotech Age and the GM controversy in Britain. This chapter takes a less technical perspective than those which have come before it, by examining public attitudes to GM crops in Britain. The reasons for this shift are twofold. Firstly, crop varieties produced by recombinant DNA technology were largely developed in the United States. Unlike the other forms of plant biotechnology covered by this thesis, there is therefore comparatively less to say about their development in Britain. The second is that the debate over GM crops engaged the British public in an unprecedented manner. Although concerns were raised regarding some of the plant biotechnologies discussed in this thesis, they are minor in comparison to the GM controversy. This chapter begins by discussing some common arguments which have been used to explain the depth of public opposition to GM in British agriculture: rejection of science, food scares, national politics and innate disgust at transgenic organisms. A fresh perspective on GM debate is then introduced with environmental philosopher Mark Sagoff's claim that different attitudes to GM on either side of the Atlantic are the result of ingrained cultural differences about what constitutes nature. The remainder of this chapter is devoted to testing this claim using contemporary reports, surveys and interviews. Evidence in favour of Sagoff's claim appears in the British context via moral ambiguity towards genetic engineering and a longstanding tradition idealising the pastoral countryside. These beliefs have led to GM crops being widely perceived as unnatural, alien and damaging for the countryside. Although attitudes towards GM are extremely complex, cultural attitudes to nature can contribute to our understanding of opposition to transgenic crops.

[74] 'Use of Nuclear Radiation for Plant Breeding' (1956): 13.
[75] Wilson (2011): 75.

Taken together, the case studies in this thesis give us a new perspective on plant biotechnology in British agriculture as a wide-ranging and somewhat unpredictable enterprise. There has been little or no guarantee that the plant biotechnologies we are used to seeing in our fields today would succeed. We do, however, see some indications of what it takes for a plant biotechnology to be taken up in agriculture: robustness, compatibility with existing industrial or technological systems and contemporary beliefs. It is in this latter context that the ideological muscles of the Cold War can be seen driving British agriculture towards certain types of plant biotechnology – industrial hybridization and mutation breeding – and away from others, particularly graft hybridization. This tension between the 'contextual' and 'conceptual' worlds of Cold War ideology and industrial compatibility will be examined in the Conclusion with reference to the work of Stephen G. Brush and Jon Agar. Ultimately, the vagaries of history have left us with an incomplete vision of plant biotechnology in Britain, which is highly problematic when the history of biotechnology is called upon as a tool by those engaged in the GM controversy.

# 1. Industrial Hybridization: British Barley as Cold War Biotechnology

> All of this can be easily summarized. There is not enough food today. How much there will be tomorrow is open to debate.
> – Paul Ehrlich, *The Population Bomb* (1968).[1]

Hybridization, the sexual crossing of distinct varieties of agricultural plants, was by no means a new plant breeding technology by the latter half of the twentieth century. Hybrids can occur naturally, or through the movement of people and their plants across the globe.[2] During the nineteenth century, hybridization was occasionally viewed as a controversial technique. Breeders of ornamental plants could find their hybrid productions under attack by those who argued that hybrids were evidence of impiety, or transgressed the laws of nature. Even botanists once objected to hybrids, albeit in purely in conceptual terms, as their classification systems held no place for hybrid plants.[3] Even as moral and scientific objections to hybridization faded, hybrid crop plants remained generally unpopular with farmers. Hybrid cereals in particular produced sterile or inferior seed, a trait that did not endear them to those growers who wished to save their seed from each year's harvest for replanting. Yet the early decades of the twentieth century saw farmers' attitudes change, as a major development in plant hybridization occurred in the American Corn Belt.

To a remarkable extent, historical analysis of hybrid crops has revolved around a single plant in a single country: hybrid corn in the United States. Between 1910 and 1935, traditionally bred – either by deliberate inbreeding or open pollination – American corn varieties were gradually replaced by their hybrid counterparts. These hybrids were partly adopted by farmers for their superior characteristics: better yield

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[1] Ehrlich (1968): 24.
[2] Kingsbury (2009): 32.
[3] A shift in attitudes towards hybrids occurred sometime around the close of the nineteenth century. See Olby (2000): 67; Kingsbury (2009): 94-96. See also a forthcoming PhD thesis from Clare O'Reilly at the University of Leeds.

and resilience. Yet wider political and economic factors were also at work behind the triumph of hybrid corn. Farmers were actually paid not to produce corn by the U.S. government following the New Deal's Agricultural Adjustment Administration, with high-yielding hybrids allowing farmers to increase their production of corn while reducing the amount of land under cultivation: those who grew hybrids were able to maximise their profits while simultaneously qualifying for government pay-outs.[4] In the era of the Great Depression, the principal concern of the American public was to obtain 'ample and affordable supplies of food, clothing and shelter', perhaps explaining why hybrid corn, this 'strange new creation of science' was widely accepted with little or no public outcry.[5] Whatever the reason for their uptake, corn yields rose steadily in the United States following the development of hybrid varieties. Between 1930 and 1965, the volume of production increased by some 2.3 billion bushels.[6]

The landmark moment in the history of hybrid corn, and even Western plant breeding occurred on an Iowa corn farm in 1958: or so the story goes. In a visit to the United States, Soviet premier Nikita Khrushchev stopped to visit the hybrid seed-producing farm of Roswell Garst. Accompanied by a crowd of journalists and photographers, Khrushchev and his farm visit was depicted in a great deal of detail by the American media. The triumphal moment came when a jovial Krushchev held aloft an ear of Garst's hybrid corn in front of a crowd of reporters. As a photo opportunity, the moment was hard to beat. Krushchev's tacit endorsement of hybrid corn, an endorsement later confirmed by his planned Soviet Corn Belt held symbolic connotations.[7] Hybrid corn was living proof of the truth and utility of Western genetics in plant breeding and thus confirmed the bankruptcy of Lysenko's biology.[8] Yet this remains a hotly contested point, as there are significant reasons to doubt that 'agricultural reality', in the form of hybrid corn, 'crushed a would-be rival to genic biology'.[9]

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[4] Fitzgerald (1989).
[5] Duvick (2001): 72.
[6] Kloppenburg (1988): 91.
[7] Kloppenburg (1988): 91.
[8] Graham (1998): 19.
[9] Radick (2005): 33. Scholarly opponents of hybrid corn have argued that hybrid varieties could only have succeeded in the context of the American Corn Belt and that there is no sign that agricultural production in the Soviet Union lagged behind that of the United States. See Levins and Lewontin (1985): 172.

Figure 1.1: Krushchev and Hybrid Corn. One of a series of iconic images from Nikita Khrushchev's 1958 visit to Roswell Garst's farm. Khrushchev held aloft ears of hybrid corn: a symbolic action later confirmed by his endorsement of hybrid corn and planned Soviet Corn Belt. Image from: http://backstoryradio.org/2013/10/06/corn-diplomacy-and-the-cold-war/. Accessed 14/03/2016.

Hybrid corn is only a single case study, which alone cannot do justice to the whole story of crop plant hybridization and its life as a Cold War biotechnology. Using previously unexamined archival material from the Plant Breeding Institute (PBI) and the NIAB this chapter examines crop plant hybridization in Britain since the mid-twentieth century and its incarnation in three different eras. Firstly, we will explore the modern reinvention of agricultural hybridization – what this chapter terms 'industrialised hybridization' – and its use to create the archetypal organism of Britain's modern agricultural revolution: Proctor barley. We will also consider why Proctor was taken up with such enthusiasm in British agriculture during the 1950s, offering new insights into its success by describing how the variety was favourably received by the British brewing industry. Next we shall move on to the 1970s, when a new wave of hybrid crop plants, particularly brassicas, were enthusiastically endorsed at the NIAB and in the wider agricultural science community. This 'hybrid enthusiasm' will be explained with reference to Malthusian population fears and alarm at Britain's supposed economic decline. Finally, we will examine some of the unintended consequences of Britain's agricultural revolution, some of the most serious of which stemmed from monocultures dominated by hybrid plant varieties. The story of hybrid barley and its newfound status as an industrial plant can enhance our understanding of new biological innovations and their uptake.

## 1. Engineering Hybrid Barley

If you were a barley grower in 1950s Britain, you might well be forgiven for thinking that you were lucky enough to be on the receiving end of a radical development in plant breeding. Under the Directorship of George Douglas Hutton Bell (1905-1993), University College of Wales graduate and expert in the genetic variability of barley, the Cambridge-based PBI had just released a game-changing hybrid plant: Proctor barley.[10] In a series of crop trials conducted by the NIAB, yields from the new hybrid had outcompeted all comparable barley varieties. The NIAB went on to highly recommend the variety for

[10] Biographical information from Riley and Enderby (2004).

farmers in 1952, and in 1953 awarded Proctor its coveted Cereal Award.[11] Combining high yield with good malting quality, Proctor barley occupied approximately seventy percent of barley acreage in the United Kingdom by 1960. Executive Secretary of the Royal Society D.C. Martin wrote that production of barley in the UK had doubled over a six year period: on the basis of which the Royal Society named Bell the first recipient of the prestigious Mullard Award in 1967.[12] There was 'general surprise' that the Award – which recognises innovations of economic benefit to Britain – was granted to an 'agricultural scientist rather than an engineer.'[13]

Official accolades heaped upon Bell by the NIAB and the Royal Society were joined by unofficial accolades from admiring farmers. Some wrote to Bell to personally express their gratitude for his 'wonderful work' on Proctor barley.[14] Such acclaim left Bell visibly uncomfortable. In a 1953 letter to one such admirer, Bell morosely remarked, 'All I can hope is that the variety [Proctor] lives up to the reputation which it has so quickly acquired'.[15] In a 1954 letter to a member of a Somerset brewing firm, Bell stated that he thought Proctor had been 'taken up' too quickly. Moreover, he recalled doing '[his] best to damp things with Proctor before it had been put on the market'.[16] Bell blamed 'advertisement… for which neither the N.I.A.B nor I was responsible' for arousing an interest in Proctor that 'has been impossible to curb.'[17] It is truly extraordinary to find a popular crop plant being talked down by its own creator. With this level of enthusiasm from British farmers – if not from Bell – in mind, the question emerges of how such a game-changing crop variety had actually been produced. Or, more accurately, what made Proctor so different from other hybrid varieties?

The high yields which made Proctor popular with growers were the end result of something new: Britain's first industrial hybridization programme. In an address to the Royal Society in 1968, Bell himself laid out the intricacies of this programme to his

[11] Morris (1953): 460. Director of the NIAB Frank Horne subsequently considered the Institute's official endorsement of Proctor in 1952 to be one of the most important moments of his twenty-five year career. See Horne (1971): 400.
[12] D.C. Martin, Royal Society Press Notice, 18 July 1967, File 1, Box 26, PBI GDH Bell Collection, John Innes Centre Library and Archives [hereafter referred to as JIC].
[13] Riley and Enderby (2004): 38.
[14] Walter K. Sternfeld to G.D.H. Bell, 16 August 1953, File 3, Box 26, PBI Proctor Correspondence, JIC.
[15] G.D.H. Bell to Walter K. Sternfeld, 19 August 1953, File 3, Box 26, PBI Proctor Correspondence, JIC.
[16] G.D.H. Bell to H.L. Thompson, 29 June 1954, File 3, Box 26, PBI Proctor Correspondence, JIC.
[17] G.D.H. Bell to H.L. Thompson, 29 June 1954, File 3, Box 26, PBI Proctor Correspondence, JIC.

audience and explained how it had differed from what had gone before. Bell described how, back in 1933, an attempt was made to cross tough Scandinavian barley varieties with established British barley varieties. This programme involved 'several departures from the then accepted practice in devising and handling hybridization programmes.'[18] These departures from the norm included a larger number of hybrid crosses than were usually performed, longer crop trials and a harsher selection procedure based on the conformity of hybrids to a preconceived and idealised morphological model. Five years of crop trials resulted in five hybrid varieties, one of which was Proctor.[19] In order to produce the new hybrid barley, the traditional hybridization process had been extended, intensified, and launched with a specific goal in mind.

As a consequence of the precise modelling and industrial-scale trials required to produce industrial hybrids like Proctor, a whole new level of technical difficulty, expense and labour now faced plant breeders. In 1957, Dr. J.H. Oliver of the Briant and Harman Brewing Company described the complexities of the new 'hybridization process', which was in many ways testing to the endurance of the barley breeder. Hybridization of barley involved the careful removal of the plant's anther (to prevent self-fertilisation), followed by the delicate task of artificial introduction of pollen from the desired cross. With this complete, the de-anthered and pollinated plant had to be further protected from pollination by insects: usually by isolating the plant from its environment in a transparent covering. All in all, Oliver proclaimed, 'what might be termed the process of fertilisation is simple, but the trouble started is considerable.'[20] With this process being conducted on a far larger scale than before, it is little wonder that ordinary farmers lacked the time and resources necessary to carry out industrial hybridization. The task was instead left in the hands of specialist state-funded research centres like the PBI or, to a lesser extent, private breeding firms.[21]

Industrialisation had moved hybridization several degrees further away from the traditional tools of selection and crossing. Traditional breeding could potentially be carried out by farmers or private breeders, whose individual experience and skill were

[18] Bell (1968): 148.
[19] Bell (1968): 148.
[20] Dr. J.H. Oliver, 'Proctor', reprinted from the *Brewers' Guild Journal*, April 1957, File 1, Box 26, PBI GBH Bell Correspondence, JIC.
[21] The role of private breeding and seed companies is discussed further in Chapter 2.

vital to grow distinctive crop varieties in diverse growing conditions.[22] Hybrid crops like Proctor barley were very different: they degenerated over time, different varieties were practically indistinguishable from each other and their outward appearance gave no clues as to how they would grow. Expert input was already necessary to successfully breed and grow hybrids.[23] Huge amounts of investment and labour were now equally vital to grow hybrid barley on an industrial scale. It was such changes to plant breeding that would lead President of the National Farmers' Union Henry Plumb to declare that 'We have experienced since the War a silent revolution in British agriculture from a craft-based industry to one based on science and high productivity'.[24] Similarly, in 1970 seed merchant T. Martin Clucas described how the modern plant breeder, while 'still an artist, like his predecessor', was now 'aided by science and technology'.[25]

Like hybrid corn in America, Proctor came to be associated with technological development and the application of Western genetics to crop improvement. It is possible that Bell himself saw his hybrid barley as another blow against Lysenko's biology in the Soviet Union. During the course of his personal research into the history of barley, Bell became a close study and admirer of Russian agronomist Nikolai Ivanovich Vavilov (1887-1943).[26] Vavilov was one of the most prominent victims of Lysenko's campaign against Mendelian genetics, suggesting that Bell – like many other Western biologists and plant breeders – would have seen their efforts in overtly political terms. Industrial hybridization and the success of Proctor barley likely held an ideological component. Of greater importance to its immediate success in agriculture, however, were economic circumstances. After all, Proctor had been specifically modelled and bred to meet the evolving needs of British brewers.

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[22] Fitzgerald (1993): 328-329.
[23] Fitzgerald (1993): 342.
[24] Plumb (1977): 363.
[25] Clucas (1970): 48.
[26] Bell conducted a colossal amount of research into the history of barley, amassing a huge collection of notes from modern scientific texts and early modern herbals. Among his papers are extensive notes on Vavilov's research, including an image of the 'fundamental centres of origin of cultivated plants of the Old World', File 5, Box 28, PBI GBH Bell Collection, JIC.

## 2. Industrial Crosstalk with the Brewing Industry

As we have seen, part of the rationale behind developing a new form of hybridization during the 1930s and beyond was to blend the malting characteristics of British barley – which made it ideal for the brewing industry – with the hardiness of Scandinavian varieties.[27] Throughout the twentieth century, British agriculture and food processing had become more and more integrated. Thus, when structural changes to the brewing industry occurred, which favoured 'cheaper and larger, supplies of sub-optimal feeding

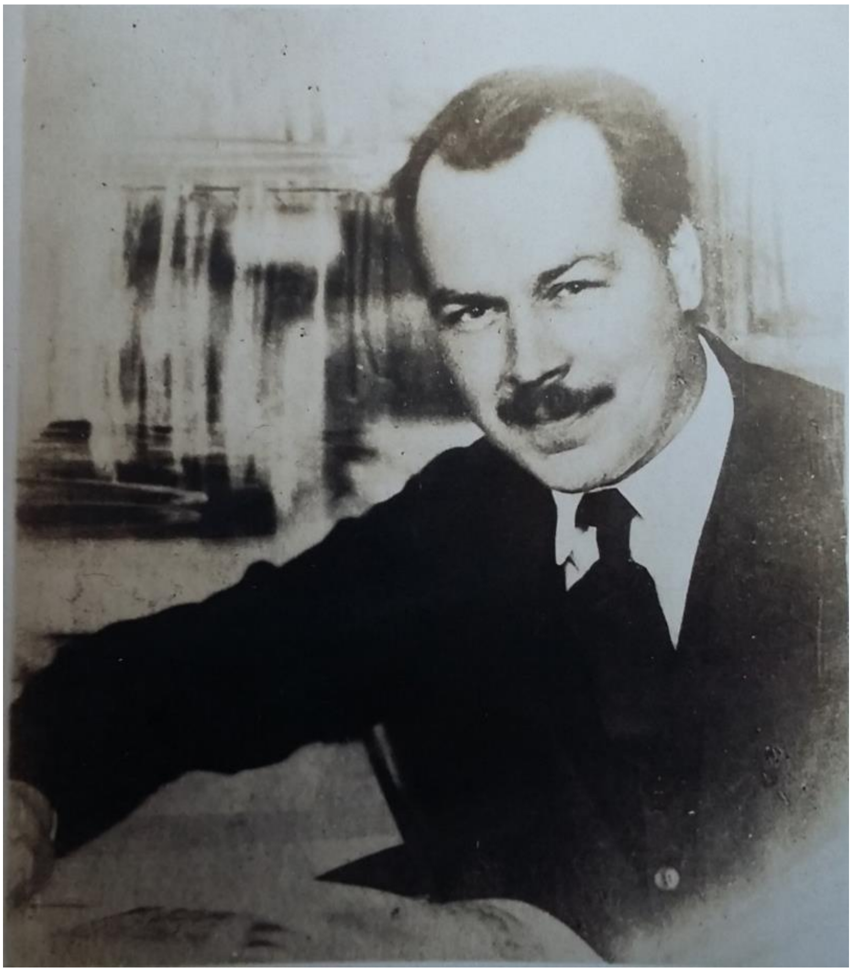

Figure 1.2: Nikolai Ivanovich Vavilov (1887-1943). This photograph can be found in Bell's personal papers at the John Innes Centre, along with extensive notes on Vavilov's work. Bell and Vavilov shared an interest in the origin of cultivated crops. Proctor barley was a living endorsement of classical genetics and a living refutation of Vavilov's rival and persecutor, Lysenko. Photograph dated January 1931. From File 3, Box 28, PBI GBH Bell Collection, JIC.

[27] Bell (1968): 147-148.

barley' for malting, barley breeders were well advised to respond to these needs.[28] The idealised model barley developed by industrial hybridizers in the 1930s was one ideally suited to the needs of the brewing industry. As one of the outcomes of this programme, Proctor barley combined high yields with the ability to be used as a malting barley. From its inception, Proctor was modified to smoothly fit into existing industrial systems.

A 1954 report from the Brewing Research Foundation noted that Proctor had been introduced 'to meet the demand for a malting barley which will give higher yields than the currently-used Archer hybrids.'[29] However, early feedback on Proctor from the brewing industry was somewhat restrained. A.R. McPherson of the Cape Hill Brewery in Birmingham only deemed Proctor 'satisfactory from the maltster's point of view' in 1955.[30] As time went on, praise for the variety did begin to grow from within the brewing industry. In February of 1955, the Director of the Norfolk Agricultural Station wrote directly to Bell, delightedly informing him that the Malting Barley Competition at the Stalham Farmers' Club had been decisively won by Proctor.[31] At a meeting of the Yorkshire Section of the Brewers' Guild in 1957, J.H. Oliver declared 'that Proctor was the most remarkable hybrid barley for brewing purposes that had ever been bred.'[32] Proctor slotted seamlessly into the British brewing industry as a biological competent overtly engineered to suit the needs of brewers. Other complicating factors were also at play in the widespread uptake of Proctor, including the growing profitability of livestock fattened on barley and a fall in oat (a rival animal feed) acreage.[33] These changes further encouraged British farmers to devote their fields to high-yielding barley.

Proctor barley and industrial hybridization in part enjoyed their success thanks to the targeted attempt by Bell and the PBI to meet the practical needs of the brewing industry. The carefully planned and hands-on production of Proctor had the further benefit of appealing to some members of the brewing community on an intellectual level. Some in the brewing industry, like J.H. Oliver, did not put much stock in laboratory scientists, particularly geneticists, as suitable experts on hybrid barley varieties. After all,

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[28] Palladino (1996): 120.
[29] Hall, et al. (1954): 464.
[30] McPherson (1955): 56.
[31] F. Rayns to G.B.H. Bell, 17 February 1955, File 3, Box 26, PBI Proctor Correspondence, JIC.
[32] Dr. J.H. Oliver, 'Proctor', reprinted from the *Brewers' Guild Journal*, April 1957, File 1, Box 26, PBI GBH Bell Correspondence, JIC.
[33] Palladino (1996): 120; Blaxter and Robertson (1995): 130-131.

the respected barley breeder Edwin S. Beaven had declared that 'the geneticist will generally offer an explanation of the plant breeder's results after they have been ascertained'.[34] By 1957 it was not Beaven's scepticism of hybridization that had endured, but rather his mistrust of scientific experts.[35] Following in this tradition, Oliver therefore put the decision of whether Proctor was a useful development or not in the hands of British brewers and maltsters. 'It would be unwise, indeed unfair,' he wrote, 'to think that it [Proctor] can be left to Lyttel Hall [The Brewing Research Foundation laboratory in Nutfield].'[36]

A favourable perception of industrial hybridization on both a utilitarian and intellectual level within the brewing industry was important in ensuring Proctor barley's commercial success. It was an advantage for Proctor to be a large-scale, field-tested, industrial technology: precisely because such an approach, and the organisms produced by it, fitted with the existing beliefs of those in the brewing industry. Laboratory science, and the geneticists' belated explanation of the heredity phenomenon, did not pass muster with either British barley breeders or brewers. By contrast, the hands-on and planned production of hybrid barley to meet certain specifications demanded by brewers appeared to be far more appealing to those like J.H. Oliver and his supporters in the Brewers' Guild.

Proctor barley was an industrial plant which achieved its prominence by meeting a pressing economic need. The variety was created in the minds of Bell and his fellow breeders before the first act of hybridization ever took place: a high-yielding crop tailor-made for malting by brewers. Yet tantalising hints emerge which suggest the success of Proctor was not only down to its smooth integration with an existing industrial process. The divisions wrought by the Cold War perhaps made themselves felt through Bell's admiration of Vavilov, while brewers like J.H. Oliver were pleased to see Proctor actively taken up and tested by maltsters, rather than being examined and recommended by geneticists. By the dawn of the 1970s, more and more hybrid crop plants were

[34] Dr. J.H. Oliver, 'Proctor', reprinted from the *Brewers' Guild Journal*, April 1957, File 1, Box 26, PBI GBH Bell Correspondence, JIC.
[35] Both Palladino and Kingsbury portray Beaven as part of an early twentieth-century backlash against Mendelian genetics. See Palladino (2002): 79-81; Kingsbury (2009): 173-174.
[36] Dr. J.H. Oliver, 'Proctor', reprinted from the *Brewers' Guild Journal*, April 1957, File 1, Box 26, PBI GBH Bell Correspondence, JIC.

becoming available to British growers. Their continued promotion and uptake, however, would now begin to rely far more upon contemporary fears and visions of the future than on economic necessity.

## 3. The NIAB's 1970 Hybrid Conference

With Proctor barley covering British fields, enthusiasm for hybrid varieties of all stripes was evident at the NIAB's 1970 conference, particularly from one of the Institute's Field Officers K.E. Haine. Leading the conference proceedings, Haine stated that the 'outstanding development resulting from basic research [in plant breeding] has been the use of F1 (first-generation) hybrids'.[37] In front of an audience of farmers, breeders and representatives of the food industry, Haine was pleased to report that a large number of brassica F1 hybrids were currently undergoing crop trials at the NIAB: including fifty varieties of that holiday favourite, Brussel sprouts. Haine went on to praise hybrid crops for their superior uniformity – meaning that few inferior 'rogue' crops existed in fields of hybrid crop plants – and yield. Rounding off his conference address, he declared that:

> In conclusion, a tribute should be paid to our plant breeders and to our seed merchants who have provided F1 hybrids, progeny tested stocks and other more general improvements to help the industry meet present-day needs. There is still plenty of work to be done and we wish them success in the future.[38]

Yet not everyone present was comfortable with Haine's vision of a hybrid future. The need for future work to better roll out suitable hybrid varieties to farmers was evident in a following talk on vegetable varieties, where F1 hybrids played a less noticeable role. In the discussion following that session, representatives of the wider agricultural community were able to voice their concerns regarding hybrids. A representative of Ross Foods, Mr. How, began by arguing that seasonal fluctuations in the performance of

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[37] Haine (1970): 1.

[38] Haine (1970): 1. Crop trials of high-yielding varieties were also conducted at the NIAB in 1970, including several varieties of Mexican semi-dwarf wheat. Unfortunately for their supporters, the damp British climate was less than kind. The semi-dwarf varieties, which had helped drive the Green Revolution, proved highly susceptible to mildew, despite the incorporation of fungicides in some trials. Director's Quarterly Report, April and May 1970, NIAB.

hybrid varieties was a matter of concern for growers. Far more damning was the next objector, a member of the National Agricultural Advisory Service (NAAS), Mr. Brown, announced that he actually preferred the consistency of older, traditionally-bred crop varieties. This remark was presumably intended as a rebuke against the tendency of hybrid crops to degenerate into parental types over successive generations. Faced with this backlash, Haine seemingly had no choice but to retreat and admit that hybrid varieties did have their faults. However, he was certain that these would be ironed out in the future.[39]

Despite doubts among their peers, the NIAB as a whole was keen to promote hybrid research and crop varieties throughout the 1970s. Moreover, this positive attitude towards new hybrid crops appeared to be shared by large segments of the British agricultural community. Addressing his colleagues in 1971, Director of the NIAB Frank Horne remarked that the 'whole concept of hybrids… is now receiving a great deal of attention by breeders.' Of particular interest was the hybrid vigour (heterosis) displayed by F1 crosses. Horne also spoke of promising developments abroad. Wheat and barley hybrids had been successfully tested in the United States, while hybridization between Scottish and Japanese brassica species had been found to display entirely new characteristics previously unknown to breeders.[40]

Although the NIAB's 1970 crop conference had largely focused upon vegetable hybrids, it was inevitable that at a least one speaker – in this case a member of the Scottish Horticultural Research Institute – would feel compelled to reference the great American success story of hybrid corn.[41] This is an important moment which demonstrated that hybridization, as a plant biotechnology, had become inexorably linked to the story of American hybrid corn. Regardless of what type of crop plant breeders sought to hybridize, whether barley or Brussel sprouts, an American success story could be drawn upon as both encouragement and justification for their continued activities. This parallel between British and American efforts at hybridization was all the more important at the NIAB's crop conference. Under pressure from opponents of hybrid vegetables, Haine had retreated and made promises of future improvements. If

[39] Reynolds (1970): 16.
[40] Horne (1971): 400.
[41] North (1970): 29.

attendees of the 1970 crop conference had stopped to consider the story of hybrid corn, Haine's promises of improvement and future success would not have seemed far-fetched.[42]

Major state-funded agricultural institutions like the PBI and the NIAB were enthusiastic supporters of hybrid varieties in Britain. Yet the 1970 NIAB conference suggests that hybridization was a contentious plant breeding technology. Discussion with the wider agricultural and food industry at the NIAB conference shows that there were those who objected to the whole technology of hybridization on fundamental grounds: not least the problem of degeneration of hybrid crops over the generations.

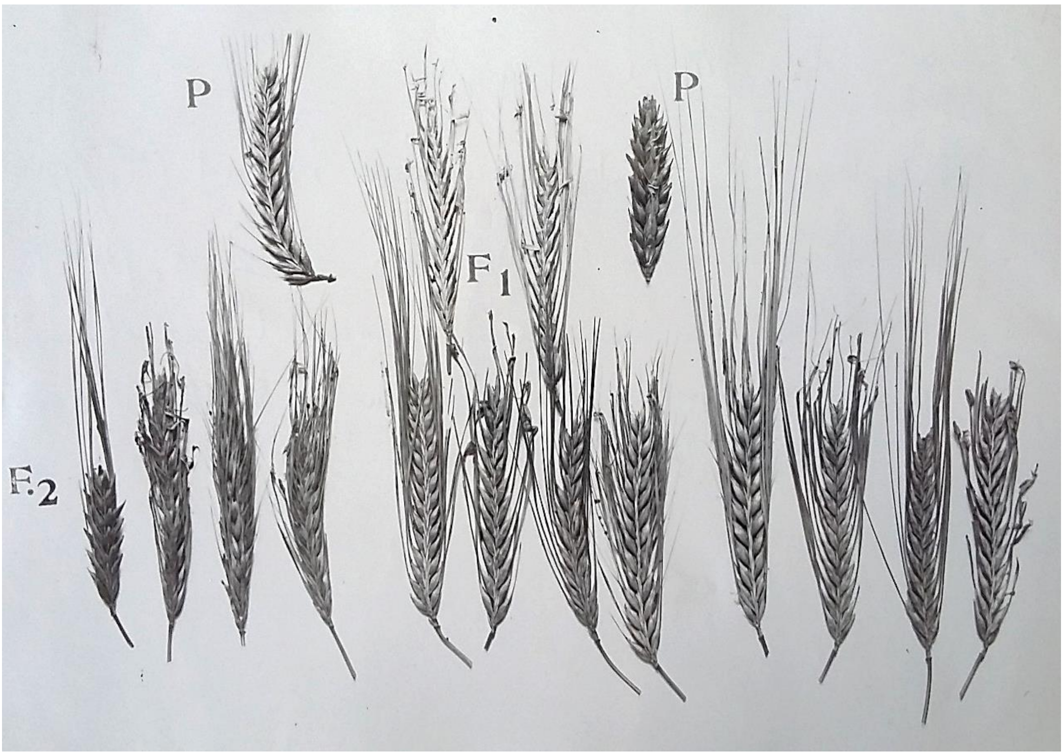


Figure 1.3: Hybrid Degeneration. With traditional crop varieties, farmers are able to collect the seed from their crop and replant it. This is not the case with hybrids. Following a cross between two parental varieties (P), a first-generation hybrid (F1) emerges. This hybrid exhibits 'vigour', or heterosis, which often manifests itself as increased size and yield. Yet the seeds of the F1 hybrid (F2) do not demonstrate this vigour. They instead begin to revert back to the parental types, increasingly displaying the characteristic of one parent or the other. The farmer is thus forced to return to a seed company on a regular basis to acquire more high-yielding F1 seeds. From File 3, Box 28, PBI GBH Bell Collection, JIC.

[42] Fortunate shifts in the barley market during the 1950s may have made Proctor barley a less compelling success story than hybrid corn. See Palladino (1996): 120.

Moreover there were alternative means of producing new crops varieties, whether through traditional selection and crossing or more outlandish forms of plant biotechnology.[43] Yet despite this opposition, hybridizers were able to move beyond Proctor barley to produce new hybrid crops into the 1970s and beyond. In the next two sections of this chapter, we will see how this continued support for industrial hybridization persisted, at least in part due to the emergence of very real fears of Malthusian population limits and economic decline.

### 4. Malthus's Shallow Grave

If you were an attendee of the NIAB's 1972 Seed Analysts Conference, the last thing you would expect would be a doomsday sermon laced with fire and brimstone. You would certainly not expect revolutionary rhetoric from the plenary speaker, Vice President of the National Farmers' Union (NFU) David H. Darbishire. Yet upon taking the podium Darbishire launched into an extraordinary speech, announcing the onset of a global crisis which threatened the very survival of humankind. The population of planet earth was growing exponentially. Food supplies were dwindling. Even inhabitants of rural Cambridgeshire could no longer ignore the ticking population bomb. Castigating his audience, Darbishire announced that farmers and scientists were too preoccupied with their own affairs, when they ought to recognise that they were part of a 'greater whole'. This recognition was vital, as population control would be unable to stem the rising human tide for several decades. Agricultural institutions such as the NIAB were desperately needed to feed the growing masses, while balancing a dangerous contrast between the world's 'affluent minority and disinherited majority'. Agriculture was both the saviour of humankind and a great social equaliser. In fact, farmers were a perfect example of democracy, their indispensable role as producers of the world's food standing the divine right of kings on its head.[44]

Darbishire's radical worldview stemmed from a doomsday tradition of Malthusian limits which, like scientifically-driven agricultural optimism, had emerged

[43] We will examine two potential biotechnologies available to breeders during the 1970s – mutation breeding and cell fusion – in Chapters 3 and 4.

[44] Darbishire (1972): 519-520.

during the immediate post-war period.[45] By the 1960s and '70s an array of influential 'neo-Malthusian' texts had emerged, most notably Paul Ehrlich's bestseller *The Population Bomb* and The Club of Rome's *The Limits to Growth*.[46] Their common theme was despair at an exponentially growing human population. Ehrlich, a Stanford entomologist, did not mince his words, declaring that the 'battle to feed all of humanity is over. In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now.' Scientific optimism was hopelessly naïve, as 'no changes in behaviour or technology can save us unless we can achieve control over the size of the human population.'[47] The neo-Malthusian worldview quickly made inroads into the British agricultural community, first entering the NIAB under the guise of former Food and Agriculture Organisation (FAO) official Norman Wright. At the NIAB's 1968 Seed Analysts Conference, Wright discussed the alarming rate of global population growth, which he believed to be increasing exponentially.[48]

Neo-Malthusians may have believed that a population crisis was inevitable and that science and technology could do nothing to avert it: yet supporters of Western agricultural practices and plant breeding held a very different position. Two years before Darbishire chastised NIAB's seed analysts, the Institute's forty-ninth annual general meeting was addressed by Professor Erik Åkerberg, agronomist and Director at the Swedish Seed Association in Svalöv. Åkerberg spoke to NIAB staff from a very different perspective, taking heart that 1970 marked seventy years since that greatest of scientific successes: 'the rediscovery of the Mendelian laws'. According to Åkerberg's potted history, once the realisation came that Mendel's laws were 'valid for agronomic characteristics in our cultivated plants', intensive research into plant breeding occurred, driving up yields.[49] If history was any indicator, the future for agriculture seemed bright. In Sweden, wheat varieties produced fifty percent more yield than those grown seventy years ago. Plant breeding would likely move growers away from their reliance on chemicals. A growing interest in genetic conservation had seen gene banks established

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[45] Vogt (1948). As a bestseller in multiple translations, Vogt's text remains the classic example. On its impact, see McCormick (2005).
[46] Ehrlich (1968); Meadows, et al (1972).
[47] Ehrlich (1968): xii.
[48] Wright (1969).
[49] Åkerberg (1970): 215.

Figure 1.4: The Neo-Malthusian Crisis. By the late 1960s, population increase was associated with overcrowding, the encroachment of urban development on the countryside, waste and pollution. Even food production once again assumed urgency as a matter of human survival, over a century since the last major famine in the industrialised world. Image from the Robert McCabe Papers, held at the University of Wisconsin-Madison Archives.

across the world.[50] Scientifically-informed agriculture and plant breeding was not only in excellent health, but held extraordinary promise.

Affiliates of the NIAB shared this optimistic stance on the application of science to agriculture during the 1970s. In an amended paper, originally given to the British Association for the Advancement of Science (BAAS) in 1970, Field Officer at the NIAB and writer on the Green Revolution W.E.H. Fiddian applauded a seventy-five percent

[50] Åkerberg (1970): 217-218.

increase in national cereal yield for England and Wales over the past thirty years.[51] A year later, plant physiologist M.B. Alcock of the University College of South Wales argued that there were no major limitations to the improvement of cereal production in Wales. First presented to a 1971 meeting of the NIAB's Fellows, Alcock's proposed strategy for pursuing this yield potential included the introduction of new crop varieties on the basis of the NIAB's trial results. Other methods for meeting Alcock's 'challenge for the future' included improving harvesting efficiency and optimising inputs of herbicides and fungicides.[52] History offered comforting rises in agricultural production through the application of science: the future appeared to hold similar promise.

Yet it was not only the NIAB's Field Officers who held a sanguine view of farming and its future. At the NIAB's 1970 crop conference, seed merchant T. Martin Clucas indulged in 'a little crystal-gazing' into future developments in plant breeding. Clucas' address listed promising advances made by both commercial breeders and state-funded ARC breeding stations. While 'still an artist, like his predecessor', the modern plant breeder was now 'aided by science and technology'.[53] A combination of intellectual property protection, in the form of Plant Breeders' Rights, state-supported basic research and hybrid crops, would result in significant improvements to yields. Laboratory techniques, including tissue culture, were another possible avenue for future research.[54] For noted figures in agricultural science and industry, science and technology held great promises for future food production.

The promises of plant breeding, including hybridization, were soon applied to the population problem in the minds of the British agricultural community. NIAB's 1976 'Fellow's Day' featured an address by President of the NFU, Sir Henry Plumb. Plumb's speech contained a mix of scientific optimism and Malthusian fears which were typical of his day. A glance at history, Plumb declared, revealed 'the magnitude of the advance agriculture has made in Britain and other developed countries'. Yet a glance at the future revealed 'the magnitude of the challenge we have yet to meet'. Alarming population growth was the challenge of the future, as the 'world's population increases

[51] Fiddian (1970).
[52] Alcock (1971).
[53] Clucas (1970): 48.
[54] Clucas (1970): 51.

by another Paris every two weeks'.[55] Like Åkerberg and Clucas before him, Plumb explained that his NIAB audience could take heart from the history of applied agricultural science: 'We have experienced since the War a silent revolution in British agriculture from a craft-based industry to one based on science and high productivity'.[56] Whilst key neo-Malthusian thinkers like Ehrlich maintained that science and technology were secondary in value to population control, those involved with plant breeding were less inclined to agree.

Improved crop varieties and changes to agricultural practice were not only important to stem starvation in the developing world. Neo-Malthusian arguments were supplemented in the British context by appeals to self-sufficiency and national security through domestic food production. Scottish ecologist Kenneth Mellanby recalled wartime rationing in his discussion of global population growth, while voicing scepticism about British reliance on the European Common Market for food supplies. For Kenneth Blaxter, agricultural scientist and fellow of the Royal Society, domestic food production was as much a strategic as an economic matter. Reliance upon food supplies from Europe was perceived as risky, since commodities from Europe could be cut off in the event of war or the emergence of new pests or diseases on the continent. Writing in a 1977 issue of the *Transactions of the Royal Society*, Blaxter instead recommended that marginal land be brought back into production as a national safeguard for food supplies.[57] Concerns over national food supplies were reinforced by other economic and social factors. Expanding agricultural production provided a means to avoid hunger, inflation and in Western Europe, the ability to avoid imports (due to a lack of American dollars), alleviating a foreign exchange crisis.[58]

For the British agricultural community, the population bomb could be defused and the threat to domestic food supplies lessened by the application of science to plant breeding. At the 1977 meeting of the BAAS, Professor Bleasdale of the National Vegetable Research Station joined a chorus of voices which urged industrialised

[55] Plumb (1977): 362.
[56] Plumb (1977): 363. In this address Plumb criticised Darbishire for what the former termed 'flights of fantasy': but not, as we might expect, for Darbishire's alarmist views on population growth. Plumb was instead referring to Darbishire's belief that nitrogen-fixing crops would be developed in the near future.
[57] Blaxter (1977).
[58] Shaw (2007): 14.

countries to use their own progress in agricultural production to supply the Third World. Part of Bleasdale's blueprint to kick-start what he termed Britain's own 'Green Revolution' was the NIAB, the variety-testing of which had revealed promising avenues for breeding, including the use of F1 hybrids.[59] Bleasdale's plan was not exactly revolutionary, as hybrid varieties had already permeated British farming by the time of the BAAS meeting. Nor did the Malthusian population bomb cause British breeders to produce hybrid crops, or farmers to grow them. Yet throughout the 1970s a sustained focus on increasing agricultural yields existed, a focus in part justified by a growing world population. High-yielding hybrid crops, grown abroad or in a domestic setting, were seen as a key part of the solution to the population problem. A renewed association of the hybrid crop plant with as a means of countering Malthusian limits had occurred exactly at the time hybridization's advocates needed it. The appeal of hybrid crops would be further increased by the perceived need to ramp up agricultural production in the face of economic stagnation and global competition.

## 5. Economic Concerns in British Agriculture

The latter half of the twentieth century saw a general assumption in political and popular thought that the British economy was falling behind its competitors. This idea of Britain's general economic decline, or 'declinism', came into its own as a political tool during the 1950s and '60s, allowing opposition political parties to declare that British standards of living had fallen behind other Western nations.[60] Declinism was a powerful force in British politics, culture and agriculture. By the early 1970s, it was undoubtedly the case that a declinist perspective existed among some members of the British agricultural community: a belief seemingly supported by convincing statistics on agricultural yields. Cereal yields were perceived to have fallen from their peak in the 1950s, the most optimistic interpretation being that one of the most important aspects of agricultural production was stuck on a plateau. A 1972 article by the NIAB's Field Officer W.E.H. Fiddian assumed that cereal yields were actually declining. This was due, Fiddian theorised, to an unidentified 'soil microbiological interaction', powerful enough

[59] Bleasdale (1977): 1-2.
[60] Tomlinson (1996): 732-733.

to counteract technologically-driven gains made during the 1960s.[61] By the end of the 1970s, the NIAB's publications portrayed yields as once again rising, albeit at a slower rate than in previous decades.[62] Fiddian was not alone. Those steeped in neo-Malthusianism also despaired at the decline of domestic agricultural yields. A sense of global crisis was further fuelled by a sense of agricultural decline.

Urban encroachment on the countryside was another one issue which caught the attention of Mellanby and Darbishire, both of whom cited the worrying figure of 50,000 acres of prime agricultural land lost per annum.[63] Plumb was similarly sanguine on the prospects of British agriculture: increasing food production, he declared, was necessary to fix Britain's 'chronically sick economy.' In the agricultural sector, this sickness manifested itself in large sums spent on imported food and animal feed. Referring to the foreign exchange crisis, Plumb noted that 'as the pound sinks lower, the bills rise higher.'[64] Despite huge gains in agricultural productivity since the Second World War, the representatives of British farming had wholeheartedly bought into the prevalent narrative of British decline. The general consensus among commentators was that intensification and expansion of food production was necessary to combat both Malthusian population limits and economic decline.

Britain's imminent 1973 membership of the European Economic Community (EEC) was another factor to consider: for Darbishire, speaking just one year before the event, the upheaval and competition posed by European partnership and the common market could conveniently be moderated by the expansion of food production at home.[65] Five years later, Kenneth Blaxter argued that in an essentially self-sufficient Europe, effective agricultural competition from British growers could provide the nation with the lucrative possibility of undercutting the competition.[66] Others also latched on to membership of the EEC as an economic opportunity. The new Director of the NIAB, P.S. Wellington, laid out his hopes for the future of the Institute at its 1972 crop conference. He hoped that the NIAB would benefit from EEC entry via increased returns

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[61] Fiddian (1972).
[62] 'The Contribution of New Varieties to Increasing Cereal Yields', NIAB Fellow's Newsletter 69, June 1978, Folder N1-11, NIAB Archives.
[63] Darbishire (1972): 520; Mellanby (1975): 12-13.
[64] Plumb (1977): 363. Loss of prime agricultural land was also referenced by Plumb in his address.
[65] Darbishire (1972): 520.
[66] Blaxter (1977): 4.

from trade in UK cereal seed, varieties and access to European Agricultural Guidance and Guarantee Funding (FEOGA) opportunities. For Wellington, competition from European plant breeders was of little concern, as there had 'never been any form of [economic] protection for British seeds or British varieties.'[67]

By the early years of the 1970s, the British agricultural community was confronted by a trinity of pressing concerns: global population growth, economic decline and membership of the European Common Market. As we have seen, the general response to all three of these concerns was to urge scientists, breeders and farmers to ramp up agricultural production. Blaxter favoured cultivation of marginal land, whereas Bleasdale attempted to encourage a British 'Green Revolution' and the widespread adoption of hybrid crop plants. In the debates over declining cereal yield in Britain, it seems that improved means of plant breeding were the favoured solution. Fiddian's 1972 paper had argued that traditional inputs like nitrogen fertilisers would not arrest the declining yields of British farms. His reasoning was that nitrogen was already being used at crops' maximum economic response level. A solution could instead be found by breeding new crop varieties which could make better metabolic use of nitrogen: this was a goal which would become the holy grail of plant biotechnology.[68]

Ultimately the arguments for increasing food production lost much of their force as Britain entered the EEC and came under the Common Agricultural Policy (CAP), described by one commentator as a state-imposed protectionist barrier against market forces.[69] British critics of the CAP questioned why a fixed-price system had been adopted which insulated domestic markets from world influences, thereby depriving consumers of cheaper supplies.[70] A situation had developed where encouragement of productivity – traditionally seen as the defining goal of government and industry in relation to agriculture – clashed with the barriers of European pricing, which prevented food being sold off cheaply elsewhere.[71] Intensified production of food using hybrid crop plants was therefore no longer necessary. Yet by the time this situation became apparent, intensive monocultures – including those dominated by hybrid crop varieties

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[67] Wellington (1972): 1.
[68] Fiddian (1972).
[69] Beresford (1975): 217-218.
[70] Tracy (1989): 269.
[71] Solbrig and Solbrig (1994): 205-206.

– pervaded British agriculture. Highly vulnerable to plant disease, these monocultures soon became the site of a major setback for hybrid crops in agriculture.

## 6. Hybrid Monocultures and Rise of Plant Disease

The drawbacks of hybridization became apparent to all when disaster struck the American hybrid corn belt in 1970. That year the southern leaf corn blight, a fungal disease, wiped out some fifteen percent of the corn crop in the United States. The corn blight was the consequence of hybrid corn's 'Genetic vulnerability', which stemmed from 'dependence on a narrow base of germplasm'.[72] In a field of crop plants dominated by a single variety, genetic uniformity can become a weakness: a weakness which allows disease to spread rapidly among near-identical plants which possess no effective defence. It was no secret that, from the 1950s onwards, British agriculture was increasingly dominated by far few varieties of crop plants than had previously existed. A meeting held at the NIAB in 1954 heard complaints that small seed merchants could no longer keep up with the demand for the small number of varieties which dominated Britain's cereal acreage.[73] As we have seen, among these domineering varieties were the new industrial hybrids: including Proctor barley.

By the early 1970s, both the NIAB and its farming membership found themselves struggling with plant disease. The NIAB's regional crop trial centres were routinely hit. A routine report from the Wye College site, for instance, described cereal disease such as rusts and mildew as 'severe at times'.[74] Contributor to the NIAB's journal and potato seed merchant, M.F. Strickland, spoke of the difficulties facing potato seed producers, merchants and growers in the form of latent disease. The problems of plant disease were such that Strickland was sceptical of those who claimed to be able to avoid disease entirely, remarking that producing healthy seed was 'not such a simple exercise as many of us, and certainly the pesticide manufacturers, would

[72] Kloppenburg (1988): 122.
[73] Dudley (1954): 198.
[74] Gregg (1971): 356. The south-west of the country was compared unfavourably in terms of cereal disease.

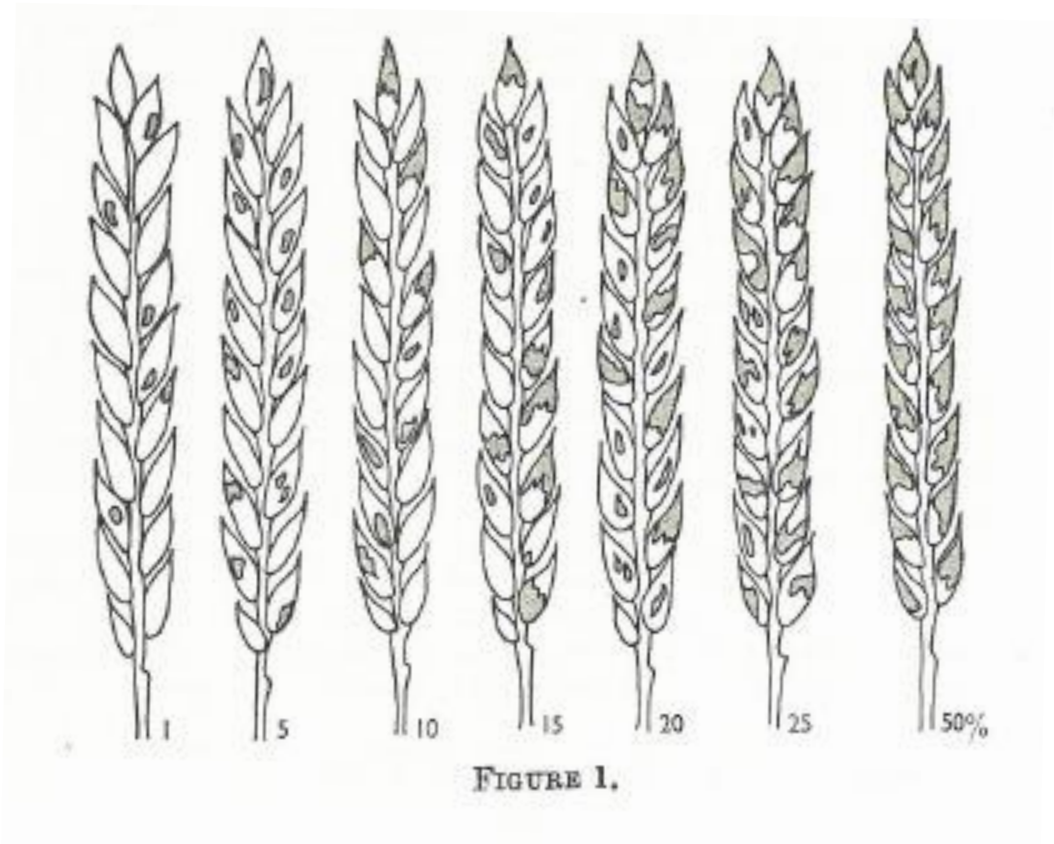


Figure 1.5: Crop Disease. Diagram of encroaching fungal infection in wheat. Mercury preparation was one method used to prevent the occurrence of such infections. This figure shows the progression of a seedling infection, *Septoria (Leptosphaeria) nodorum*. From Baker (1971): 280.

like us to believe'.[75] The problem of plant disease only grew in intensity during the 1970s. A report of the NIAB's Plant Pathology branch, delivered in 1981, informed the Institute's governing council that previously unknown diseases were emerging: including, perhaps revealingly, 'net blotch of barley'.[76] But were hybrid crops seen as part of the solution, or part of the problem?

The southern leaf corn blight had demonstrated that hybrid crops were just as vulnerable to disease, if not more so, than their traditionally-bred counterparts. Even the keenest advocates of hybridization in Britain could not ignore this unwelcome truth.

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[75] Strickland (1970): 89.
[76] Quarterly Report to Council, September-October 1981, Box C-3, Document No. 766, NIAB.

At the NIAB's 1970 crop conference, Haine recognised that 'If a disease… severely affects an F1 hybrid, the result may be disastrous, with every single plant showing symptoms of the disease'.[77] However, some continued to see plant breeding and hybridization as one of the most promising routes to combat disease in the long-term. Strickland saw the combination of new disease-resistant varieties, alongside chemical treatments, as potential parts of a long-term solution to latent disease.[78] Director of the NIAB Frank Horne used his final 1971 address to claim that hybrid crops could 'counter new races of disease'.[79]

Horne's contemporaries were less sure that dramatic means of unconventional plant breeding could provide easy solutions. Darbishire used his 1972 address to criticise the tendency of breeders to think in the short term by seeking high resistance to plant diseases through the alteration of single major genes. Learning to live with the lower but more permanent levels of resistance granted by 'a number of more humble genes' would, Darbishire claimed, would be preferable to a genetic arms race and pathogens playing 'Jekyll and Hyde' with breeders.[80] By 1980, B.D. Harrison, a biologist at the Scottish Horticultural Research Institute, could argue that crop protection problems had increased over the 1970s, despite the application of new technology. A 'philosophy of harmonisation' harnessing all known methods of pest control, was therefore necessary to ensure the future of agriculture.[81] Radical and rapid returns by altering the genetics of crop plants through hybridization were increasingly recognised as problematic.

Something approaching Harrison's vision of harmonised agriculture began to emerge during the late 1970s. In 1977, D.R. Marshall, a member of the Commonwealth Scientific and Industrial Research Organisation, remarked that the world's major crops were genetically uniform and 'hence markedly vulnerable to disease and pest epidemics'. Marshall was also sceptical of plant breeders' efforts to improve crop plants. He noted, contrary to Fiddian and Darbishire's arguments, that all the proposed alternatives to the use of single resistance genes in disease and pest control were

[77] Haine (1970): 2.
[78] Strickland (1970): 87.
[79] Horne (1971): 406.
[80] Darbishire (1972): 521.
[81] Harrison (1980): 274.

laborious and demanding of the breeders' time and resources.[82] The only solution was to increase crop diversity in farmers' fields. This realisation has not only informed modern farming practice, but has driven modern campaigns for preserving vintage varieties, alongside calls for bioengineering and bio-prospecting. At the NIAB, this approach became a major research programme during the 1980s, termed 'Varietal diversification in cereals'.[83] In the face of crop disease, hybrid monocultures and agricultural intensification had been reconsidered.

The growing popularity of hybrids like Proctor barley undoubtedly contributed to the expansion of cereal monocultures in agriculture. As a direct consequence of these monocultures, new and virulent crop diseases had arisen. Despite the hopes of NIAB Director Frank Horne, hybrid varieties did not counter these diseases. Ultimately, steps were taken to increase varietal diversity in British fields, while accepting that some crop losses to disease were inevitable. Yet despite this realisation, industrial hybridization as a plant breeding technology did not appear to come under fire, either for its role in producing fields of vulnerable crops or for failing to produce disease-resistant varieties. It is likely that the problem of disease was perceived as a problem of farming practice, or as a problem for all crop plants, regardless of what technique was used to breed them. The benefits of industrial hybridization, in the form of increased yields and hence profit, perhaps outweighed its disadvantages for breeders and farmers.

## Conclusions

Barley, like many other crops, clearly displayed all the characteristics of an industrial plant during the mid-twentieth century. Hybridization may have been a well-known plant breeding technique, but its ambition and scale were significantly ramped up over the course of the twentieth century. By the 1950s the end result of this new industrialised hybridization, Proctor barley, had emerged. This chapter has argued that its commercial success was partly the result of a planned programme of hybridization, which created an organism ideally suited to the needs of the British brewing industry.

[82] Marshall (1977): 17-18.
[83] 'Varietal Diversification in Cereals', Sixty-Second Report and Accounts 1981, NIAB.

Favourable market conditions certainly help explain the unbridled enthusiasm with which Proctor barley was received by both brewers and growers. There are also promising suggestions, both within Bell's personal papers and the wider historiography of the hybrid, that Cold War divisions played a significant role in the favourable reception of hybrid crop plants in Britain.

Other hybrid crops besides barley received a glowing reception within the British agricultural community during the 1970s and beyond. This sustained enthusiasm, or rather lack of any vocal opposition to hybrids, was driven by contemporary fears, ideology and politics. By 1970 new hybrid vegetable varieties had been produced in Britain and some opposition to hybrids was evident. Yet major national and international factors favoured the uptake of high-yielding hybrids in British agriculture, including a perceived Malthusian population crisis. The imagined economic decline of Britain gave an additional incentive for agricultural institutions and scientists to back hybrid crops. Both domestic and global fears favoured the uptake of hybrids: in the same way that hybrid corn faced little opposition during the era of the Great Depression.[84] Industrial hybridization also offered something less tangible that traditional breeding could not: the opportunity not to rely on natural variations but to achieve 'absolute control over nature.'[85] Yet this ambition proved difficult to achieve in Britain. One consequence of the drive for higher agricultural production through hybridization was the expansion of monocultures and unexpected rise of new plant diseases.

The history of industrial hybridization as a plant biotechnology did not end with the 1980s. Attempts to hybridize a wider range of crop plants using increasingly dramatic methods continued well into the 1990s.[86] Some staple crops have proved less than amenable to commercial hybridization: wheat being the primary example. As wheat is a self-pollinator, carrying out the necessary crosses for hybridization (particularly F1 hybrid production) is unreliable. Creating significant quantities of hybrid seed proves difficult, while resulting varieties only yield small advantages. One

[84] Duvick (2001): 73.
[85] Palladino (1991): 513-514.
[86] Another method developed to overcome sexual barriers to plant hybridization was cell fusion, the subject of Chapter 3.

proposed solution to the hybrid wheat problem was chemical hybridizing agents (CHAs), which induce male sterility in wheat. The first CHA – Maleic hydrazide – was tested in 1953. Yet it was not until the early 1980s that improved CHAs led to a renewed interest in hybrid wheat. By 1983 hybrid wheat varieties had entered the trial stage in Europe.[87] Wheat varieties produced by CHAs first appeared in the NIAB's certification scheme in 1985. CHA research programmes were shrouded in commercial secrecy, making information on them hard to come by. However, the technology was eventually rejected by regulators in both Britain and the United States when a promising CHA was found to have left toxic residues in treated seed.[88]

By viewing Proctor barley as an industrial plant, this chapter has contributed to our understanding of the nature of twentieth-century crop plant hybridization and why hybrid varieties were readily accepted in British agriculture. While hybridization was not a new biological innovation, the hybridization programme used to produce Proctor was quite different from its predecessors: both in scale and technique. By designing an idealised model of a hybrid barley and carrying out hybrid crosses on a vast scale, Bell and the PBI were able to create a barley ideal for the needs of the British brewing industry. The industrialization of the hybridization process should be considered an important part of the history of hybrid plants and their uptake. This chapter has also demonstrated that contemporary ideas and fears were equally as important as the engineering and marketing of new hybrid crop plants. Hybrids were promoted as practical products of Western genetics amidst the Cold War, or seized upon as a means to combat national decline and feed an exponentially expanding global population.

Industrial hybridization is one example of a biological innovation which successfully translated into practical products for agriculture. Yet this process was a complex one. The story of industrial hybridization, particularly Proctor barley, demonstrates that the application uptake of plant biotechnology is significantly facilitated by a number of factors: economic circumstance; effective synchronisation with existing industrial systems; prevailing genetic ideology; Malthusian fears and a sense of economic crisis. As we will see in the later chapters of this thesis, these factors

[87] Pickett and Galway (1997): 16.
[88] The CHA in question – WL 84811 – was first developed by the Shell Company in 1980 and withdrawn by 1988. Pickett and Galway (1997): 16-18.

will emerge as influences on the development and reception of plant biotechnology time and time again. After all, industrial hybridization was not the only tool harnessed by British barley breeders in their attempts to create high-yielding and profitable crop varieties. By crossing more and more crop plants, hybridizers had successfully tapped into a new reservoir of genetic diversity. Yet the root cause of change and diversity – mutation – seemed to lie beyond their control. This limitation would apparently be overcome in the mid-twentieth century, as breeders harnessed evermore powerful sources of radiation to artificially induce beneficial mutations in crop plants. It would not be long before mutation-bred barley could even challenge the supremacy of Proctor.

# 2. Mutation Breeding: Chromosome Breakage in the Atomic Age

> The first barley, Golden Promise, to be granted plant breeders' rights was produced by irradiation or mutation breeding, not by hybridization.
> – Roy Hay, *The Times*, July 14, 1970.[1]

Throughout the 1950s and '60s, a whole set of plant breeding technologies – seemingly far more futuristic in nature – were developed alongside industrial hybridization. Mutation breeding, the practice of exposing seeds to chemicals or radiation in the hopes of inducing beneficial mutations, was one example of a plant breeding technology which experienced a surge of interest in the 1950s. Hopes for the technology only grew with the newfound availability of a side product of atomic energy: radioisotopes capable of emitting gamma radiation. Addressing the Royal Society in March 1968, the creator of Proctor barley George Douglas Hutton Bell explained how 'artificially controlled hybridization or the experimental production of mutations on a rational and scientific basis have replaced the natural process in a conscious attempt to produce desirable genetic variation.'[2] Yet for Bell, these desirable variations had been largely achieved through hybridization: not mutation breeding. Since the late 1940s, Bell argued that efforts by his contemporaries to harness chemicals, X-rays and other techniques to produce mutations had failed to produce practical results: 'the general experience has so far been that the new forms induced by the various treatments have little or no economic value as far as the improvement of crop plants is concerned.'[3] Mutation breeding faced competition in the form of industrial hybridization.

Hybridization and mutation breeding were at least similar in one respect: both have emerged in their modern form from a long and often contentious history. Mutation breeders generally mark the foundation of their discipline with the work of

[1] Hay (1970): 10.
[2] Bell (1968): 147.
[3] Bell (1948): 190-191.

nineteenth-century Dutch botanist and evolutionary theorist Hugo de Vries (1848-1935). In the first volume of his 1901 *Die Mutationstheorie*, de Vries suggested that it might one day be possible to artificially induce beneficial mutations in plants and animals. De Vries expanded upon this ambition four years later in his *Species and Varieties: Their Origin by Mutation*, exclaiming that 'if it once should become possible to bring plants to mutate at our will and perhaps even in arbitrarily chosen directions, there is no limit to the power we may finally hope to gain over nature.'[4] Power over a seemingly random and arbitrary natural phenomenon is a highly appealing prospect: de Vries's works have subsequently taken on something of a canonical status in mutation breeding circles.[5]

The ambition to control induce and direct mutations to improve basic crop plants experienced a resurgence in mid-twentieth century Britain, a resurgence which manifested itself in a number of different ways in a number of different institutional settings. Current historical treatments of twentieth-century mutation breeding have thus far focused on America, Germany and the International Atomic Energy Agency (IAEA).[6] This chapter therefore introduces the story of British attempts to apply mutation breeding to agriculture from the 1950s to '70s. It introduces three episodes of interest in mutation breeding at different institutions: each best seen as different expressions of an atomic and technological Cold War optimism followed by decline. New archival sources harnessed in this chapter demonstrate that a straightforward account of technological ambition and failure cannot always be applied in the British context. Mutation breeders did achieve some success prior to the decline of mutation breeding research: a decline driven as much by heightened fears of nuclear fallout, an overreliance on a single model organism and the growing appeal of genetic biotechnology, as a lack of practical results.

[4] De Vries (1905): 688.

[5] De Vries is quoted at length in Van Harten's magisterial text on mutation breeding, which is in turn extensively cited by a 2011 FAO guide. For a historical treatment of purported milestones in mutation breeding, see Curry (2015). Mutation breeding has also experienced something of a resurgence since the 1970s, if its advocates are to be believed. In 1969 there were some seventy-seven mutant varieties of horticultural crop in existence. By 1990 more than 1300 existed, including 850 arable crops. Forster and Shu (2011): 14. Also see Van Harten (1998): 283-302 for a practitioner's account of the achievements of mutation breeders.

[6] These accounts have thus far argued that mutation breeding was often driven by ulterior motives and achieved little in the way of commercial success. On America, a comprehensive account is given by Curry (2016). On Germany, see Zachmann (2015). On the IAEA, see Hamblin (2009) and Hamblin (2015).

This chapter begins by exploring the rise of a new science in 1950s Britain: chromosome breakage. At the centre of the attempts to place chromosome work at the heart of biology was a 1952 symposium at the John Innes Horticultural Institution (JIHI) and its Director, Cyril Dean Darlington (1903–1981): evolutionary theorist, cytologist and outspoken opponent of Lysenkoism.[7] The chapter then moves on to examine the efforts of the Milns Seeds Company to create new barley varieties using gamma radiation from the late 1950s. Far from being another example of failure or exaggerated claims, this case offers a distinctive and highly successful example of a plant breeding programme originally based upon radiation. Finally, the chapter moves into the 1960s and early 1970s to examine research conducted at two government-funded laboratories: the Agricultural Research Council Radiobiological Laboratory in Wantage, Berkshire and the Medical Research Council (MRC) Radiobiology Unit at Harwell, Berkshire. Examining the contributions of these institutions to the *Radiation Botany* journal from 1962-1975 reveals that enthusiasm for mutation breeding and an atomic future for agriculture rapidly waned among British researchers over the course of the 1960s and '70s. Instead, both the Wantage and Harwell programmes would devote more time to assessing the negative consequences of nuclear fallout on arable farming.

## 1. Chromosome Breakage: A New Branch of Cold War Science

Just prior to his resignation as Director of the JIHI, Darlington addressed the participants of a 1952 symposium held at the Institute on 'chromosome breakage'. A divisive and controversial figure, Darlington had begun his scientific career as an unpaid intern at the JIHI under William Bateson. A meteoric rise in the biological community had followed. By the 1940s, Darlington had not only taken over as Director of the JIHI, but had managed to reinvigorate cytogenetics and place the chromosome 'at the heart of evolution.'[8] The JIHI symposium now offered him the chance to also place the study and manipulation of chromosomes at the forefront of medical research and plant genetics. Darlington began his address by reminding symposium participants of the discovery,

[7] The most extensive study of Darlington's life and work is a biography by Harman (2004). However, to the best of my knowledge, no mention of the 1952 JIHI symposium is found in the secondary literature on Darlington.
[8] Harman (2003): 73.

some twenty-five years earlier, of the 'permanent effects of radiation in the cell' by his friend and colleague Hermann Joseph Muller (1890-1967).[9] By bombarding the sperm of *Drosophila* fruit flies with X-rays, Muller had produced mutations that could be passed down through three or four generations of flies.[10] With these experiments it seemed that Muller's upbeat prediction, made in 1922, that 'perhaps we may be able to grind genes in a mortar and cook them in a beaker' had come one step closer to reality.[11]

Darlington used his introduction to the 1952 chromosome breakage symposium to announce that 'experimental gene mutation and chromosome breakage have proved comparable with the discoveries of Mendelian experiment… they have created a new branch of technology and are in the process of creating a new branch of science.'[12] A glance at the papers presented during the course of the symposium does show that scientific work on chromosome manipulation had more or less ignored what we might regard as established disciplinary boundaries. Speakers from a range of fields and scientific institutions were represented: agriculture, horticulture, animal genetics and medicine. One paper examining the effects of irradiation on the ornamental *Tradescantia* plant came from P.C. Koller, a cytologist based in the Chester Beatty Research Institute at London's Royal Cancer Hospital.[13] Another researcher from the Chester Beatty Institute presented a paper on chemical mutagenesis in faba beans.[14] Other offerings, however, followed more traditional disciplinary lines, such as J.W. Morrison of the JIHI speaking on X-rays and their effect on wheat.[15] What emerges from the line-up at the JIHI symposium is the impression that chromosome breakage research represented a union of medicine and agriculture: two of the key areas biologists have traditionally used to justify their science.[16]

Yet Muller's *Drosophila* experiments and his emphasis on the chromosome were not universally welcome. As we saw in the case of barley breeding and hybridization,

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[9] Darlington (1953): v.
[10] Muller (1927): 84.
[11] Muller (1922): 15.
[12] Darlington (1953): v.
[13] Koller (1953).
[14] Revell (1953).
[15] Morrison (1953).
[16] Pickstone (2000): 19.

the twentieth century was an era when heredity and its manipulation were highly politicised. Muller experienced this first-hand, when his Institute of Genetics, located in Moscow, came under political attack following the rise of Lysenko during the 1930s. By the time of the 1952 chromosome breakage symposium, Muller, Darlington and, by extension, mutation breeders, had set themselves firmly on one side of the Cold War divide over genetics and plant breeding.[17] Darlington, once sympathetic to the socialist cause, dramatically denounced the rise of Lysenko and subsequent repression of genetics in the Soviet Union. To some extent, the dispute was scientific: Lysenko had rejected the chromosome theory of heredity in favour of sex cells assimilating upon union.[18] Yet Darlington also had personal cause to despise all things Lysenko, including the arrest and death of his friend Nikolai Vavilov. Another factor was Darlington's growing distance from his former mentor John Burdon Sanderson Haldane (1892-1964). Haldane had begun to further embrace Communism just as Darlington began to reject the Soviet cause. Their divide was accelerated by Darlington's bid for Directorship of the JIHI in 1936, at a time when Haldane was employed by the Institute in an advisory capacity.[19] Science, emotion and ambition had served to set Darlington firmly against Marxist biology. By the time of the 1952 JIHI symposium, therefore, the chromosome theory of heredity, the director of the JIHI and Muller – the pioneer in the use of radiation to induce mutation – all supported the cause of Western science and genetics. Biology was never far removed from the politics of the Cold War.

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[17] Intriguingly, research into mutation breeding in the Soviet Union did not completely halt with the rise of Lysenko and denunciation of the chromosome as the agent of heredity. In an infamous 1948 speech, Lysenko addressed the subject: 'Some go so far as to assert that the Michurin trend denies the action upon plants of factors producing mutations, such as X-rays, colchicine, etc. But how is it possible to assert anything of the sort? Certainly, we Michurinists cannot deny the action of such factors. We recognise the action of the conditions of life upon the living body. Why then should we refuse to recognise the action of such potent factors as X-rays or a strong poison like colchicine, etc.? We do not deny the action of substances which produce mutations. But we insist that such action, which penetrates the organism not in the course of its development, not through the process of assimilation and dissimilation, can only rarely and only fortuitously lead to results useful for agriculture. It is not the road of systematic selection, not the road of progressive science.' Lysenko (1954): 548.
[18] Harman (2003): 316.
[19] Harman (2004): 148-149, 162-163.

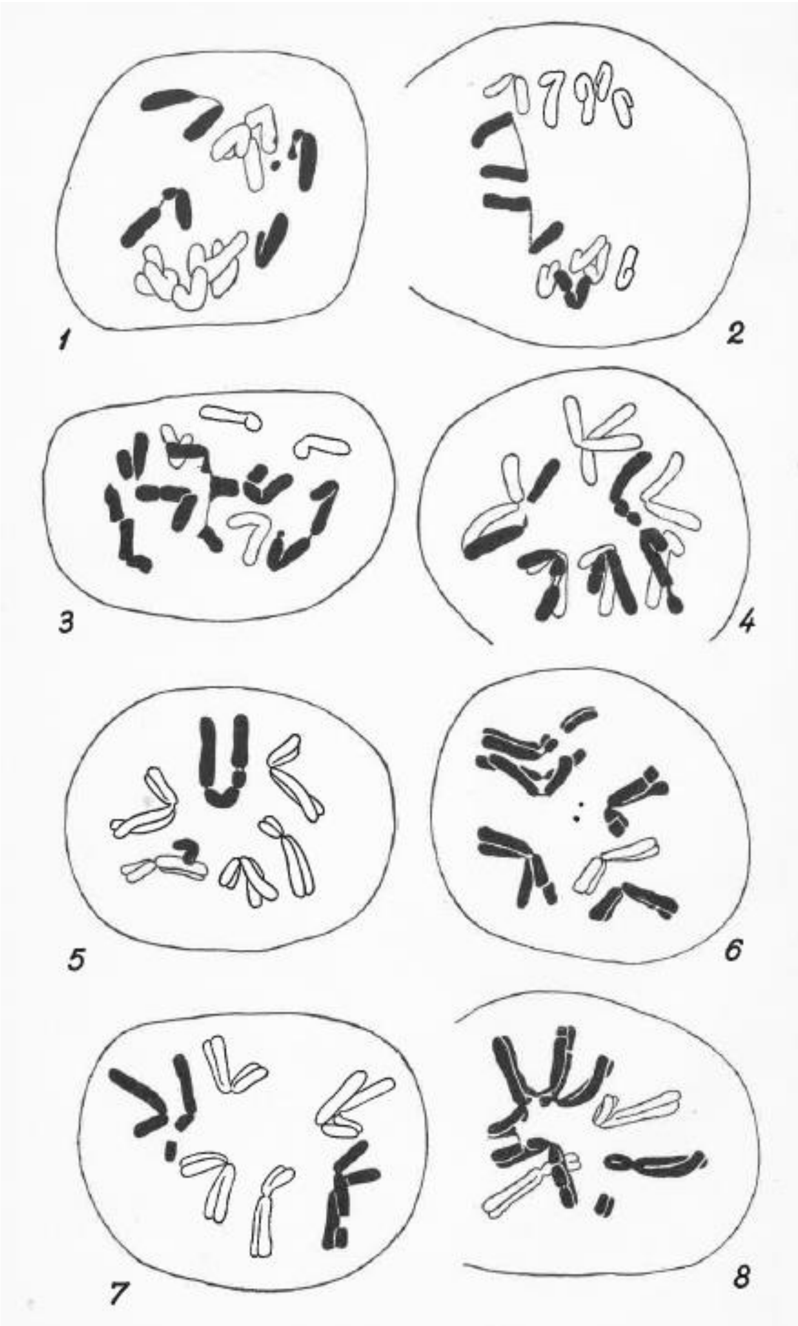


Figure 2.1: Chromosome Breakage: X-rays were the primary means of manipulating chromosomes by participants in the 1952 JIHI symposium. This diagram shows the shattered chromosomes in the pollen grains of *Tradescantia* following irradiation. Image from Koller (1953): 8.

Darlington advertised the new science of chromosome breakage as both a means of studying the cell, in tandem with gene mutation – 'the agent of all genetic and evolutionary change' – and 'the chief means of cancer treatment' available.[20] The use of radiation to alter the genetics of agricultural and horticultural plants began to attract greater attention in Britain throughout the 1950s. At the 1955 meeting of the British Association for the Advancement of Science (BAAS), a session on 'Genetics and plant breeding' was addressed by D. Lewis of the JIHI. Although genetics could not yet 'produce plants to order', Lewis saw great potential in the use of X-rays to release hitherto unrealised variability hidden in the chromosomes of crop plants. He could also point to a concrete example to support this ambition: the successful production of fertile cherries following X-ray induced mutation.[21] Also present at the BAAS meeting was the driving force behind hybrid Proctor barley and Director of the PBI, George Douglas Hutton Bell. Striking an accommodating tone, Bell emphasised the need for all scientific methods to be further utilised in plant breeding, thereby eliminating the unhelpful division of science into the pure and the applied.[22]

The goal of producing new crops for growers seemed to be within striking distance for those in the field of chromosome breakage by the end of the 1950s. Not only had the use of X-rays and mutagenic chemicals provided new insights into the nature of the chromosome, but it was providing practical applications in medicine and agriculture. At the 1957 BAAS meeting, radiation and its agricultural applications was the focus of a paper by another member of the PBI, R.N.K Whitehouse. Although 'few mutation-bred strains [of crop plants] have yet reached the market', Whitehouse declared, this was simply 'because insufficient time has elapsed.'[23] The future of mutation breeding looked promising. If anything, British plant breeders were actually falling behind on the international mutation-breeding stage. Mutation-bred barley had been released onto the Swedish market; barley with improved straw-strength and

[20] Darlington (1953): v.
[21] Williams (1955): 719.
[22] Williams (1955): 720-721.
[23] 'Radiation and Biology' (1957): 629.

mildew resistance had been developed in Germany and Austria, while in the United States, mutation breeding had been applied to wheat, oats, peas and peanuts.[24]

By the end of the 1950s, radiation had come into its own as a useful tool for biologists of all stripes in Britain. Radiation simultaneously appealed to medical researchers, the devotees of Darlington's science of chromosome breakage and agriculturalists keen to explore the commercial potential of mutation breeding. Yet there was a spanner in the works. In 1953 Darlington left the JIHI for the Sheridan Chair of Botany at Oxford University. In part, his decision was simply a means to escape the burden of administrative work as Director of the JIHI. Yet another significant factor in his move was Watson and Crick's 1953 discovery of the structure of DNA. Darlington could sense a 'molecular revolution sweeping across the biological world', which would not favour researchers based in horticultural institutions.[25] Genetics, human evolution and work on his new book *The Facts of Life* (1953) steered Darlington away from the JIHI and chromosome breakage. Just as mutation breeding began to see practical applications in British agriculture, it seemed that ambitious leaders in the scientific world were moving on.

Despite the departure of Darlington from the JIHI and renewed scientific focus upon DNA as the molecule of heredity, the application of radiation to plant breeding would continue. The interconnectedness of chromosome breakage and plant breeding – exemplified by the 1952 JIHI symposium – had important consequences for the favourable reception of mutation breeding as an agricultural biotechnology. For instance, the prominent place of medicine and cancer treatment within biological radiation work undoubtedly gave such work good publicity, or, at least far better publicity than could be expected than association with military or civic atomic research.[26] Chromosome breakage also came to prominence at the JIHI and BAAS meeting in the midst of the Cold War. Just as the hybrid crop was seen as a vindication of Mendelian principles against the tyranny of Lysenko, so mutation breeding vindicated the chromosome and its role in heredity. Darlington himself had openly argued that

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[24] 'Radiation and Biology' (1957): 629. The session also featured papers on the clinical applications of radiation and its impact on human health.
[25] Harman (2004): 206-207.
[26] Rasmussen (2014): 22-23.

Lysenkoists had attacked Western genetics because the Soviet regime relied on the absence of ingrained class and race differences among humankind.[27]

Flashes of Cold War divisions over genetics and mutation breeding even appeared in the British press. In 1956 an article in *The Times* on the 'Use of nuclear radiation for plant breeding' described the utopian rhetoric of mutation breeders as 'reminiscent of that to which we have become accustomed from Soviet plant-breeders'.[28] There was, however, one important distinction: namely that the 'outlook' of Western mutation breeders was at least based upon 'orthodox genetics.'[29] Overall though, the science correspondent for *The Times* remained largely sceptical. At best, 'radiation can supply him [the plant breeder] with an increased supply of mutant plants, most of them useless'. Effectively, radiation could only provide a small amount of promising 'raw material' for plant breeders to work with, rather than 'finished [commercial] products'.[30] Practical products may have been some way off, but at least mutation-bred crop plants conformed to existing Western ideals.

Fortunate timing was a significant factor in mutation breeding successfully meeting accepted social and scientific norms. When invited to deliver the 1958 Woodhull Lecture at the Royal Institution, Darlington chose the 'Control of evolution in man' as his subject. Darlington claimed that governments, by involving themselves in the lives of individuals or the economy, were unconsciously interfering in human evolution. However, this unconscious intervention into human breeding could well become conscious as new processes such as 'ionizing radiation, sterilization and artificial insemination' started 'attracting attention.'[31] Darlington did not rate radiation highly as a tool for altering the human species, instead pointing to artificial insemination as a means of avoiding the stagnation and inbreeding produced by 'the rigidity of human breeding systems'.[32] Yet to have mutation breeding even tangentially associated

[27] Harman (2004): 151.
[28] 'Use of Nuclear Radiation for Plant Breeding' (1956): 13.
[29] 'Use of Nuclear Radiation for Plant Breeding' (1956): 13.
[30] 'Use of Nuclear Radiation for Plant Breeding' (1956): 13.
[31] Darlington (1958): 17.
[32] Darlington (1958): 17. Here, Darlington is referring to traditional marriage. He claimed that, in the past, illegitimate 'class-crosses' had produced extraordinary individuals such as William the Conqueror and Abraham Lincoln. With illegitimacy in 'advanced societies' declining, such individuals capable of altering 'the course of history or of human evolution' might no longer be born.

with eugenics cannot have been comfortable for its advocates, especially in the wake of the Second World War.

As Darlington's career progressed, he became more fixated on human genetics and evolution. His 1953 *Facts of Life*, published shortly after his departure from the JIHI, had met with scathing reviews. Coming hot on the heels of the 1950 UNESCO Statement on Race, Darlington's work – which argued there was a 'genetic base' for race and class – came under fire from the growing post-war consensus that race had no basis in science.[33] Darlington's later publications were even more overt on the question of race. By the 1960s and '70s, Darlington was criticised for holding unscientific and racist views.[34] Thankfully for the cause of mutation breeding, by this time Darlington had left the JIHI behind and did not raise radiation treatment as a possible means of breeding better humans. In fact, when Darlington produced a potted history of plant breeding for the *Transactions of the Royal Society* in 1981, he made no mention of mutation breeding whatsoever.[35] By losing Darlington sooner rather than later, British mutation breeders may have dodged an ideologically-charged bullet.

The early development and uptake of mutation-bred crop varieties in Britain was clearly facilitated by a fortunate timing. Mutation breeding was likely favoured by many of the same ideological factors which helped industrial hybridization become a staple tool of British plant breeding and agriculture. The imagined threat posed by a growing world population and a sense of economic decline likely helped to quell qualms about the application of radiation and mutagenic chemicals to crop plants. In the divisive realm of Cold War ideology, mutation breeding may not have achieved the same status of hybridization as an economic tool against Marxist biology. Yet chromosome manipulation certainly stood on the side of Western genetics and against Lysenko. Moreover, manipulating chromosomes with radiation was a promising research avenue in cancer treatment. Advocates of mutation breeding for agriculture were therefore able to associate themselves with promised breakthroughs in medicine. Despite the decline of chromosome breakage and rise of the post-1953 molecular revolution, practical advances in mutation breeding – as discussed during successive

[33] Harman (2004): 236-241.
[34] Harman (2004): see Chapter 15.
[35] Darlington (1981).

BAAS meetings – continued. It would only be a matter of years before radiation-bred crop plants were ready to enter commercial agriculture in Britain.

## 2. Gamma Radiation and British Barley Breeding

A little over a year after the 1952 symposium, none other than US President Dwight D. Eisenhower reemphasised the link between the atom, medicine and agriculture. On the 8th of December 1953, at the United Nations General Assembly in New York, Eisenhower gave his famous 'Atoms for Peace' speech. Speaking 'Against the dark background of the atomic bomb', Eisenhower urged delegates to form what would later become the IAEA. He declared that the chief responsibility of the IAEA 'would be to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind.' These pursuits would consist of attempts to 'apply atomic energy to the needs of agriculture, medicine and other peaceful activities.'[36] Eisenhower's speech was part of a wider realisation that, in the wake of negative publicity surrounding the atomic bomb, radiation must adopt a publicly acceptable face. Agriculture and medicine were two means of making atomic research palatable to the general public.[37] As we have seen, mutations in crop plants had long been induced using X-rays or chemicals. Now radioactive material, produced as a by-product of nuclear fission, would form the raw material of promised atomic age mutation breeding programmes. With an existing nuclear energy programme, Britain – and other Western nations – possessed the means to harness radioactive isotopes in their agricultural mutation breeding programmes.

One element of Britain's existing nuclear infrastructure was the Atomic Energy Research Establishment at Harwell. By 1949 the Establishment had become the world's 'leading isotope exporter', supplying Western Europe with the isotopes necessary for a new form of mutation breeding.[38] One of the Establishment's customers was a private

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[36] A transcript of the speech, plus audio and visual recordings, is available on the IAEA website: https://www.iaea.org/about/history/atoms-for-peace-speech. Eisenhower's speech serves a good starting point for histories of post-war mutation breeding: however, events at the JIHI do predate it.
[37] Rasmussen (2014): 22-23.
[38] Zachmann (2015): 312.

seed company in Britain.[39] In 1957 Milns Seeds began a breeding programme at their Plant Breeding Station in Chester.[40] Grains from an existing barley variety Maythorpe 'were exposed to gamma-rays and the resulting material carefully screened.'[41] The most promising mutants were then multiplied and placed in field trials, where a variety numbered 759/4 proved to be the most successful. Subsequently named 'Milns Golden Promise', the new barley was released onto the market in 1965.[42] It had taken some eight years, plus the acquisition of nuclear isotopes, for Milns Seeds to successfully breed Golden Promise.

So why did a long-established seed firm like Milns decide to invest its time and money into obtaining radioactive isotopes and applying them to plant breeding? A *Financial Times* correspondent called the business of breeding a new crop variety 'a fantastic gamble' for private firms, with new varieties costing an estimated £20,000 - 50,000 to produce.[43] Producing a new crop variety without state support could result in financial disaster. Mutation breeding using radioisotopes may have given Milns Seeds newfound confidence in their ability to breed a commercially successful variety. By using nuclear radiation, breeders could accelerate the availability of promising variations which could then be entered into field trials. New crops could therefore, at least in theory, be produced much more quickly than was formerly the case. Milns may also have received advanced warning of the introduction of the UK Plant Varieties & Seeds Act in 1964, which allowed plant breeders to collect royalties whenever their seeds were purchased.[44] Royalties paid to breeders by farmers gave private companies a guaranteed income beyond the profits from a single crop: a breeder could now expect

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[39] Although this is not explicitly stated in archival material from the firm, it is overwhelmingly likely that Milns Seeds was one of the recipients of radioactive material shipped from Harwell.

[40] It has been suggested that private breeding firms could ill-afford to be inventive research centres in the post-war era, as 'the mutagenic effects of colchicine, mustard gas and then radiation seemed too far removed from the business of breeding.' Palladino (2002): 62. Milns Seeds appears to be a rare exception to this rule.

[41] Milns Seeds Seed Catalogue Spring 1967, GRSRM: 2002.165.274.1. Gressenhall Farm and Workhouse. Museum of Norfolk Life, Museum Library [Hereafter abbreviated to Gressenhall Library].

[42] Milns Seeds Seed Catalogue Spring 1967, GRSRM: 2002.165.274.1. Gressenhall Library.

[43] 'Sales battle growing in grain seeds' (1966): 2.

[44] The Plant Royalty Bureau was established in 1966 to collect royalties for breeders.

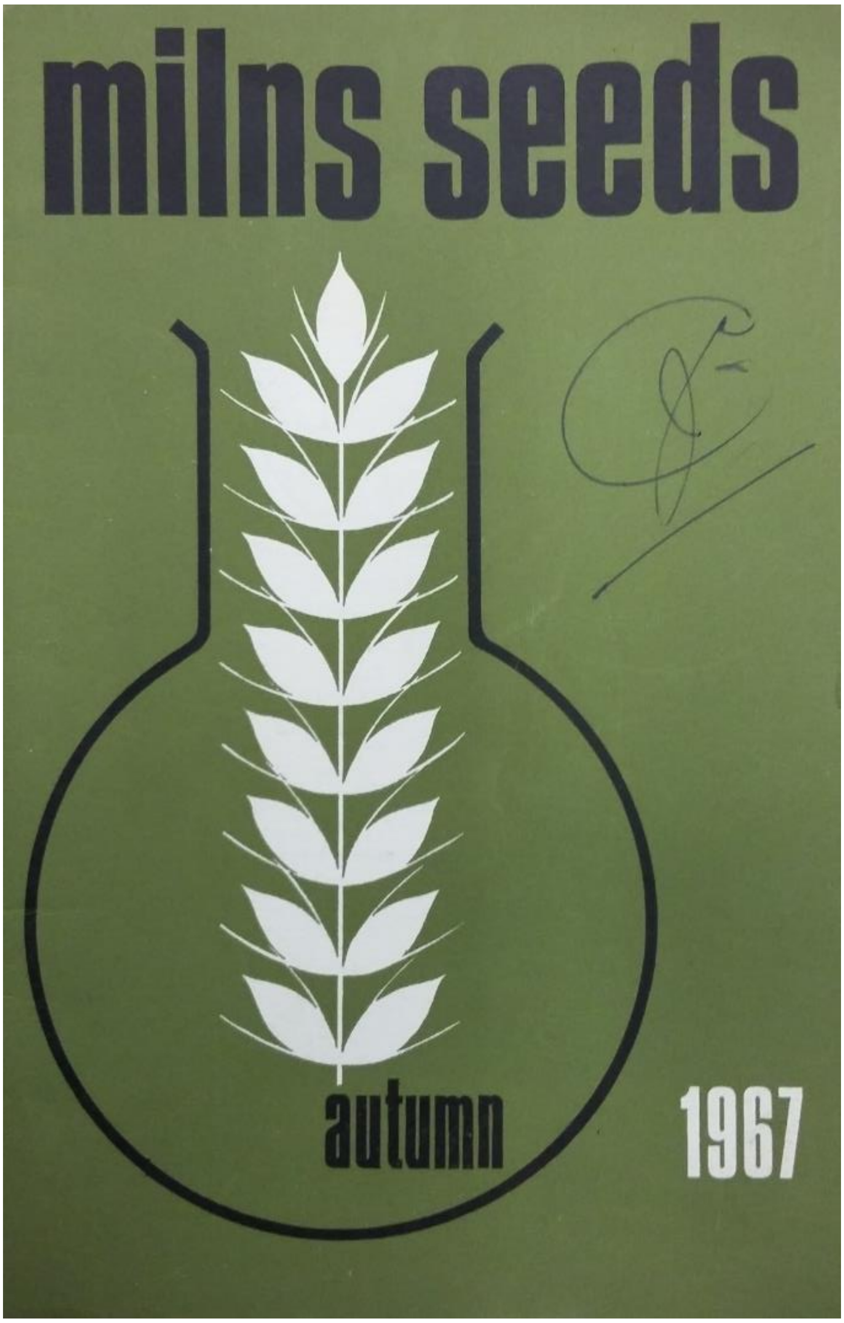


Figure 2.2: Milns Seeds. Cover image from the 1967 Milns catalogue. By the time this catalogue was printed, the company had already used gamma radiation to produce the highly-successful 'Golden Promise' barley variety. Image from Milns Seed Catalogue Autumn 1967, GRSRM: 2002.165.275. Gressenhall Library.

a highly successful crop variety to return approximately £100,000 every year. Golden Promise would be the first barley variety on which royalties could be collected.[45] Golden Promise proved a worthwhile investment for Milns Seeds. Two years after the variety was released, the company could boast that the variety's performance 'in all parts of the country has led to increasing demand and widespread popularity.'[46] Even more of a coup for the firm was news that Golden Promise gave a higher yield per acre than Bell's hybrid Proctor barley.[47] Until this point Proctor had dominated the British barley market, proving extremely popular years after its release. Although private firms like Milns could also sell Proctor, by developing their own variety Milns could claim intellectual property rights, granting the right to produce Golden Promise to select seed merchants in exchange for a fee. Mutation breeding, when it resulted in a popular crop variety, could be a highly profitable venture. Yet Milns was also concerned about ongoing challenges in plant breeding and how future crop varieties could overcome them. These challenges included the rise of new diseases created by intensive cultivation and the need to make barley compatible with modern mechanical handling of cereals.[48]

A clear economic rationale, buoyed by the success of Golden Promise, encouraged Milns to continue its mutation breeding work. In 1969 the company announced that it would be pursuing 'exciting possibilities' in barley breeding, using a combination of radiation and hybridization. Milns did admit that its unusual varietal improvement programmes 'may result in the use of cereals that are somewhat unorthodox in appearance.'[49] The unorthodox cereal, another barley variety named Midas, was bred at the firm's Chester Plant Breeding Station and released in 1971. According to the Milns Seed Catalogue of that year, Midas was the result of 'a cross involving a very short strawed mutation, produced by irradiation, together with Proctor and North American selections with Mildew resistance.' The barley was described as a

[45] 'Sales battle growing in grain seeds' (1966): 2. The unnamed *Financial Times* correspondent also noted that the renewed interest of commercial seed firms in plant breeding undermined the traditional role of state funded plant breeding institutes like the PBI.
[46] Milns Seeds Seed Catalogue Spring 1967, GRSRM: 2002.165.274.1. Gressenhall Library.
[47] Milns Seeds Seed Catalogue Spring 1967, GRSRM: 2002.165.274.1. Gressenhall Library.
[48] Milns Seeds Seed Catalogue Spring 1969, GRSRM: 2002.165.285. Gressenhall Library.
[49] Milns Seeds Seed Catalogue Spring 1969, GRSRM: 2002.165.285. Gressenhall Library.

'variety with very unusual and distinct characteristics and all the essential factors.'[50] Company advertisement aside, Midas did appear on the NIAB's 1971 Recommended List and was highly regarded at the Institute. Field Officer W.E.H. Fiddian praised Midas for its high yields and 'ideotype' characteristics: an ideotype being a crop plant which displays low levels of inter-plant competition.[51]

Milns Seeds had apparently harnessed the power of gamma radiation to achieve notable successes. Yet it was not the case that radiation-bred barley varieties had simply replaced their traditionally-bred or hybridized counterparts. At the NIAB's Fellows Conference of 1978, an afternoon discussion turned to the subject of 'why Golden Promise had done so well commercially, but had not done so in NIAB trials.' In attendance was Fiddian, who claimed that the growing characteristics of Golden Promise had been so well documented that 'farmers were able to treat the variety accordingly, and thus grow it successfully.'[52] The commercial success of Golden Promise, therefore, may have been due more to farmers being provided with sufficient information, rather than the application of a novel form of radiation-based biotechnology. Although Golden Promise did earn Milns Seeds significant profit, the variety did not achieve anything like the dominance of Proctor barley. Golden Promise did achieve a high level of popularity for malting purposes in Scotland, comprising some ten percent of barley seed sales from 1973 to 1984.[53]

Crop varieties based on older plant breeding techniques continued to dominate British agriculture, even when new radiation-bred crop plants were readily available. Proctor barley continued to appear alongside Golden Promise and Midas in Milns Seed catalogues throughout the 1960s. The firm's 1969 catalogue described the now ageing Proctor as 'a well tried variety.'[54] As late as 1971, the seed catalogue of Marsters Seeds informed its customers that Proctor was sold out: Golden Promise, however, remained in stock.[55] The popularity of Proctor may simply have been a hangover from the

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[50] Milns Seeds Seed Catalogue Spring 1971, GRSRM: 2002.165.290. Gressenhall Library.
[51] Fiddian (1976): 213.
[52] Cereals in the West and South: papers given at the Fellow's Conference at Harper Adams Agricultural College and the Hampshire Agricultural College, Sparsholt, January 1978. NIAB.
[53] Silvey (1986): 162.
[54] Milns Seeds Seed Catalogue Spring 1969, GRSRM: 2002.165.285. Gressenhall Library.
[55] Marsters Seeds Seed Catalogue Spring 1971. GRSRM 2002.165.289. Gressenhall Library.

overwhelming popularity of the variety during the 1950s: farmers may have felt more comfortable and confident managing a field of Proctor.

The radiation-bred barley varieties produced by Milns Seeds proved extremely popular, seemingly provoking little or no opposition from farmers or the general public. The characteristics of Darlington's science of chromosome breakage give some indication as to why this might be, with radiation associated with advances in Western genetics and medicine. Yet the mutation breeding programme conducted by Milns Seeds clearly differed from the chromosome breakage research discussed at the JIHI in 1952. Not only had Milns carried out mutation breeding on a far larger scale than anything that had gone before, but the company had used a different source of radiation – gamma radiation, as opposed to X-rays – for their breeding work. The simplest explanation for a general lack of resistance – or indeed, reaction of any sort – to Milns Seeds and its irradiated barley is that few people actually knew about the programme. Given the open advertisement of Golden Promise and Midas as the products of mutation breeding, however, this seems somewhat unlikely.[56] Golden Promise and its origins as a mutation derived from gamma radiation even received a brief mention in the *Financial Times* in 1966.[57]

An alternative explanation for the passive acceptance of mutation-bred barley in British agriculture is that supposedly radiation-bred crop varieties were far more reliant upon existing plant breeding techniques then some of their advocates would readily admit. In their 1969 seed catalogue, Milns Seeds announced their intention to develop 'new hybrids' which would incorporate the 'dwarf material [referring to the short straws of Golden Promise] obtained by induced mutation'.[58] New barley varieties like Midas therefore owed as much to hybridization as they did to mutation breeding. The Milns Seeds mutation breeding programme did not suddenly produce a new generation of miracle crops. Gamma radiation would only play one part in a plant breeding programme which relied upon established – and accepted – traditional breeding techniques. The agricultural community may therefore have viewed crop varieties like

[56] One piece of evidence in favour of this view is found in Blaxter and Robertson (1995): 130, who could only claim that Golden Promise was 'said to originate… by ionising radiations (gamma rays).'
[57] Golden Promise (1966): 2. The variety appeared in the newspaper as it was the first barley to be granted Plant Breeders' Rights (PBI).
[58] Milns Seeds Seed Catalogue Spring 1969, GRSRM: 2002.165.285. Gressenhall Library.

Golden Promise and Midas as less exotic than their promoters at Milns Seeds would have liked.[59]

The wider British public may also have viewed mutation breeding and its application to agriculture with a sense of familiarity, if not indifference. By the late 1950s, the use of gamma radiation in agriculture would also have been old news to a significant proportion of the British public. In 1947, members of the Atomic Scientists' Association (ASA), spurred into action by public feeling that the drawbacks of nuclear energy outweighed its benefits, commissioned the 'Atom Train': a hugely popular travelling exhibit on atomic energy.[60] Part of the carriage-based exhibit introduced visitors to the potential uses of atomic energy in medicine, industry and agriculture. One subsection, 'Atomic Energy in Agriculture', suggested that radioactive tracers could one day lead to a better understanding of plant growth and disease.[61] The idea that atomic radiation could find a useful place in farming was present in British life from a surprisingly early date. This message of radiation as a beneficial force would be further enforced and applied in the context of plant breeding over the coming decades.

For its post-war advocates, nuclear power possessed the potential to 'return mankind to an idyllic, prelapsarian bliss'.[62] In Britain, none endorsed this potential with more enthusiasm than Muriel Howorth (1886-1971). An acolyte of Nobel laureate Frederick Soddy, Howorth sought to promote the atom at every opportunity: including its agricultural benefits. A 1959 dinner at the Royal Commonwealth Society presented Howorth with the opportunity to treat her guests to 'NC 4x': a variety of unusually large peanut produced through exposure to X-ray irradiation by Walton C. Gregory of North Carolina State College.[63] Drawing upon press coverage of the event, Howorth went on to found the Atomic Gardening Society (AGS). The Editor of *Amateur Gardening*, A.G.L. Hellyer, actually found the use of irradiated seeds and subsequent press coverage

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[59] The seed catalogues cited throughout this chapter are, after all, promotional material designed to sell crop varieties. Numerous and blatant references to the use of gamma radiation occur whenever Golden Promise and Midas are mentioned. We can therefore assume that Milns Seeds thought mutation breeding to be a unique selling point. Whether this tactic succeeded in boosting sales is open to question.
[60] Laucht (2012): 591-593. The Atomic Train travelled across Britain for 168 days and drew 146,000 visitors.
[61] Laucht (2012): 605.
[62] Johnson (2012): 553.
[63] Johnson (2012): 566. The peanuts were sent as a gift to Howorth after she had written to Gregory to compliment his work in atomic agriculture.

rather mundane. Writing in the *Financial Times* in 1960, Hellyer argued that 'there is nothing very new about the practice of irradiating seeds, though the present easy availability of many radio-active chemicals has greatly increased the range of application.'[64] For some farmers and gardeners, radiation was clearly a familiar tool. The AGS went on to grow seeds supplied from 'atomic entrepreneur' Dr. C.J. Speas of Oak Ridge, Tennessee, before the Society abruptly declined in 1963.[65]

The mutation-bred barley varieties produced by Milns Seeds entered British agriculture against a favourable economic and cultural background. Novel means of barley breeding made economic sense with the introduction of Plant Breeders' Rights. More broadly, mutation breeding received a favourable hearing in both the scientific and public arena. Chromosome breakage and irradiation of seeds were associated with food security, medical advances and Western genetics: all factors that made for the ready acceptance of mutation-bred crops on the farm and on the table. Of course it cannot have hurt that substantial investment and production was carried out by an established British seed company, rather than an atomic energy agency or foreign firm. Yet attitudes towards the atom, in both the scientific and public arena, were changing. If we move outside the commercial world of barley breeding, the application of radiation to crop plants was greeted with less enthusiasm and much more caution.

### 3. Farming and Fallout: Radiation Botany at Wantage

If we temporarily leave the commercial world behind, it is clear that public research on the biological effects of radiation did not simply grind to a halt with Darlington's departure from the JIHI in 1953. Yet this research largely took place not at plant breeding stations, but at state-funded atomic research laboratories. In Britain, these included the Agricultural Research Council (ARC) Radiobiological Laboratory in Wantage, Berkshire and to a lesser extent the Medical Research Council (MRC) Radiobiology Unit at Harwell, Berkshire. The 'new Wantage laboratories' were championed by *The Times* in 1956 as a site where 'cautious' and 'extended research' into mutation breeding could

[64] Hellyer (1960): 4. Here Hellyer was referring to the use of X-rays for seed irradiation at least '30 years ago and probably before.'
[65] Johnson (2012): 568.

be safely carried out.[66] Wantage seemed to initially represent a means by which British mutation breeders could catch up with their colleagues in Sweden and the United States. For much of the 1950 and ‘60s, it seems that researchers at Wantage were busy fulfilling this ambition. When the journal of *Radiation Botany* was launched in 1961 with an international editorial board representing dozens of atomic research laboratories, members of both Wantage and Harwell were included on the board at one time or another.[67]

Early contributions to mutation breeding research from staff at the Wantage laboratory were very similar to the examples of chromosome breakage research presented at the JIHI back in 1952. Wantage staff kept a close eye on the commercial possibilities of their findings. For instance, one paper received by *Radiation Botany* in 1962 dealt with the effects of gamma radiation from cobalt-60 on chrysanthemum cuttings. Introducing their work, the authors noted that traditional means of producing new chrysanthemum varieties for the ornamentals market had relied upon the chance appearance of new mutations, or ‘sports’. This was a slow and unpredictable process. In the case of the popular ‘Sweetheart’ chrysanthemum variety, produced in 1939, growers had to wait six years before the first sports appeared. Yet by 1950, eleven had appeared in rapid succession.[68] By bombarding their cuttings with gamma radiation, the Wantage team produced ‘eleven different propagable sports’ in one year, ‘one of which (Cream Sweetheart) is certainly an unrecorded type.’ It took eleven years for a comparable number of sports to occur by natural means, from a far larger population of plants.[69] Mutation breeding was portrayed as a means of control over formerly spontaneous and unmanageable natural process.

Other research programmes at Wantage focused on major crop plants and involved collaboration with British universities. Samples of rye, contributed by the Genetics Department at Birmingham University, were exposed to radiation at Wantage in 1963.[70] Other institutions, including Harwell and plant breeding stations, were also

[66] ‘Use of Nuclear Radiation for Plant Breeding’ (1956): 13.
[67] In terms of published research papers, Wantage was the more prolific in the pages of *Radiation Botany* throughout the 1960s and ‘70s.
[68] Bowen, et al. (1962): 297-298.
[69] Bowen, et al. (1962): 303.
[70] Lawrence (1963): 94.

involved in mutation breeding by the early 1960s. In 1962 the Welsh Plant Breeding Station in Aberystwyth published a paper on the irradiation of oats in *Radiation Botany*, its authors declaring that 'the production of new [crop] types by mutagenic means offers the theoretical possibility of achieving improvement' where hybridization would be inappropriate.[71] Harwell also conducted its own research on the effects of radiation on plants, albeit later and far less frequently than Wantage.[72] For instance, a 1969

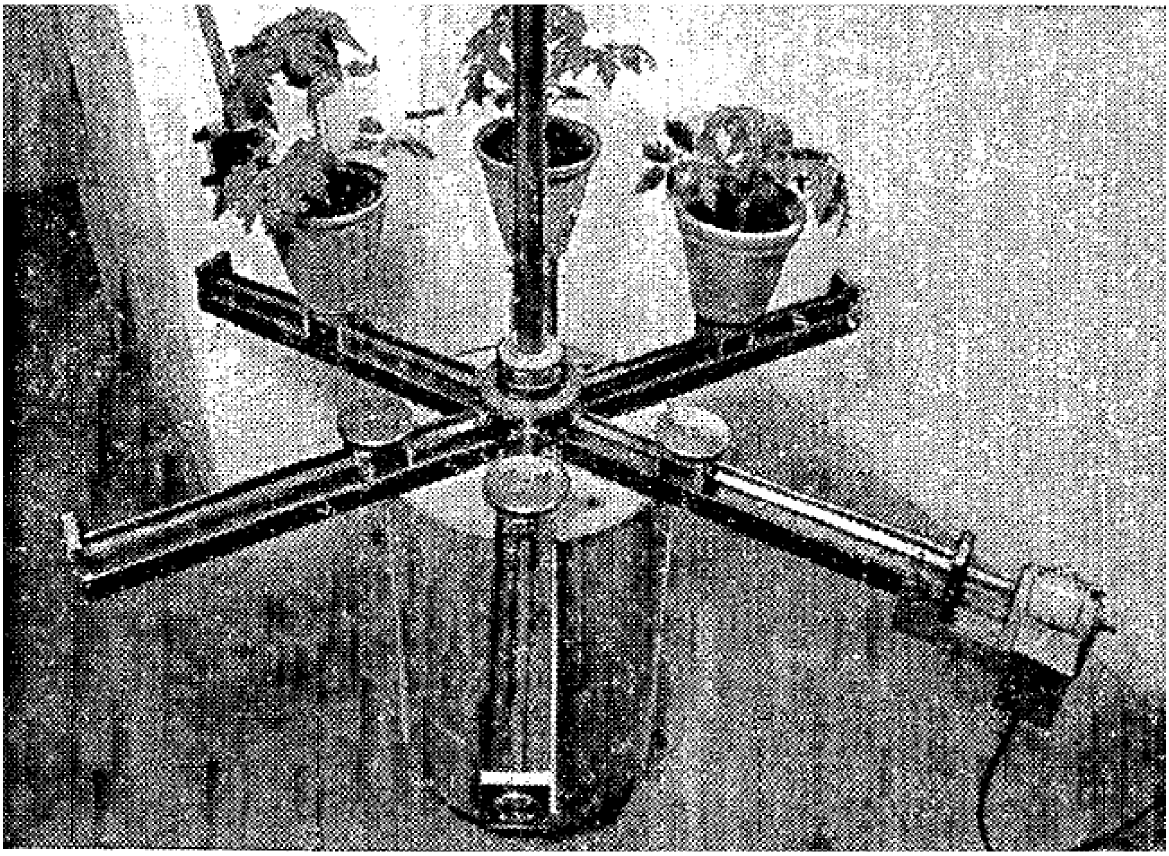

Figure 2.3: Wantage Laboratory Apparatus. This instrument was specially constructed to expose plants (located on the arms of the device) to a source of radioactivity located in the central chamber. From Powell and Davies (1959).

[71] Griffiths and Johnston (1962): 42.
[72] Harwell hosted a MRC-funded laboratory rather than an ARC-funded one. Yet as the papers presented at the JIHI in 1952 demonstrate, a position in a medical laboratory could potentially be used to test the effects of radiation on both plants and animals.

article described how chromosome exchange rapidly occurred when the ornamental plant *Campelia zanonia* was exposed to X-rays. Its authors hoped that the easy to grow and observe *Campelia* would become a new and versatile subject for irradiation research.[73] Mutation breeding, whether using X-rays or gamma radiation, occupied a significant number of state-funded institutions in Britain well into the 1960s.

Despite some promising results and clear examples of the commercial application of mutation-bred plants from both radiobiological laboratories and private breeding firms, it seemed that all was not well in the world of atomic agriculture. We have already seen how the discovery of the structure of DNA and rise of molecular biology pulled some biologists away from the field of chromosome irradiation. Formerly positive attitudes towards the utility of the atom also shifted at this time, as public anxiety rose in the wake of the nuclear arms race throughout the 1950s, a trend which culminated in the foundation of the CND (the Campaign for Nuclear Disarmament) in 1958.[74] Public opinion in Britain seemed to be turning against all things nuclear. Anti-nuclear protests had grown in strength and frequency during the early 1960s.[75] Whether as a response to changing scientific interests, anti-nuclear feeling or political interests, the research priorities of Wantage rapidly shifted away from mutation breeding.

In 1968 the first in a new series of research papers by the ARC laboratory at Wantage appeared in *Radiation Botany*. The experiments described in these papers involved large-scale experiments on agricultural land conducted over a number of years. Yet they were not another milestone in the history of mutation breeding. They were instead intended to understand the impact of radioactive fallout on British agriculture. The author of one such experiment conducted at Wantage, C.R. Davies, described exposing spring wheat to high levels of gamma radiation, in order to better 'assess possible effects of environmental contamination, for example near-in fallout

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[73] Savage and Anne Pritchard (1969): 138.

[74] Forgan (2003): 191. The year before CND's foundation a major incident occurred at the Windscale nuclear facility, which spread radioactive fallout over the surrounding countryside. Laucht (2012): 138-139.

[75] Wittner (2009). By the closing years of the 1960s, nuclear disarmament movements had lost much of their momentum. It is therefore likely that a shift away from mutation breeding at Wantage and other state-funded institutions was the result of a host of factors.

from atomic weapons.'[76] Davies explained that the 'primary object of the present investigations was to provide information which would assist in civil defence assessments of the possible consequences of catastrophic discharges of radioactivity onto agricultural land'.[77] Similar tests were carried out at Wantage on barley, oats, potatoes and legumes. In each case, the impact of high levels of gamma radiation on crop growth and yield were overwhelmingly negative, resulting in dying or stunted plants.

Another experiment conducted at Wantage in 1963 had involved large-scale trials, with strontium-90 applied (in spray form) to pastures on sites at Rothamsted Experimental Station and the University of Reading.[78] The investigation of strontium-90 during the 1960s is significant, as during the 1950s the isotope was revealed to have accumulated in 'animal bones, milk and soil' following years of nuclear weapons testing.[79] Wantage was just one institutional example of wider concerns regarding the long-term consequences of radioactive fallout on the environment. A comparative example can be found with Brookhaven National Laboratory, which also published its own analysis of how maize and common fruit and vegetables would react to nuclear fallout in 1970. Here, high rates of radiation were also found to damage crop plants and restrict their growth.[80] To accurately gauge the potential impact of nuclear fallout on farming across Britain, Wantage conducted its own experiments on a nationwide scale. A 1973 study by Davies and D.B Mackay saw irradiated cereals and potatoes germinated at the Official Seed Testing Station (OSTS) in Cambridge and grown at the NIAB's regional crop trials centres: Headley Hall (Yorkshire) and the Norfolk Agricultural Station.[81]

Yet newfound pessimism on the impact of radiation in agriculture encountered at Wantage and Brookhaven from the late 1960s was not a general rule. Elsewhere, in European research institutions, technological optimism remained the order of the day. One widely respected centre of mutation breeding research was found at the

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[76] Davies (1968): 29. A similar research programme at Harwell involving mice is described by de Chadarevian (2006).
[77] Davies (1973): 134.
[78] Ellis et al. (1968): 284.
[79] Lutts (1985): 214-215.
[80] Sparrow, et al. (1970).
[81] Davies and Mackay (1973): 137-139.

Cytogenetic Department of the Swedish Seed Association.[82] The Department opened in 1931, to conduct 'research on chromosomes and the breeding methods based thereon.'[83] Its work had initially focused upon chromosome doubling through the use of colchicine, but in 1940 the Association had 'embarked on a programme for the intentional production of vital mutants', harnessing chemical treatments, irradiation, mustard gas and neutrons.[84] By the 1960s the Association had produced commercial crop varieties, including barley, using radiation and held an esteemed position on the international stage. At a 1964 FAO meeting on mutations and plant breeding, the head of Swedish barley breeding efforts, Professor Å. Gustafsson, found himself elected President of the Meeting of the first day of proceedings.[85]

Yet the activities of the Cytogenetic Department of the Swedish Seed Association are also revelatory of the wider difficulties faced by anybody who wished to harness induced mutations in plant breeding. Seeds exposed to radiation were found to form chimeras, with part of the organism possessing its original genotype and part possessing the induced mutation(s). Breeders were therefore forced to grow another generation of plants from these chimeras before the true 'search for mutations can begin.'[86] According to a 1961 survey of polyploidy and mutation research (first published in Britain in 1962) conducted at the Association's Cytogenetic Department, locating beneficial mutations was a rather crude and exceptionally laborious undertaking. It required 'detailed and often repeated observations', as 'the investigator must seek the deviating plants among thousands and thousands of specimens. A trained eye and strenuous effort is required to find the mutated plants.'[87] Given the then unavoidable reliance on morphological identification of mutants, it is clear that a large and lengthy investment of expert labour was required to make mutation breeding programmes work. Moreover, it is highly questionable whether such investment would result in significant returns. As we have seen, induced mutations were used as a supplementary technique, alongside established breeding methods like hybridization.

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[82] In Chapter 1 we encountered the Association's Director, Professor Erik Åkerburg, speaking at the NIAB on the application of Mendelian laws to agriculture.
[83] Levan (1948): 304.
[84] Gustafsson and Mackey (1948): 339.
[85] Swaminathan (1965): 65.
[86] Hagberg and Åkerburg (1962): 87.
[87] Hagberg and Åkerburg (1962): 87.

Crop improvement through radiation was, according to John R. Laughnan of the University of Illinois's Biology Division, 'difficult to assess, and sometimes embarrassingly short-lived.'[88]

In both Sweden and the United Kingdom, it was no accident that the most promising breakthroughs attributed to mutation breeding through radiation were accomplished in barley. At the Swedish Seed Association, barley was considered 'the model material for mutation breeding' and the material on which 'the most extensive mutation breeding trials have been performed.'[89] Either barley was the easiest cereal crop to manipulate using radiation, or repeated trials and experimental data had encouraged more and more researchers to study the crop. In either case, to turn away from barley and attempt to breed other crop types through irradiation would pose a significant investment, to either finances or reputation.[90] Barley varieties, on the other hand, provided 'good examples of clear and considerable differences' that could arise from mutation. Hence new barley lines were developed on an international scale, in Britain, Sweden, Germany, and Argentina.[91] The shape of national economies seemed to play a major role in dictating which crop plants were subjected to mutation breeding programmes. In Canada, mutation-bred rapeseed and flax were developed during the 1950s and '60s. In Italy, approximately seventy percent of durum wheat varieties – used to make pasta – were mutant varieties by 1994.[92]

Despite the success of private companies at home and research centres abroad, widespread interest in mutation breeding seems to have declined in Britain by the late 1970s. In 1976 *Radiation Botany* changed its title, to become the journal of *Environmental and Experimental Botany*. Its editors expressed an interest in papers on a wide variety of topics: cytogenetics, photobotany, pollution studies and cytochemistry (including research on DNA content and labelling).[93] Thereafter, the number of papers on mutation breeding published by the journal rapidly declined. By 1976, one of the great specialist journals for the scientific study of mutation breeding had effectively

[88] Laughnan (1960): 3.
[89] Hagberg and Åkerburg (1962): 90.
[90] On the impact and problems associated with model organisms in biology, see Hunter (2008); Leonelli and Ankeny (2012).
[91] Hagberg and Åkerburg (1962): 90.
[92] Kharkwal (2011): 28.
[93] Announcement (1975): 313.

been lost to that field. This was only part of a larger trend which, along with changing research priorities at Wantage and other agricultural research centres, suggests that mutation breeding had lost a significant amount of its appeal to both biologists and breeders in Britain. Beginning in the late 1960s, greater attention was instead diverted to modelling the damage caused to crop plants by nuclear fallout, rather than the positive benefits of radiation in plant breeding.

This decline may in part be attributed to a lack of practical results. After all, we have seen that mutation breeding required considerable investment, was often reliant on other plant breeding techniques and was only of commercial value for a few crop types. In the United States, interest in mutation breeding had declined by the mid-1960s, in part due to 'continued failure to produce convincing results via induced mutation.'[94] Yet other factors were also in play. The departure of Darlington from the JIHI in 1953 was in part driven by his sense of dawning molecular revolution following Watson and Crick's 1953 discovery of the structure of DNA. In the United States, a 'burgeoning interest in other means of genetic manipulation' also led to a general loss of enthusiasm for mutation breeding.[95] The rise of genetic biotechnology, with its promises of radical and targeted crop improvement, effectively left mutation breeding looking out-of-date. Soon enough, even the most ardent supporters of mutation breeding were forced to admit its time in the sun was over, as 'During the period 1985-95 the great attraction of biotechnological approaches started to overshadow the value of mutation work.'[96]

## Conclusions

Between them, the three episodes examined in this chapter – the 1952 JIHI symposium, Milns' barley breeding programme and the Wantage fallout research – throw important light on the rise and decline of mutation breeding as a major plant breeding technology in Britain. The history of mutation breeding, particularly in barley, reinforces a number of lessons from both the first chapter of this thesis and the wider historiography on

[94] Curry (2016a): 153.
[95] Curry (2016a): 153.
[96] Van Harten (1998): 62.

twentieth-century plant breeding. As in the case of industrial hybridization, the uptake of mutation breeding was reliant upon its compatibility with existing industrial, technological and ideological systems. Mutation breeding was developed at state-funded institutions like the JIHI, while the radioisotopes required by private industry for mutation breeding programmes were supplied by the Atomic Energy Research Establishment at Harwell. As in other national case studies, mutation breeding programmes were part of a wider technological system based on atomic energy.[97] The use of radiation to alter the chromosomes – and hence the heredity – of crop plants was also politicised activity, with successes in the field once again seen as a refutation of Lysenko's biology. Contemporary ideas and fears once again interacted with technology and marketing to ensure the uptake of mutation-bred crop plants.

The history of mutation breeding is also revelatory of two important themes which reoccur later in this thesis. Firstly, the 1952 JIHI symposium demonstrates that in the world of biotechnology the boundaries between biological disciplines can be extremely porous. For instance, we have seen how cytologists working on plant cells can find themselves based in medical institutions and how Darlington articulated a Cold War technological ambition shared among the biological sciences: to understand and manipulate the fundamental processes of heredity. Ambitions, ideas and even techniques were circulated between biologists in different disciplines, a theme we shall return to in Chapter 3. Secondly, the development of Golden Promise by Milns Seeds represents a significant and growing divide in how plant biotechnology was investigated. On the one hand were state-funded plant breeding stations and atomic laboratories, and on the other commercial seed firms. The arrival of Milns Seeds as a rival to the PBI and its famed Proctor barley was made possible by both technological developments – the newfound availability of radioactive isotopes – and changes to intellectual property law in the form of Plant Breeders' Rights. The scope for private investment in plant biotechnology would only grow throughout the 1970s and 1980s, as government cutbacks drastically altered the landscape of agricultural research in Britain.[98]

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[97] Curry (2016a).

[98] The impact of government cuts on agricultural research during the 1980s is discussed more fully in Chapter 4.

Although interest and state-sponsored research into mutation breeding died back during the course of the 1960s, this did not spell the end of mutation-bred crop varieties in British agriculture. Golden Promise remains a popular barley variety with specialist brewing firms, while in the early 1980s another mutant cultivar – Triumph – dominated the UK barley market.[99] It would therefore be premature to dismiss mutation breeding as a completely failed or impractical biotechnology. Yet in a classic example of bio-hype, the desire of mutation breeders to 'produce plants to order' never materialised.[100] Naturally occurring mutations were still relied upon by breeders. Take the discovery of a mutant plant nestled among a field of faba beans in Lincolnshire in 1971. Once spotted, the mutant bean plant was isolated and carted off for further study. Nicknamed 'Ostler's mutant', the plant possessed unusually narrow leaves. If commercially grown, the mutant would reduce canopy coverage in bean fields: a characteristic of potential agronomic value. Yet what so excited agricultural botanists and breeders was not so much the physiology of Ostler's mutant as its rarity. Although similar mutants had been spotted before, their occurrence was estimated to be as low as one in a million plants. More than two decades later, little had changed. A second faba bean mutant, this time with tendril-like structures, was discovered in a Cambridge field in 1999 and generated similar excitement. Although mutation breeding was harnessed to replicate the plant's tendrils, the resulting offspring were sterile.[101]

The ability to alter chromosomes through radiation had seemingly offered plant breeders the chance to reach inside the cell and alter the material basis of heredity. Yet the ambition to drastically alter the genetics of organisms for plant breeding purposes reached far beyond mutation breeding and even the realm of both the state-funded and private plant breeder. In 1976 the journal of *Radiation Botany* sought to rebrand itself with a new title – *Environmental and Experimental Botany* – and an expanded range of contributions. Among the list of contributions sought in the field of experimental botany were those on 'Somatic cell genetics and parasexual hybridization'.[102] Parasexual hybridization, or cell fusion, was another form of Cold War

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[99] Van Harten (1998): 251.
[100] Williams (1955): 719.
[101] Bond and Crofton (2001).
[102] 'Announcement' (1975).

technological ambition: one designed to dissolve the very boundaries between different forms of life.

# 3. Cell Fusion: Biotechnological Optimism in Plant Physiology

> The Brookhaven team, looking ahead, hopes to apply its techniques to fairly closely related species so as to improve the drought and disease resistance of important food crops. They have already discounted science fiction hybrids such as trees bearing immense crops of runner beans all the year round.
> – Arthur Bennet and Ted Schoeters, *The Financial Times*, August 23, 1972.[1]

In the last chapter we saw how a surge of Cold War technological optimism, powered by nuclear energy, gave rise to renewed efforts to breed better crops using radiation. Other radical technologies aimed at unlocking the genetic diversity hidden within plant cells were also explored during this time. In this chapter, we explore one such technology: the fusion of plant cells which, during the 1960s and 1970s, promised a new era of crop improvement. Among a number of techniques which emerged from cell fusion technology, the most promising was somatic hybridization, or the fusion of plant cell nuclei. Somatic hybridization is the particle collider of the biological world: plant cells stripped of their cell wall are fused to create interspecific crosses containing a huge range of genetic information. For a time, it even seemed that somatic hybridization would become the premier technique in plant biotechnology. As late as the 1970s, a recombinant DNA future was by no means a foregone conclusion. Cell fusion offered an alternate means of revolutionising both medicine and agriculture through biotechnology.

If you travelled back to the 1960s to ask a respectable biologist about the most promising means of modifying crop plants, they may well point you towards somatic hybridization. If you asked the same question in the 1990s, the firm answer would be genetic modification through recombinant DNA technology. At the 1970 meeting of the British Society for Social Responsibility in Science (BSSRS) in London, Yale's Professor of Biology Arthur W. Galston exemplified the perceived importance of somatic hybridization. Speaking to a mixed audience of scientists, historians, technicians and

[1] Bennet and Schoeters (1972): 8.

social radicals, Galston announced that 'One can dream of many exciting possibilities' when considering a future dominated by 'new somatic genetics of higher plants'.[2] Yet in only a matter of years, this exciting future had ebbed away, to be replaced by modern biotechnology as we know it today. Recombinant DNA is now synonymous with genetic biotechnology. The whole technology of somatic hybridization – including the fusion, resurrection and reproduction of plant cells stripped of their cell walls (termed protoplasts) – is now a largely forgotten history.[3] Instead, the history of modern biotechnology and its application to agriculture is dominated by the meteoric rise of molecular biology and the development of recombinant DNA technology in the United States.[4]

It is not only the intricacies of technology that made cell fusion and somatic hybridization different from the development of recombinant DNA. Unlike the traditional narrative of modern biotechnology, critical developments in somatic hybridization occurred in an international academic setting, largely due to the work of plant physiologists and pathologists. For much of the twentieth century, plant physiologists had considered their discipline best able to 'study and explain biological functions and processes'.[5] By the 1960s, at the height of 'Cold War technological optimism', plant physiologists had claimed not only to have achieved their goal of unlocking the underlying laws of plant physiology, but to have overcome the barrier posed by the plant cell wall.[6] The removal of the cell wall promised the ability to study plant cells with newfound clarity, to merge these cells through somatic hybridization and bypass the limits of traditional sexual reproduction. By contrast, standard histories of the development of recombinant DNA technology take place in a commercialised and

[2] Galston (1971): 158. The BSSRS meeting provides a useful 'case-study of sea-change arguments.' The conference was large and represented a plethora of views and attitudes to modern science. See Agar (2008): 571-573.
[3] Like GMOs, somatically hybridized plants keep the additional genetic information gained via fusion across the generations (although sterility poses a major barrier). Short references to somatic hybridization occur in Kloppenburg (1988): 192; Daniel (2001): 9; Lurquin (2001): 102; Schurman (2003): 20. Despite these references, somatic hybridization has yet to be subjected to thorough historical treatment.
[4] As we have seen, recombinant DNA technology comes complete with its own scientific narrative. Significant names and dates include the discovery of the structure of DNA by Watson and Crick in 1953, and the creation of recombinant DNA molecules in 1972, closely followed by bacterium in 1973 and so on. See Wright (1986): 303.
[5] Munns (2015): 29.
[6] Munns (2015): 29. On the contribution of plant physiologists to molecular biology, see Zallen (1993).

localised context.[7] However, it was recombinant DNA technology that was able to quickly produce products suitable for agriculture.

This chapter sets out the reconstructed story of somatic hybridization: its origins, key developments, heyday and eventual decline. Firstly, we will briefly explore the history of early protoplast research and the background to its emergence as a possible tool for plant breeders from the 1960s: including prior work on animal cell fusion in biological and medical circles and the rise of plant physiology. Moving into the mid-twentieth century, the chapter then relates how plant cells were first stripped of their cell walls using enzymes at the University of Nottingham's Department of Botany, which allowed a renewed interest in somatic hybridization to flourish. The third section of the chapter covers the heyday of somatic hybridization, including the creation of the world's first somatic hybrid (in the modern sense). Finally, an account is given of why somatic hybridization failed to become a widespread agricultural biotechnology, relative to recombinant DNA technology. Cultivars of somatic hybrids did not appear in commercial agriculture until the 1990s. This late arrival was largely a consequence of technical difficulties and supply problems, which hampered research.

## 1. Plant Physiologists and the Cell

The history of somatic hybridization begins with a scientific dichotomy. Enterprising botanists, plant breeders and even gardeners claimed to have created somatic hybrids since (at least) the mid-nineteenth century. Yet by the 1950s most biologists insisted that somatic hybrids were an impossible fable.[8] This inconsistency arose due to longstanding arguments surrounding an age-old botanical technique: grafting. For a century or more, everyone from Charles Darwin to the authors of botanical textbooks had claimed that plant grafts somehow interacted at the cellular level, making them true somatic hybrids.[9] Yet this claim was largely abandoned in mainstream botany and

[7] Kenney (1986); Smith Hughes (2001); Kleinman (2003); Rasmussen (2014).
[8] Constabel (1976): 743.
[9] For much of the nineteenth and twentieth century, many botanists believed that grafting could result in the exchange of hereditary particles or cell fusion. A thorough treatment of this complex topic appears in Chapter 5 of this thesis.

graft hybrids were labelled as chimeras by 1949.[10] Such was the taboo against graft hybrids that as late as 1965 the *Encyclopaedia of Plant Physiology* was unequivocal in its dismissal of somatic hybrids. Contributor Professor F. Brabec announced that 'somatic hybrids do not exist and taking all possibilities into consideration, it appears unlikely they will ever exist.'[11] In all fairness, somatic hybridization – the fusion of plant cell nuclei – faced a number of major obstacles. Foremost among these was the seeming impenetrability of the cell wall. To create fused plant cells, it is necessary to remove their walls without damaging the contents. Plant cells devoid of their walls are now termed protoplasts.

The first recorded protoplasts were created in the late nineteenth century. Yet early milestones in what we now recognise as protoplast research were disconnected from more modern developments. These milestones were only recognised as significant following reviews of the scientific literature from somatic hybridization enthusiasts during the 1960s and 1970s. It was such reviews which uncovered the work of John Klercker (1866-1929), Associate Professor of Botany at the University of Stockholm, who in 1892 had mechanically cut away the wall of plant cells to release their cytoplasm and observe their contents.[12] Further studies of plant cells by European botanists yielded experimental observations which would later be seized upon as further milestones in the field of plant cell fusion. Protoplast fusion was subsequently observed in epidermis cells by German botanist Ernst Küster in 1910 and interspecific fusions were recorded by Küster's protégé W. Michel in 1937.[13] The problem of peering inside the cell would engage plant physiologists on an international level.

Mechanical methods of removing the cell wall were extremely difficult and labour-intensive, severely limiting the number of protoplasts available for study. Writing in 1931, Janet Q. Plowe of the University of Pennsylvania's Department of Botany

[10] Constabel (1976): 743. Chimeras are organisms possessing two or more genomes. The complexities of this history and the persistence of graft hybrids within the British agricultural community and certain sections of the scientific world are also discussed in Chapter 5.
[11] Brabec's section of the 1965 *Encyclopaedia of Plant Physiolog*y did not appear with an English translation. His dismissal of the possibility of a somatic hybrid appeared in Constabel (1976): 743.
[12] Cocking (1965). For the original nineteenth-century paper, see Klercker (1892). Klercker's short piece can be accessed at the Digitale Sammlungen. http://sammlungen.ub.uni-frankfurt.de/botanik/periodical/pageview/4449862. Accessed 16 February 2016.
[13] Protoplasts can occur naturally, allowing fusion between plant cells to occur. Küster observed 'naked vacuolar membranes' in the sap of solanaceous berries. Küster (1927). Decades later, protoplasts, protoplasmic units and vacuoles were observed in tomato fruit locale tissue. Cocking and Gregory (1963).

described the agonising process of separating dehydrated epidermal cells of Bermuda onions from their walls, using nothing more than a blunt needle and a scalpel.[14] It is worth reiterating at this stage that the early pioneers of protoplast creation and fusion were not interested in creating somatic hybrids.[15] They were plant physiologists based within university botany departments. As Plowe's paper, which explained how 'the existence and function of the plasma membrane' concerned physiologists 'from both a practical and… theoretical point of view', demonstrates, their interests were focused squarely upon the plant cell: its structure and function.[16] It would not be until the 1960s that the means of producing large numbers of plant protoplasts – hence raising the possibility that somatic hybrids could be a useful tool in plant breeding – would become available.[17]

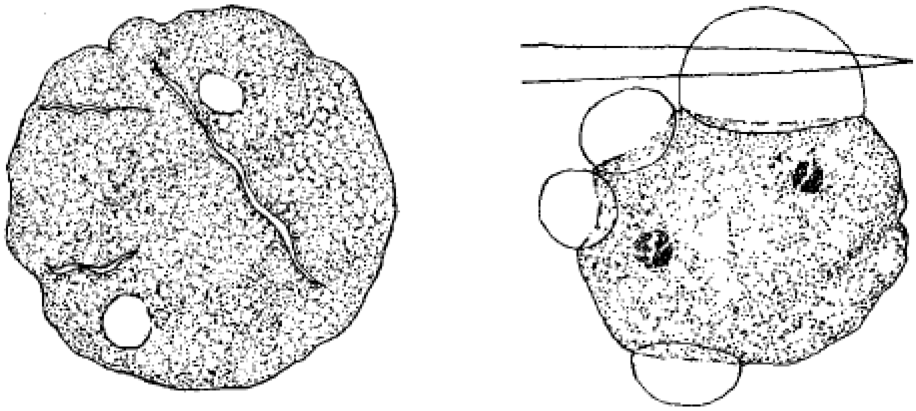

**Figure 3.1: The Plant Cell Nucleus. Following the surgical removal of the cell wall and protoplasm, plant physiologists could finally see the nucleus of plant cells. Yet the procedure for manually creating protoplasts was extremely difficult. Furthermore, there was no effective way of manually manipulating the nucleus without causing damage. From Plowe (1931): 213, 215.**

[14] Plowe (1931): 197-198. Plowe saw herself within a tradition of cell research and micromanipulation, beginning with de Vries's 1885 study of the tonoplast (the layer of cytoplasm around the plant vacuole). Plowe favoured the term 'micromanipulation' over 'microdissection' for her work, as the latter implied the study of dead organisms.

[15] It was only later that improvement in plant tissue culture technology made the resurrection of altered cells to full-grown plants viable. See Nickell and Torrey (1969): 1068.

[16] Plowe (1931): 196.

[17] Another important development came in the form of tissue culture, required to 'regenerate' fused cells in a viable plant. See Landecker (2006).

Throughout the twentieth century, plant physiologists had insisted on the primacy of their discipline within botany. By the 1950s this 'self-image' manifested itself with a focus on the basic processes underpinning life, an experimental methodology and a belief that plant physiology was the 'leading edge of plant science.'[18] Yet despite a sense of primacy and an experimental drive, by the 1960s protoplasts existed only as a research tool for plant physiology. However, cell fusion was of great interest to other biologists interested in fundamental questions of heredity and the plasticity of life. During the 1950s new discoveries indicated that somatic cells could exchange genetic information, leading molecular biologist and bacteriologist Joshua Lederberg (1925-2008) to criticise biologists for their 'antisexual bias.'[19] Cell fusion – and later, plant somatic hybridization – would become part of a larger project in the life sciences, aimed at testing the limits of life's plasticity.

Fusion of human and animal somatic cells had been achieved by the mid-1960s, leaving researchers surprised by the cellular compatibility, or 'internal homology' of organisms.[20] To journalists, the fusion of human and mouse cells by Henry Harris and John Watkins in 1965 heralded everything from the creation of monsters to a new understanding of life.[21] Yet fusion of microbial and animal cells also served as a source of dialogue and inspiration for those involved in somatic hybridization. For instance, both parties were wholly reliant upon tissue culture for their work, with techniques being readily shared across disciplinary boundaries throughout the twentieth century.[22] As somatic hybridization developed throughout the 1960s and 1970s, new innovations were passed onto colleagues concerned with animal cell fusion. For instance, Henry Harris recalled how a highly-effective chemical used to encourage plant cell fusion in the mid-1970s was also found to be of equal benefit for fusing animal cells.[23]

In the public sphere, cell fusion faced a mixed reception. A 1967 BBC programme entitled 'Assault on Life' was criticised by John Watkins for not revealing the medical purpose behind his experiments with hybrid cells. Responding to a distressed

[18] Munns (2015): 32.
[19] Landecker (2007): 188. The source cited here by Landecker is Lederberg (1958): 384.
[20] Landecker (2007): 199. A similar trend can be seen with recombinant DNA technology, which was first applied to bacterial and animal cells before its use in plants.
[21] On cell fusion and its portrayal in the media, see Harris (1987): 192-194; Wilson (2011): 75.
[22] Landecker (2006): 153.
[23] Harris (1995): 142.

viewer of the programme, Watkins argued that cell fusion was not the same as fusing animals, stating that 'We are not, for example, trying to create centaurs.' Nor would cell fusion create 'species of subnormal intelligence', or 'ferocious species in invincible armies'.[24] In a very different manner to his publicity-courting colleague Harris, Watkins stated that the public reaction to the BBC programme provided an 'awful warning' to scientists tempted by the world of 'mass media, fashion photographers and pop stars'.[25] Such a level of publicity and controversy did not emerge in the world of plant cell fusion. However, the aims and ambitions of somatic hybridizers within the discipline of plant physiology were no less grandiose than those of their colleagues elsewhere in the biological sciences.

The twentieth century had seen a growing self-confidence among plant physiologists that their experimentally-orientated discipline could unlock the fundamental processes of life. Part of this ambition manifested itself in attempts to remove the plant cell wall and study protoplasts, as attempted by Klercker and Plowe. Yet to some extent, this history of protoplast creation was an invented tradition. In 1967, controversy erupted when Swiss botanist A. Frey-Wyssling suggested that plant protoplasts should be termed gymnoplasts. Frey-Wyssling based his challenge upon historical precedence, citing Küster's (1935) use of gymnoplasts.[26] Unfortunately for Frey-Wyssling, his claim to historical precedence using Küster was overridden by the (re)discovery of Klercker's 1892 manuscript.[27] Disputes over terminology can be seen as part of a more important struggle to construct a scientific tradition. As protoplast research dramatically surged forward during the 1960s, the creation of commercially important somatic hybrids became a tangible possibility. The recognition of who came first suddenly became a matter of urgency.[28]

A growing sense of purpose among plant physiologists was joined by the general realisation that somatic cells could be involved in heredity. Throughout the 1950s and

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[24] Watkins (1967): 7.

[25] Watkins (1967): 7. Wilson (2011): 75 argues that experiments fusing human and mouse cells were conducted by Harris in an attempt to bring publicity to his research.

[26] Frey-Wyssling (1967): 516.

[27] Pojnar and Cocking (1968): 289.

[28] Just as molecular biology possesses a scientific narrative, so plant physiologists attempt to build their own, following successful advances in protoplast creation. While the former finds its origins in the 1953 discovery of DNA, Cocking found his in Klercker's release of the protoplast in 1892.

1960s, biological researchers were astonished to find that very different organisms were compatible on the cellular level: somatic hybridization would therefore operate alongside a wider scientific discourse on the possibilities offered by cell fusion. By the 1960s, therefore, the stage was set for the revival and future development of protoplast research with a new aim: the creation and reproduction of somatic hybrids. Research into protoplasts and somatic hybridization would initially take place within the world of plant physiology, rather than the realm of molecular biology. All that stood in the physiologist's way was the barrier posed by the cell wall: a barrier which would be eventually be overcome using an enzymatic method recommended by microbiologists.

## 2. Enzymes and Protoplast Production

A key moment in the modern history of somatic hybridization occurred at the University of Nottingham's Botany Department in 1960. Some forty years later, its principal instigator and lecturer in plant physiology Edward C. Cocking recounted the event. Cocking was attempting to develop a new cell culture method. Noting that cell division did not occur in tomato root cells, he speculated that releasing the cell contents from their confining wall would aid the culture process. Drawing upon discussions with workers at the Microbiological Research Establishment in Porton, Cocking decided that the use of a cellulase enzyme would be most effective for degrading plant cell walls.[29] Fruitless attempt after fruitless attempt followed his decision. Commercially available enzyme preparations were simply not up to the task. A promising avenue finally opened when Cocking came across the studies of D.R. Whitaker of the National Research Laboratories in Ottawa, who had developed his own cellulase preparation.  When Cocking tested Whitaker's preparation, the solution was a complete success, releasing protoplasts.[30]

What was the significance of applying Whitaker's enzyme preparation to plant cells? Cocking's initial report to *Nature* (1960) on the phenomenon was purely descriptive. Yet a paper published the following year showed developments in both his techniques and ideas on the use of protoplasts. Cocking noted that 'liberated bacterial

[29] Cocking (2000): 77.
[30] Cocking (1960).

and fungal protoplasts' were of great value in 'morphological, biochemical and genetic work.'[31] Protoplasts released from the root tips of tomato seedlings in Cocking's laboratory 'indicated their unique potentiality for similar studies.'[32] More important was an unspoken truth. An enzymatic means of creating protoplasts freed physiologists from the constraints of micromanipulation of cells via surgical instruments as described by Plowe in 1931. Relatively speaking, protoplasts could now be created quickly and in the

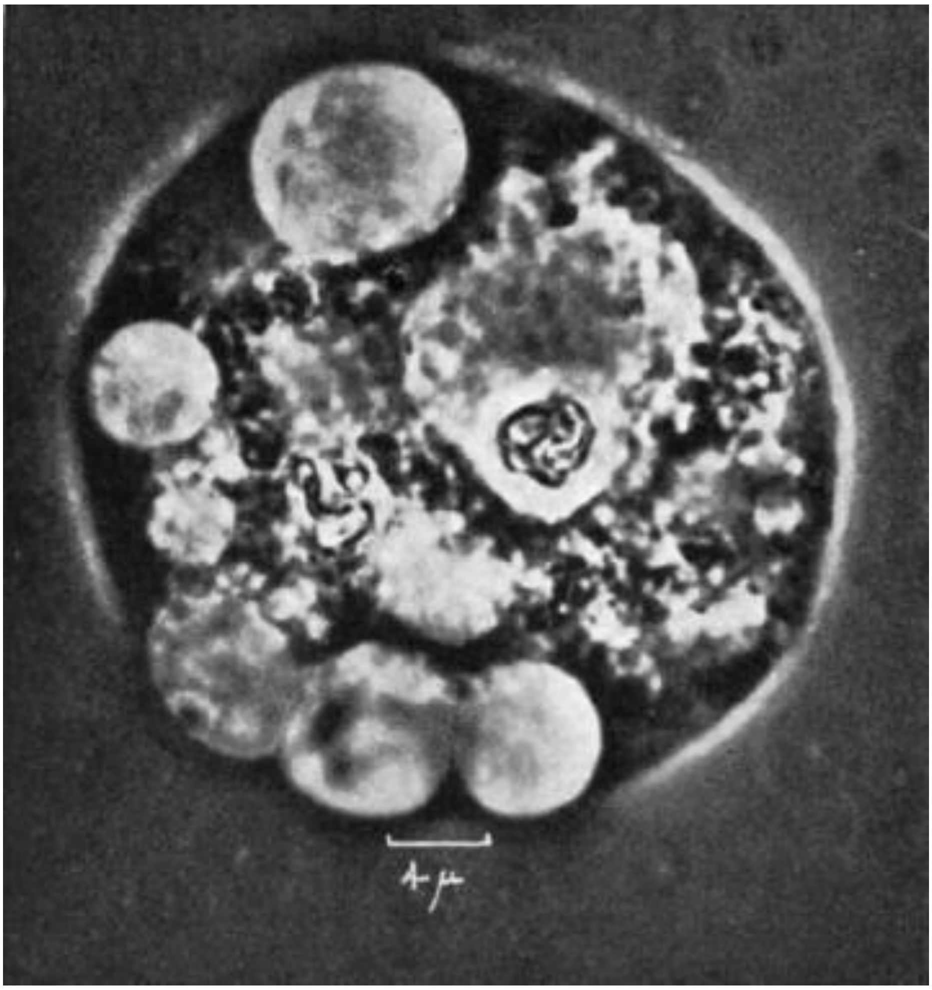

Figure 3.2: Protoplast Production. Treating plant cells with enzymes to dissolve the cell wall enabled the creation of protoplasts on a large scale. Here the cell wall (the white boundary surrounding the cell) is being gradually dissolved, with the contents of the cell beginning to escape (bottom). From Cocking (1961): 781.

[31] Cocking (1961): 780.
[32] Cocking (1961): 780.

large numbers required for research. Yet in these early years, experiments conducted at the University of Nottingham focused purely upon means of harnessing protoplasts to solve 'present problems associated with growth and differentiation in plants.'[33] Somatic hybridization had yet to re-enter the scientific discourse.

Scientists at the University of Nottingham may have been reticent to make wild claims regarding the potential of protoplasts for plant breeding. Yet other biologists were not so reserved, excitedly noting the potential for somatic hybridization. Speaking at the 1970 BSSRS meeting, Arthur Galston embodied this excitement. But why did naked cells in a Nottingham laboratory so excite this Professor of Biology? In the spirit of a conference sceptical of scientific triumphalism, Galston characterised intensive agriculture as beset by technological problems, from overreliance on fertilisers to disease-vulnerable monocultures.[34] Radical advances in plant breeding would be required to produce new crops: plants capable of yielding more food at a lower cost to the environment. This issue was made all the more pressing by the publication of Rachel Carson's *Silent Spring* (1962), which revealed the extent of environmental damage caused by indiscriminate pesticide use in industrialised agriculture.

Only the year before the BSSRS conference, Paul Ehrlich (1968) published his own bestselling work *The Population Bomb*. The book warned of the precise dangers to modern agriculture cited by Galston, including the environmental degradation caused by nitrogen fertilisers, while predicting global food shortages from overpopulation. Population concerns would go on to feature in a prominent fashion at the first Earth Day in 1970.[35] On the one hand, industrialised agriculture was a source of pollution and environmental damage. Yet growing more food was one way to counter the looming population crisis. Among a number of promising solutions discussed by Galston was somatic hybridization. Referring to Cocking's removal of the plant cell wall, Galston announced that somatic hybrids might one day emerge, possessing remarkable qualities: from nitrogen fixing to disease resistance.[36]

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[33] Cocking (1961): 781.
[34] Galston (1971): 158.
[35] Galston (1971): 158. Ehrlich's work formed part of a wider neo-Malthusian literature, which emerged in the post-war era. For an overview, see Schoijet (1999). On the connections between the neo-Malthusian and early environmentalist movement, see Robertson (2012).
[36] Galston (1971): 159. Disease resistance in plant varieties was a major concern at this time, as monocultures led to a narrow genetic base in key crops: a weakness we have seen highlighted by a 1970

Within purely scientific exchanges, a similar level of excitement was displayed. At a 1969 meeting of plant physiologists and geneticists, somatic hybridization was designated by observers to be 'still experimental, but… shows great promise.'[37] Suggestions arose that sexual barriers to crossing in plant breeding could be overcome. Advances in protoplast manipulation hinted that 'asexual fusion might become a major method for 'crossing' unrelated plants which are not easily crossed using sexual methods.'[38] Reported in *Science*, the meeting 'Crop Improvement through Plant Cell and Tissue Culture' was no minor affair and included important figures such as Cocking.[39] Yet despite the sanguinity of the attendees and Galston's optimism, it had now been some ten years since Cocking had first harnessed enzymes to release protoplasts. Not one plant had yet been created using somatic hybridization.

Two barriers stood in the way of somatic hybrids. Once released from the confines of their cell wall, protoplasts were no longer viable as living cells outside of their nurturing medium. Vulnerable to the environment, the regeneration of a new cell wall was necessary for their long-term survival. With this achieved, efforts could then turn to growing viable plants from protoplasts. These barriers were overcome due to the efforts of Japanese researchers. In 1970, Toshiyuki Nagata and Itaru Takebe of the Institute for Plant Virus Research in Chiba, Japan observed protoplasts regenerating their lost walls. Their subject, tobacco mesophyll, was also capable of cell division.[40] Takebe was hopeful. Citing then-unpublished observations, he stated his belief that protoplasts were capable of fusion, offering 'a unique experimental material for plant genetics'.[41] Collaboration between Takebe and researchers at the Max-Planck-Institut für Biologie in Tübingen the following year saw the regeneration of a whole plant from protoplasts. These results established 'for the first time that cell protoplasts from the mesophyll can be cultured to give rise to whole plants.'[42] Extensive cell division in

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outbreak of southern corn leaf blight, which destroyed fifteen percent of the corn crop in the United States. Bouts of plant disease also occurred in Britain throughout the 1970s. Kloppenburg (1988): 122.

[37] Nickell and Torrey (1969): 1068.

[38] Nickell and Torrey (1969): 1068.

[39] Nickell and Torrey (1969): 1070.

[40] Nagata and Takebe (1970): 303-304.

[41] Nagata and Takebe (1970): 307.

[42] Takebe, et al. (1971): 320.

protoplasts opened new possibilities, including 'the breeding of new plants through somatic hybridization.'[43]

Given the pre-existing interest of plant physiologists in protoplast work, it comes as little surprise that an enzymatic means of releasing protoplasts was first developed in a botany department. Cocking's work raised much interest, with funding for future research provided by esteemed bodies such as the Royal Society and the Department of Scientific and Industrial Research.[44] The regeneration of whole plants from protoplasts marked another important step towards a new future in plant breeding, one dominated by somatic genetics. These results also emerged from the plant sciences sector, albeit a plant pathology institute, rather than a department of botany. The shift in protoplast research to Japan is explained by the country's advanced enzyme-production facilities.[45] The cellulase enzyme used for protoplast production was produced commercially in Japan from 1968, enabling domestic researchers' easy access to the raw ingredients necessary for advanced work with plant protoplasts. Although Takebe, Labib and Melchers had openly invoked the possibility of somatic hybrids in 1971, the actual regeneration of a higher plant from fused protoplasts would take place the following year, in the United States.

### 3. Somatic Hybridization and Plant Breeding

In 1972 – a year usually associated with the first recombinant DNA molecules – a team at the Department of Biology at Brookhaven National Laboratory used protoplast fusion to create an interspecific plant hybrid.[46] This achievement marked a major advance in the field of somatic hybridization, moving the fledgling technology one step closer to its ultimate commercial aim: creating new varieties of enhanced crop plants in agriculture. Human manipulation had essentially overcome the usual sexual barriers to species crosses. The Brookhaven National Laboratory team's paper, published in the *Proceedings of the National Academy of Sciences*, bore clear references to the difficult

[43] Takebe, et al. (1971): 320.
[44] Cocking (1961): 782.
[45] Cocking (2000): 78.
[46] As early as 1948, the Brookhaven Department of Biology had hired geneticist and plant breeder W. Ralph Singleton, and was involved in testing the effects of radiation on crop plants. See Curry (2016): 147.

and terminologically confusing past of somatic hybridization. Nagata and Takebe's experimental conditions and regeneration medium were also exactly recreated.[47] The Brookhaven team also sought to distance their hybrid protoplasts from grafting. Their paper described how tumour formation on the stem of their tobacco plant did not occur following a 'graft union', instead being characteristic of a first-generation ($F_1$) hybrid and amphiploid.[48]

Back in Britain the success of the Brookhaven Laboratory team featured in *The Financial Times*. The editors of the newspaper's technical section, Arthur Bennet and Ted Schoeters, used the somatically hybridized Brookhaven tobacco plant to announce that 'Birds and bees [are] not wanted'. Cell fusion of different crop varieties had superseded the traditional hybridization, avoiding the need for a 'complex programme of cross-fertilisation of parent plants'. Carlson and the Brookhaven team also claimed their plants could create 'seeds which are fertile and breed true, which is not often the case with the hybrids now being produced by plant breeders.'[49] To elements of the British press, therefore, somatic hybridization possessed two major positives as a plant breeding technology. Firstly, fusion of distinct plant varieties and even species could overcome traditional sexual barriers to result in new drought or disease resistant crops. Secondly, somatic hybrids offered an alternative to hybrid crops like Proctor barley. Not only could cell fusion replicate the results of hybridization, but the fertile seeds yielded by somatically hybridized plants could potentially put the ability to replicate seeds back in the hands of farmers.[50]

Brookhaven's hybrid tobacco plant can be safely said to mark the beginning of somatic hybridization as a biotechnology with clear agricultural applications. By 1977, Cocking and his colleagues had further developed their laboratory methods to create somatic hybrids from sexually incompatible species.[51] Kloppenburg has described how a period of 'bio-hype' surrounded genetic engineering during the 1970s, before giving way to a 'traditional concern' with practical products.[52] The hype surrounding somatic

[47] Carlson, et al. (1972): 2292.
[48] Carlson, et al. (1972): 2292.
[49] Bennet and Schoeters (1972): 8.
[50] The transfer of seed multiplication from the farmer to the hybrid breeder is described in Chapter 1.
[51] Cocking, et al. (1977): 7-12.
[52] Kloppenburg (1988): 200. Hype can lead biotechnology through phases of 'legitimation' and 'delegitimation', a shift readily apparent in the history of somatic hybridization. See Brown (2003): 11-12.

hybridization encompassed both the 1970s and '80s, largely occurring in Britain and the United States. Although the technique was recognised as an important 'breakthrough in cytological and genetical methodology', supporters seized upon its potential to bypass 'the limits of traditional plant breeding.'[53] Somatic hybridization was not only recognised within scientific circles, but continued to inform attitudes to global population and food security. Addressing the Economic Club of Detroit in 1980, Clifton R. Wharton Jr, Chancellor of the State University of New York, included somatic hybridization alongside germplasm banks as a future means of combating world hunger.[54]

In 1981 an issue of the *Philosophical Transactions of the Royal Society* entitled 'The manipulation of genetic systems in plant breeding' was published, which included a number of articles on somatic hybridization. The issue was not only significant for advocates of somatic hybridization, but discussed numerous breeding techniques and challenges facing contemporary plant scientists and breeders. Cocking noted a marked improvement in the commercial prospects of somatic hybridization, several horticultural and crop species having been created through protoplast fusion.[55] Yet he also acknowledged that further research and close collaboration with breeders would need to occur before protoplasts (whether through cloning at the cellular level or somatic hybridization) would 'add significantly to the armoury of the plant breeder'.[56] Geneticist Sir Kenneth Mather was more upbeat, asserting that the main obstacle to the development of new crop varieties through somatic hybridization was the regeneration of whole plants from protoplasts. Recent advances in regeneration and tissue culture made this obstacle less daunting, leading Mather to claim that regeneration from protoplasts would 'soon be achieved in our cereals'.[57]

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[53] Constabel (1976): 747.
[54] Wharton was a member of the Presidential Commission on World Hunger, which delivered its final report to President Carter in March 1980. Wharton Jr. (1980): 1415.
[55] Cocking (1981): 557. Some of these varieties had not been created through somatic hybridization, but cytoplasmic hybridization, which can involve the movement of organelles or transfer of nuclei via a fusion event.
[56] Cocking (1981): 566.
[57] Mather (1981): 607. In reference to Wernicke and Brettell, (1980).

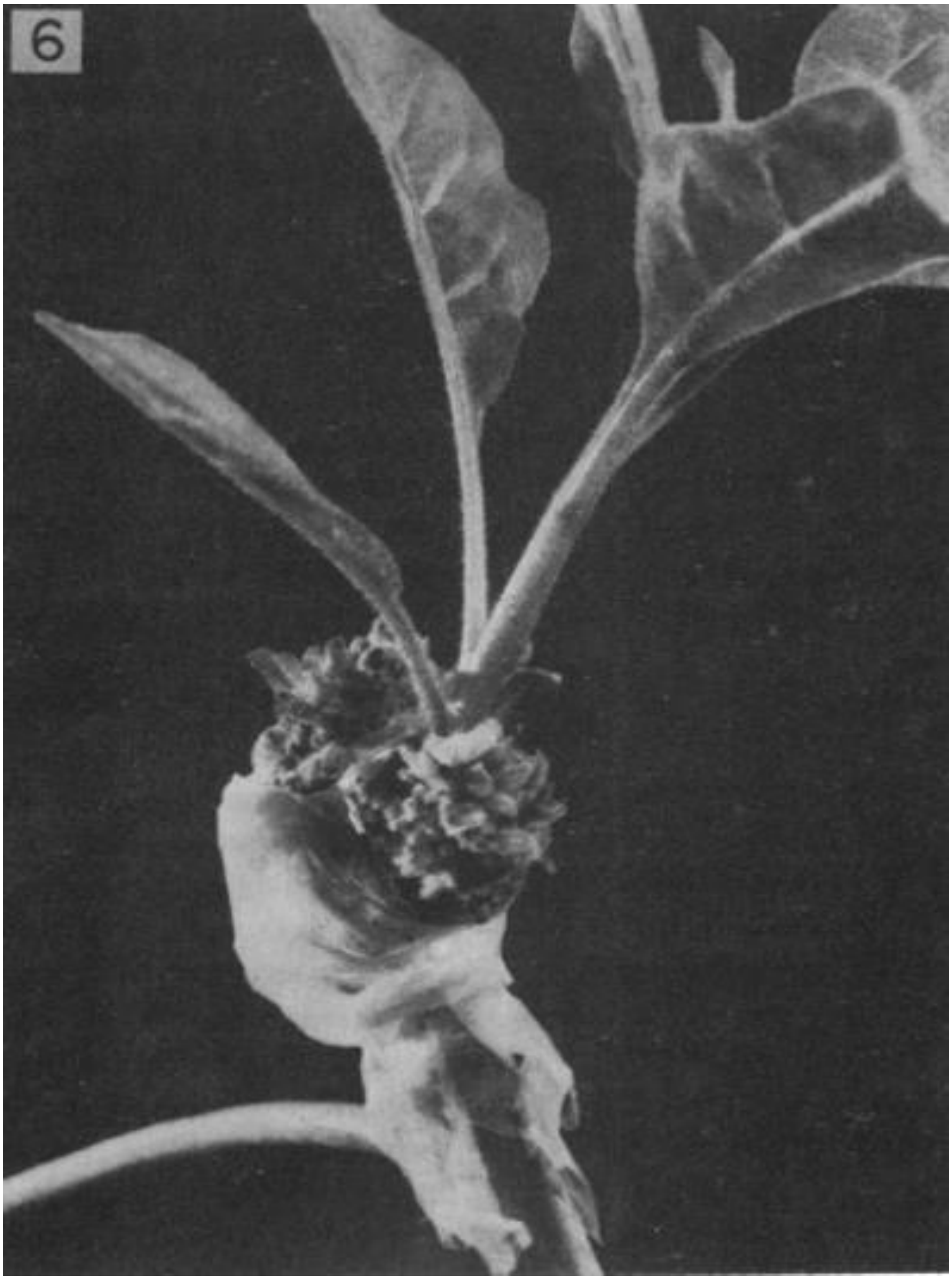


Figure 3.3: The Brookhaven Somatic Hybrid. The tobacco somatic hybrid (foreground) was grafted onto the rootstock of a mature plant to aid its development. This decision meant the Brookhaven team were forced to clarify that their plant was the result of cell fusion, not graft hybridization. From Carlson et al. (1972): 2293.

As the 1980s progressed, somatic hybridization continued to appear in scientific publications on plant breeding and biotechnology, albeit accompanied by a promising newcomer: genetic manipulation through recombinant DNA. The latter become a viable agricultural technology in 1983, with the first permanent uptake of genetic information by a plant.[58] Simultaneous achievements occurred in the production of somatic hybrids, including a (infertile) cross between a potato and tomato.[59] In 1985, M.W. Fowler of the Wolfson Institute of Biotechnology in Sheffield listed protoplast fusion and genetic manipulation side-by-side in a review of methods in cell and tissue culture.[60] Yet for Fowler, somatic hybridization remained a potential tool in agriculture, rather than a practical reality.[61]

In 1984, an international symposium on genetic manipulation in crops was held in Beijing. Li Xianghui of the Academia Sinica's Institute of Genetics used his platform to note that somatic hybridization had been hampered by resulting hybrid plants failing to display even a 'minimal level of fertility'.[62] Technical difficulties hampered somatic hybridization, at the very moment that recombinant DNA technology began to display agricultural applications. Yet all was not lost. At the same symposium, a team comprising of members of Agriculture Canada and Carleton University's Biology Department announced practical advances in cultivar creation through somatic hybridization. Working on a tobacco breeding programme, researchers had somatically crossed two varieties, selected for their disease resistance and elevated nicotine levels.[63] Unlike their predecessors, these hybrids displayed useable levels of fertility. Some twenty somatic hybrid lines were transferred from Ottawa to Delhi, to be incorporated into a backcrossing programme.[64] This line of research finally paid dividends. Some ten years after the symposium, a commercial crop of tobacco created through somatic hybridization was planted in Ontario.[65]

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[58] Bevan (1983).
[59] Shepard, et al. (1983).
[60] Fowler (1985): 215.
[61] Fowler (1985): 220.
[62] Xianghui (1984), 219-220.
[63] Keller, et al. (1984): 192.
[64] Keller, et al. (1984): 192.
[65] Simmonds and Smartt (1999): 290.

Closing the 1984 symposium, W.R Scowcroft of the Commonwealth Scientific and Industrial Research Organisation's division of plant industry gave his reflections. Scowcroft chose to emphasise the importance of plant biotechnology, which, under his definition, included techniques in tissue culture and genetic engineering.[66] He described the ability to produce large numbers of protoplasts and to induce their regeneration into plants a 'truly remarkable technological achievement.'[67] Protoplast fusion was a different matter. Although somatic hybridization allowed 'the circumnavigation of barriers to sexual hybridization', fertility problems meant it was 'still uncertain whether somatic hybridization will permit useful nuclear gene introgression for crop improvement.'[68] As GM crops achieved success and provoked controversy on the international scene during the 1990s, news from the world of somatic hybridization was muted. Notable milestones were achieved during this time, particularly in Canada. Yet the fact remains that somatic hybridization achieved nothing like the status and ubiquity of GM in agriculture. The final section of this chapter will examine the reasons for this disappointing performance in commercial farming and ask if we should consider somatic hybridization an example of technological failure.

## 4. Technical Difficulties and Competition

The story of somatic hybridization appears to be one of unrealised ambition, despite vast potential. Why, then, are fields of somatically hybridized crops absent from our countryside? The large chronological gaps present in the reconstructed story of somatic hybridization offer some indication. If recombinant DNA was a rapidly emerging technology, then protoplast fusion moved at a snail's pace. The technique was later described by British geneticist Norman Simmonds as 'theoretically elegant, but technically demanding.'[69] Yet the technical difficulties involved in creating and fusing protoplasts is only part of the explanation: as with industrial hybridization and mutation breeding, integration with existing industrial systems and competition from other

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[66] Scowcroft (1984): 13.
[67] Scowcroft (1984): 15.
[68] Scowcroft (1984): 15 described genetic manipulation as 'a truly generalised method for plant genetic transformation.'
[69] Simmonds and Smartt (1999): 288.

methods of plant breeding were significant factors in the slow and halting development of somatic hybridization.

Results from protoplast research came periodically. It was over a decade after Cocking had first used an enzymatic procedure to create protoplasts that the next step towards somatic hybrids was made: the regeneration of the cell wall of protoplasts.[70] Reflecting upon this gap, Cocking would later describe how his isolation of protoplasts 'was ahead of the then technology of plant cell-wall-degrading enzyme production.'[71] Shortages of enzyme held back the work of plant scientists at the University of Nottingham. The personal interests of Cocking also held back protoplast work. By his own admission, Cocking was more interested in light microscopy and electron microscopy during the early 1960s, inspired by his work with Irene Manton at the University of Leeds and Heinrich Matthaei in Göttingen. Even if large amounts of commercially available enzymes were available, Cocking considered it 'unlikely' that he would have become a pioneer in protoplast fusion.[72]

Cellulase enzyme was made commercially available in Japan in 1968, for the purpose of baby food and biscuit manufacturing. This enabled Japanese protoplast researchers like Nagata and Takebe to carry out their experiments.[73] Yet enzyme shortages continued elsewhere. A 1974 letter from Keith Roberts of the John Innes Institute to James Watson (located at Cold Spring Harbor Laboratory) discussed the possibility of the Institute running a course on higher plant cell protoplasts. Despite promising steps in resurrecting somatic plant cells, Roberts identified ongoing difficulties in the field, not least a lack of published literature. The laboratory setup required for a course was relatively simple: a greenhouse, tissue culture facilities, water baths and bench centrifuges. Yet Roberts did note that cellulase enzymes constituted a significant expense, being directly obtained from Japan.[74] As a cutting-edge biotechnology, protoplast production was ahead of existing enzyme production techniques, therefore requiring rare and expensive materials. The development of

[70] Nagata and Takebe (1970): 303-304.
[71] Cocking (2000): 78.
[72] Cocking (2000): 78-79.
[73] Cocking (2000): 78.
[74] Letter from Keith Roberts to James D. Watson, 1974-11-18, JDW/2/2/1550/52, James D. Watson Collection, Cold Spring Harbor Laboratory archives repository.

protoplast research (and hence somatic hybrids) was significantly slowed by enzyme shortages during the 1960s and even into the 1970s.

Technical difficulties with the technology became increasingly evident following the creation of the first somatically hybridized plant in 1972 at Brookhaven National Laboratory. A close reading of the 1972 *Proceedings of the National Academy of Sciences* paper reveals that somatic hybridization was not only extremely complex, but once again ran ahead of existing technology and practices in the biological sciences. Protoplast fusion was not a precise technique. The Brookhaven team found that about a quarter of their protoplasts were actually involved in a 'fusion event' (unusually efficient for the time) and even less of these contained the genetic information from both parent plants necessary for regeneration.[75] Although an impressive achievement, the somatically hybridized tobacco created at Brookhaven was far from a commercially viable organism. Shoots and leaves developed, but not roots, leading the team to graft their new shoots onto the stems of other plants to further observe the development of their somatic hybrids. Furthermore, spontaneous tumours were observed to develop on the stems of the somatic hybrids.[76] The new plants were delicate and unstable. Yet an equally important and difficult challenge for the researchers was determining whether their new tobacco plants were true somatic hybrids.

Three promising isolates (regenerated plants) were selected for testing to confirm that somatic hybridization had taken place. The Brookhaven team largely relied upon detailed morphological observations, which gave circumstantial evidence that their isolates were somehow different to either parent species.[77] Yet morphological characteristics could only be relied upon to a certain extent. These characteristics were not necessarily representative of genetic differences and did not indicate exactly which chromosomes had been exchanged between protoplasts. On a practical level, morphology was slow work, requiring researchers to wait for plants to fully develop before required measurements could be taken.

Other means of determining whether and to what extent protoplast fusion had occurred were also used by the Brookhaven team. Electrophoretic analysis

[75] Carlson (1972): 2292.
[76] Carlson (1972): 2292-2293.
[77] Carlson (1972): 2293.

demonstrated that the new plants possessed differences in their protein makeup: yet electrophoresis did not show which chromosomes had been exchanged and was a relatively crude tool for protein fingerprinting of plants by the early 1970s.[78] Extracting chromosomes from the young leaves of the growing plants gave a more definite answer. These samples contained a chromosome number of forty-two, not unexpected when 'the complexity of the fusion event and divisions after fusion' prevented the complete exchange of chromosomes from the parental protoplasts.[79] It was this very unpredictability that led geneticists like Simmonds to dismiss somatic hybridization as an overly-complex biotechnology. Uncertainty and genetic instability caused by the uncontrolled mixing of chromosomes was not an endearing trait of somatic hybridization.

So far, somatic hybridization has been portrayed as a research topic of international interest, crossing disciplinary boundaries between plant science and genetics with ease. Yet international collaboration was hampered by disciplinary boundaries. A 1984 book on somatic hybridization by Yury Gleba and Konstantin Sytnik, both based in the Ukrainian Academy of Sciences, noted that work on hybridizing somatic cells had been carried out almost entirely by plant physiologists, not plant geneticists. Physiologists had designed methods for cell and protoplast isolation, yet an 'instillation of genetic ideology and the strict logic of genetic experiments' were needed for further progress.[80] A lack of practical progress and subsequent benefits for plant breeders may have tempered enthusiasm for somatic hybridization. Gleba and Sytnik centred themselves within the biological revolution. Distinct from the 'passive' analysis of organisms, somatic hybridization embodied the 'synthetic' spirit and purpose of genetic engineering. For them, recombinant DNA technology was in no way seen as superior, as 'The results of the experiments [on somatic hybridization] reported on in this book force us to believe more and more that the way chosen by their authors for sculpting a novel plant is the efficient one.'[81]

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[78] Carlson (1972): 2292. On electrophoresis, see Chapter 4.
[79] Carlson (1972): 2293-2294.
[80] Gleba, Sytnik and Shoeman (1984): 188.
[81] Gleba, Sytnik and Shoeman (1984): 179-188. Cocking reviewed Gleba and Sytnik's monograph and described it as 'essential reading.' Cocking referred to the author's call for an 'instillation of genetic ideology' as 'unfortunate phraseology.' Cocking (1986): 432.

The development of recombinant DNA technology is portrayed as highly focused, in stark contrast to the geographic and disciplinary divides surrounding work on somatic hybridization. The former arose from biotech firms in the United States, the product of a merger of university biology and commerce.[82] Yet commercial links alone cannot completely account for the rise of DNA-based technology. Unlike protoplast fusion, recombinant DNA technology was applicable to a wide range of activities in the biological sciences, hence its adoption by 'molecular biology laboratories around the world.'[83] Somatic hybridization was instead the preserve of plant scientists, hence the complaints of Gleba and Sytnik. Cocking believes it was the genetic expertise of the Brookhaven team that allowed them to create the first somatic hybrid: in fact, geneticists initially turned to protoplasts in their quest to modify organisms.[84] Yet a number of factors ultimately favoured the uptake of recombinant DNA technology as the go-to method of genetic modification of plants. It was not a simple matter of recombinant DNA being a far easier or more reliable technology, as the creation of GM plants still involves elements of chance and wastefulness. Recombinant DNA was also favoured by its place within the rising discipline of molecular biology, leading to widespread interest from both science and industry. Yet this is not to say that somatic hybridization research suffered due to a lack of investment. Cocking, for instance, found himself with sixteen years' worth of funding from the UK's Agricultural Research Council from 1969.[85]

So can somatic hybridization be classed as a failed technology? If so, why is it worth examining? The criteria for classifying an innovation as failed can include marketing performance, efficiency of development, favourable management characteristics, effective communication and understanding of user needs.[86] Under many of these criteria, somatic hybridization can be classed as a failed technology for approximately twenty years, encompassing the 1970s and '80s. In this time, somatic hybridization did not create commercial plant breeds and the technique was plagued by

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[82] Kenney (1986); Smith Hughes (2001); Kleinmann (2003); Rasmussen (2014).
[83] Smith Hughes (2001): 542.
[84] Cocking, conversation with author. 24/03/2016.
[85] Cocking (2000): 80.
[86] For a useful introduction to this literature, see a special issue of *Social Studies of Science* on failed innovation. Braun (1992): 216.

slow and periodic development. Its complexity and unpredictable nature was also uninviting to users: namely plant breeders. Cocking was aware of this problem, urging 'protoplast workers' to engage in 'a continuing dialogue with breeders'.[87] Yet there are recognised benefits to studying a seemingly failed innovation.

Useful parallels emerge from the history of mutation. In a study of the General Electric Research Laboratory, Helen Anne Curry describes a failed research programme which struggled to use X-rays to induce beneficial mutations in plants during the 1920s and '30s. Ultimately, the only marketable product to emerge from the laboratory was a single variety of ornamental lily.[88] Yet even this relatively small case study speaks to a number of contemporary themes, including the belief in the plasticity of organisms when subject to technological intervention and collaboration between different scientific disciplines. Likewise, somatic hybridization is revelatory of both the ambitions of plant physiology and wider collaborative attempts to exploit the plasticity of living things on the cellular level from the 1960s. Somatic hybridization is yet another example of a technique that has been largely 'lost to the history of biotechnology, and yet constitute[s] an important component of that history.'[89]

## 5. Biotechnological Collaboration and Cybrids

Somatic hybridization was not the only promising technique to emerge from plant physiologists' investigations into cell fusion. By the 1980s it had become apparent that, more often than not, a fused cell would shed one set of its parents' chromosomes (chromosome segregation). The once 'considerable hope' that fusion of plant nuclei could result in improved crops faded, to be replaced by the interest in 'the introduction of small genetic elements from alien species into ones of practical interest [crop plants].'[90] By focusing on the introduction of desirable characteristics from 'extranuclear' genes contained within the cytoplasm of cells, a cytoplasmic hybrid or 'cybrid' could be created. Back at the University of Nottingham's Department of Botany

[87] Cocking (1981): 566.
[88] Curry (2013).
[89] Curry (2013): 747.
[90] Shepard et al. (1983): 683. The phenomenon of chromosome segregation also occurs in animal cell fusion.

in 1975, Cocking and his team had fused two members of the grape family (*Parthenocissus tricuspidata*) with a petunia (*Petunia hybrida*), the chromosome segregation of which indicated 'the possible limitations of somatic hybridization between distantly related plant species'.[91] But despite the loss of one set of chromosomes, some hybrid cells survived. These contained a mixture of cytoplasm from both species but with the nucleus of the *Parthenocissus*.[92] Cytoplasmic hybridization therefore seemed to provide a means of overcoming chromosome segregation to transfer desirable characteristics between distinct plant species.

In a 1983 paper in *Science*, a team from the Plant Pathology Department at Kansas State University described the production of four somatic hybrids following cell fusion between 'Russet Burbank' potatoes and 'Rutgers' and 'Nova' tomato cultivars. Chromosome counts indicated that chromosome segregation had not been complete: some regenerated 'pomato' plants showed 'a more tomato-like morphology… including more intense red pigmentation, more pointed terminal leaflets, and more extensive leaf serration.' The plant pathologists, including future Director of the NIAB Tina Barsby, concluded that small chromosome segments may have survived, offering the possibility of using cell fusion for 'introducing genes from unconventional sources.'[93] The experiments conducted at the University of Nottingham and Kansas State University seemed to indicate that partial somatic hybridization, or cytoplasmic hybridization, offered a means of overcoming chromosome segregation to combine completely different plant species. Furthermore, these techniques could prove valuable as 'directed transformation with cloned genes', or recombinant DNA technology was still relatively unsophisticated. On the other hand, recombinant DNA technology was improving and was admittedly a more precise means of introducing genes than cell fusion.[94]

'Research on protoplast fusion', announced David A. Evans, Associate Scientific Director at the DNA Plant Technology Corporation in 1983, 'has been increasingly focused on the transfer of organelle-encoded traits.'[95] While this may have been the case, the biological mechanism underpinning cytoplasmic hybridization was complex. By

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[91] Power et al. (1975): 198.
[92] Power et al. (1975): 206.
[93] Shepard et al (1983): 687.
[94] Shepard et al (1983): 687.
[95] Evans (1983): 857.

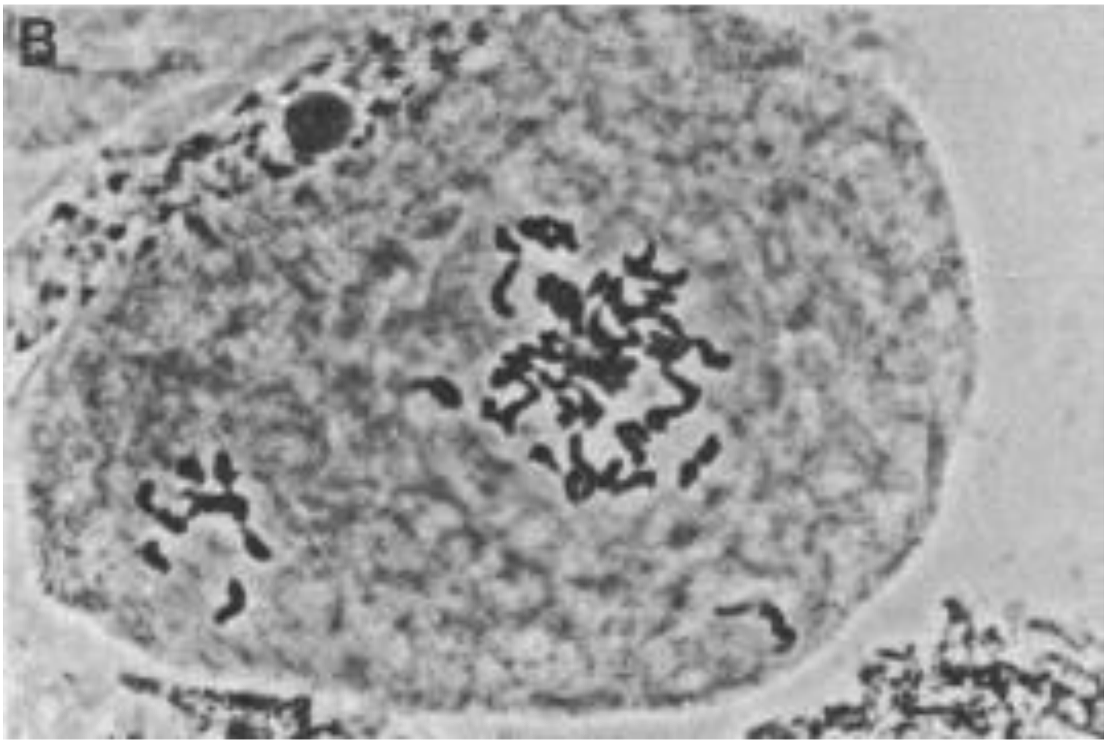


Figure 3.4: Chromosome Segregation. One of the main obstacles to plant cell fusion was the tendency of fused cells to reject one set of chromosomes. This image shows a somatic hybrid cell undergoing chromosome segregation. The ejected chromosomes can be seen at the bottom of the image. From Shepard et al (1983): 687.

the early years of the 1980s a general consensus was beginning to emerge on how cytoplasmic genetics actually worked.[96] Theoretical complexity and disagreements did not discourage plant scientists and geneticists from attempting to apply cytoplasmic hybridization to agriculture. Several laboratories, including those at the University of Nottingham and Kansas State University, had attempted to transfer cytoplasm via cell fusion. Evans recognised that a number of 'agriculturally useful traits are cytoplasmically encoded', including 'male sterility [important in the hybridization of wheat] and certain herbicide and disease resistant factors'.[97] However, like Cocking before him, Evans stressed the need for those working on cell fusion to talk with their counterparts in

[96] Evans (1983): 857.
[97] Evans (1983a): 259.

'plant genetics and plant breeding to encourage interchange of biotechnology objectives.' [98] If cell fusion did not meet the needs of agriculture, the hope of developing practical products from the technology was remote.

The need to transform both somatic and cytoplasmic hybridization into agricultural biotechnologies was also at the forefront of Cocking's mind in 1987. By this time, cell fusion – involving the transfer of nuclear and cytoplasmic encoded genes – had been conducted in major crops such as rice, to induce salinity tolerance and disease resistance.[99] Yet despite such advances, interest in recombinant DNA had surged. The 1984 international symposium on genetic manipulation in crops had shown that more and more researchers considered recombinant DNA technology a superior plant breeding technology to cell fusion. Writing in *Science* with co-author Michael R. Davey of School of Biosciences at the University of Nottingham, Cocking saw two ways forward for protoplast research. On the one hand, cell fusion could be quickly and practically applied to agricultural crops – as had been accomplished with rice varieties in 1986 – as 'non-recombinant DNA somatic cell fusion procedures… do not rely for their implementation on a detailed knowledge of the genes involved.'[100] 'Somatic hybridization and genetic transformation' were 'two radically different approaches to manipulation of plant genomes.'[101] Following a cell fusion event, whether involving nuclear or cytoplasmic transfer, resulting plants could simply be screened and selected based on their characteristics in manner familiar to traditional breeders. Recombinant DNA technology, according to Cocking, was 'dependent upon relating genotype to phenotype in a tangible way so as to ascertain what biochemical and developmental activity is controlled or modulated by a DNA sequence.' Establishing this relationship from genotype to phenotype was no easy feat, but could be avoided entirely by using cell fusion.[102]

Yet Cocking was not entirely combative in his comparison of plant cell fusion with recombinant DNA technology. By the early 1980s it had become apparent that protoplast research and recombinant DNA technology could complement each other. In

[98] Evans (1983): 858.
[99] Cocking and Davey (1987): 1262.
[100] Cocking and Davey (1987): 1262.
[101] Pental and Cocking (1985): 90.
[102] Pental and Cocking (1985): 90.

the 1981 issue of the *Philosophical Transactions of the Royal Society*, Cocking also used his contribution to explain how protoplasts could aid those struggling to insert sections of foreign DNA into crop plants using the *Agrobacteri tumefacieins* bacterium, which 'naturally manages to transfer, maintain and express its prokaryotic DNA in plant cells.' By inserting the bacteria into protoplasts, followed by cloning in tissue culture, the number of transformed plants available to researchers could be significantly increased.[103] In a similar manner, Davey and Cocking claimed in 1987 that 'gene transfer in cereals' using somatic or cytoplasmic hybridization could benefit from 'close integration of cell culture and molecular approaches.'[104] Yet details on the shape of this collaboration were not forthcoming.

Cytoplasmic hybridization was pursued during the 1980s as the limits of somatic hybridization became apparent. Chromosome segregation meant that a far smaller range of crop varieties could be crossed with each other to form fertile somatic hybrids than was once realised. Moreover, plant physiologists and geneticists realised just how much chromosome segregation limited the potential of somatic hybridization, just as the potential of recombinant DNA technology to bypass these same limits became apparent. Cytoplasmic hybridization therefore appeared to offer advocates of cell fusion the timely opportunity to cross crop plants from diverse species. Yet throughout the 1980s cytoplasmic hybridizers were seemingly forced to justify the practicality of their biotechnology by appealing to its advantages over recombinant DNA technology. There were some successes in the production of new crop varieties and some attempts to integrate cell fusion with recombinant DNA technology. Ultimately though, these efforts were not enough for plant cell fusion to regain its place as the premier form of modern plant biotechnology.

## Conclusions

The dominance of recombinant DNA technology has extended not only to farmers' fields, but to history as well. In reconstructing an account of a little-known form of biotechnology, this chapter has shown that this dominance was not inevitable. Somatic

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[103] Cocking (1981): 564-565.
[104] Cocking and Davey (1987): 1262.

hybridization is a technically exacting technique, but with its fair share of misfortune. At the right time, a surplus of cellulase enzyme, the support of geneticists or mishaps in the development of recombinant DNA for agricultural use may all have shifted the balance of history in its favour. Somatic hybridization continues to be taken seriously as a plant breeding technique, even if its returns are meagre in comparison to recombinant DNA technology or even mutation breeding. To dismiss its story would be a serious misstep, not only on grounds of historical nuance. Plant breeding is often a slow affair, with innovations taking years or even decades to reach their full potential. Plant cell fusion – still a relative newcomer in the long history of biotechnology – may yet have its day in the sun.

Even if somatic hybrids remain, commercially speaking, a lost cause, their existence speaks to important points in our understanding of biotechnology on a number of levels. The first is a historiographical matter. There is an ongoing debate in historical circles over the meaning and scope of what we term biotechnology, a perplexity reflected in current definitions released by industry and government. This was characterised as a divide between 'ancients' and 'moderns' in a 1986 edition of the French biotechnology journal *Biofutur*.[105] A modern view of biotechnology only begins with the discovery of the structure of DNA in 1953 and developments in molecular biology. Advocates of the ancient view embraced a much wider conception of biotechnology. A three-stage history of biotechnology is envisioned: moving from Egyptian and Babylonian brewing to Pasteurian-informed 'rational fermentation' and finally to 'genetically based molecular biology.'[106] Somatic hybrids do not fit into any of the aforementioned conceptions or categories.[107] Plant cell fusion is certainly not a form of brewing or rational fermentation, nor does it manipulate organisms on the genetic level.[108]

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[105] Comar (1985).
[106] Bud (1991): 416-417.
[107] Somatic hybrids and cybrids are usually classed as genetic biotechnology. However, their history seems to indicate they in fact have just as much – if not more – affinity with mutation breeding than recombinant DNA technology.
[108] Somatic hybridization does fit within a far more general historiographical theme: that of the molecularization of the life sciences. Yet this is problematic, as the molecularization story is generally associated with molecular biology. For a succinct synopsis of the literature, see Steven Turner (2008): 223-224.

As a method of transplanting chromosomes across the species divide, somatic hybridization seems to defy traditional categories within biotechnology. Plant cell fusion instead lends itself to a certain view of the history of plant breeding, as a series of often overlapping developments. In this view, the lines between the different forms of plant breeding are weaker and more blurry than commonly assumed. New forms of biotechnology are regularly marketed as revolutionary, with their practitioners declaring that they are the first to have attained 'a properly engineered biology.'[109] Broader histories of biotechnology lead us to question these claims, while suggesting that past forms of biotechnology should not be so easily cast off.

The importance of plant physiologists, and even plant pathologists, within the history somatic hybridization also demonstrates that biotechnology has involved a broad array of biological disciplines. Moreover, these disciplines have not operated in isolation. Dialogue between researchers blurred the boundaries between microbial, animal and plant cell fusion, as demonstrated by Cocking's turning to the Microbiological Research Establishment for advice in 1960. Somatic hybridization is only part of a wider history of attempts to harness the internal plasticity of organisms to bypass the limitations of "traditional" breeding and crossing. This 'parasexual approach' to life also led to the realisation that 'biological incompatibility', including the species barrier, was practically non-existent at the cellular level.[110] Just as barriers against the crossing of organisms were dissolved by cell fusion, so barriers between scientific disciplines were dissolved by a shared interest in the fundamental questions of life: not least, how far life could be manipulated for the purposes of humankind.

The case of plant cell fusion also provides a fresh demonstration of how a biotechnology can falter in the long and torturous route from laboratory innovation to practical product. Even with sufficient financial backing and enthusiasm from multiple scientific disciplines and the public, somatic hybridization did not make the transition to agriculture until late in its career. Cell fusion technology lacked 'robustness', in the sense that it was technically difficult and hence off-putting to researchers, particularly in genetics. The technology also faced difficulties integrating itself into existing industrial systems, with demand for the enzymes used to create protoplasts

[109] Campos (2009): 16.
[110] Landecker (2007): 217-218.

outstripping supply into the 1970s. Like mutation breeding, cell fusion also faced competition in the form of recombinant DNA technology. Despite unrealised ambition, plant cell fusion does at least show us that genetic engineering was far more malleable and wide-ranging than we might expect.

In 1980, the West German National Laboratory unveiled an automated laboratory tool, capable of encouraging plant cells to fuse using an electric field. Rights to the technique were then obtained by the Battelles Geneva Research Centre, which spent the next two years refining the device for the industrial sector.[111] Breaking down and manipulating plant cells with new machinery was characteristic of 1980s biotechnology, as were attempts to market such technology to industry. Yet as the next chapter of this thesis demonstrates, even the turn to the molecular was not inevitable. Different biotechnologies were not only in competition with each other, but also found themselves pitted against established fields of expertise in the agricultural sciences.

[111] Fishlock (1983): 18.

# 4. Electrophoresis: The Contested Process of Molecularization at the NIAB

> In summary this modernisation plan involves fuller computerization of data capture and reporting, the automation of chemical analysis techniques and the development of new chemical methods for varietal identification.
> – The NIAB's sixty-third annual report (1982). [1]

Until this point this thesis has focused exclusively upon the alteration of plants and their cells for breeding purposes. Yet under a broad definition of biotechnology as the manipulation of organisms for industrial or commercial purposes, a great deal of twentieth-century biological practice can also be said to be "biotechnological" in nature: not least methods of analysing biological materials, including protein and DNA sequencing. Some of these technologies – which rely upon the separation of organic samples into their constituent parts – have clear parallels with processes explicitly acknowledged as examples of mainstream biotechnology, notably the Cohn fractionation process.[2] Electrophoresis, a form of protein fingerprinting, is one example of a classificatory technology that falls under this category. Electrophoresis involves the separation of a biological sample into its constituent proteins in order to gain a commercially valuable resource: information. From the 1980s, the NIAB recognised that electrophoresis could be harnessed as a method of classifying crop plants.[3] Just as advocates of mutation breeding and cell fusion had sought a modern revolution in plant breeding, so advocates of electrophoresis at the NIAB sought to transform the often arduous task of crop classification.

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[1] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, National Institute of Agricultural Botany [hereafter referred to as NIAB] Archives.
[2] See Creager (1998).
[3] Information that could be used to help classify crop plants had always been valuable. However, the 1964 Plant Varieties and Seeds Act meant that royalties were awarded to breeders for their varieties, adding a new level of mercantile importance to crop classification.

Yet the transformation of classification work using molecular-level biotechnology was not a straightforward task. By 1995 the NIAB had become the site of an experiment to settle which means of classifying crop plants was the most accurate. Morphological, visual and molecular techniques were all pitted against each other. Electrophoresis seemingly provided the 'most efficient discrimination' between varieties. Yet the technique had its problems, including sustained opposition from plant breeders and difficulties in detecting foreign genes. Ultimately, the instigators of the experiment recommended combining different techniques to create an 'integrated' approach to crop analysis and classification.[4] The NIAB had first begun to adopt new classificatory techniques like electrophoresis during the 1980s. Yet some fifteen years on, deciding upon the best means of classifying crop plants at the Institute was still no easy matter.

The range of different techniques and technologies available at the NIAB by 1995 was testament to the challenges faced in differentiating one crop variety from another. As most crop plants are bred from closely-related stock, differences between them can be minute. As more and more crop varieties are bred, simply telling one variety from the next has become increasingly difficult. Agricultural botany seeks to classify crop plants on specific, commercially valuable qualities: in other words, it is not so much the appearance or ancestry of crop varieties that matters. Instead, agronomic characteristics such as yield, disease resistance and nutritional content are more important in distinguishing one variety from another.[5] The NIAB's classification workload had increased exponentially following the passing of the 1964 Plant Varieties and Seeds Act (providing intellectual property rights for breeders) and European Economic Community (EEC) demands that British varieties conform to, and be included in, European-style 'National Lists' by 1973.[6] Looking back in 1990 at the history of the

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[4] Mudzana et al. (1995).
[5] Keefe and Draper (1986).
[6] P.S. Wellington, 'Director's Notes for Fellows on the Annual Report and Accounts for 1978', NIAB Fellow's newsletter 76, July 1979, Folder N1-11, NIAB. The substantial delay between the passage of the 1964 Act and submission of new varieties to the NIAB occurred as it generally took plant breeders between ten to twelve generations to produce a new variety from an initial cross.

NIAB, two of its Field Officers described how ‘the difficulty of identifying varieties as many new ones were introduced’ had shaped the Institute.[7]

During the 1980s, a series of technological advances were portrayed by the NIAB as revolutionising the classification of crop varieties. Computer-aided measurement, spectroscopy, chromatography and electrophoresis were all applied to variety classification and analysis. Automation and mechanisation possessed a powerful allure for the overworked and underfunded Institute. By the end of the 1980s the NIAB was creating its own laboratory techniques and standards for biochemical analysis of crop varieties, a field broadly labelled “chemotaxonomy”. The NIAB overcame its reputation as a less-than-premier research organisation to carve out its own institutional niche in the identification and analysis of varieties, particularly through the novel use of electrophoresis. In the words of one of the Institute’s biochemists, this research began the NIAB’s transition from a ‘technical institution to research organisation’.[8] A powerful institutional narrative had emerged, which described the move towards molecular-level manipulation of crop plants – a form of modern biotechnology strongly associated with plant breeding – as synonymous with modernity. By harnessing previously unexamined archival materials from the NIAB, this chapter instead argues that changes to late twentieth-century crop taxonomic techniques were not the inevitable result of molecular methods replacing older morphological work. Instead, techniques such as electrophoresis appealed to the NIAB for practical, economic reasons.

This chapter begins by exploring the challenges posed to the partly state-funded NIAB and other research institutes due to government funding cuts during the 1980s. These cuts, as the chapter goes on to demonstrate, were fundamental in driving the NIAB towards molecular-level classification technology, which promised to be more efficient and save on manpower costs. The chapter then moves on to examine three technologies subsequently used or produced at NIAB for crop identification and analysis during the 1980s: electrophoresis, near-infrared spectroscopy (NIRS) and machine vision systems. Electrophoresis initially became the Institute’s flagship research

[7] Kelly and Bowring (1990): 148. Recent historical work has likewise recognised that agricultural institutions can serve as nurturing spaces for emerging ‘biological specialties’. See Harwood (2006); Kimmelman (2006); Bonneuil, (2006).

[8] Robert J. Cooke, interview with author, 09 March 2015. This institutional transformation was also brought up at a seminar with the NIAB Retirement Group, 21 April 2016.

programme. Yet it faced stiff competition from machine vision systems based on morphological analysis by the late 1980s and 1990s. Tracing the pursuit of different types of classificatory technology at the NIAB reveals underlying commercial and scientific ambitions, and even contemporary visions of a future taxonomic practice based on molecular manipulation. This chapter therefore explores the factors behind the success and failure of variety analysis technologies at the NIAB, in the process drawing upon the arguments made in favour of different techniques during the 1980s. Within these debates, social contingencies, including scientific values, research prestige, intellectual property concerns and commercial applications, are evident.[9] As with the previous case studies of plant breeding technology examined in this thesis, the triumph of new technology based upon manipulating plants on the molecular level was not assured.

## 1. Cutbacks to Agricultural Research Funding

The period around 1980 has been considered to mark the general faltering of generous state funding of the life sciences, as neoliberal economic policies associated with the Thatcher and Reagan governments introduced ‘market forces’ to public institutions.[10] British agricultural research during the 1980s was consequently viewed as faltering in lieu of government support. By the mid-twentieth century, British agricultural institutions were heavily dependent upon public funding, largely distributed through the Ministry for Agriculture, Fisheries and Food (MAFF) or the Agricultural Research Council (ARC). An overwhelming proportion of the budget of significant agricultural research centres, including the John Innes Institute and PBI, came from state funds.[11] Reduction or withdrawal of government support directly affected these institutions’ research programmes and technical work. In the case of the already overworked NIAB,

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[9] Such considerations continue in variety analysis today, with wider implications for conduct in agricultural science and policy: moreover, the technology harnessed in modern day variety analysis and classification often differs little from that of the 1980s. Electrophoresis continues in use for variety classification and analysis purposes in agriculture today. See Cooke (1992). Since the release of Cooke’s original handbook, the International Seed Testing Association (ISTA) has held a number of meetings and workshops on electrophoresis: for instance a 2010 workshop on ‘Species and Variety Testing / Protein electrophoresis’ held in Hanover, Germany.
[10] Rasmussen (2014): 3.
[11] Palladino (1996): 124.

financial pressure led to mechanised means of variety analysis being perceived in a mercantile light. Saving time and labour meant – or at least was perceived to mean – saving money.

A 1986 edition of *Nature* estimated that the UK budget for agricultural research would shrink by twenty-six percent between 1983 and 1991. Attempting to account for the government's 'beastly' budgetary behaviour towards the Agricultural and Food Research Council (AFRC, successor to the ARC), a contributor to the journal suggested that surplus commodities produced under the EEC's Common Agricultural Policy (CAP) and criticism of farmers' attitudes towards the environment were to blame.[12] Later issues of *Nature* carried equally pessimistic predictions on the future of British agricultural research. The MAFF suffered cuts in its research budget throughout the decade, while the AFRC shed a quarter of its workforce from 1983 to 1988.[13] By the closing years of the 1980s, what were termed 'near-market research' programmes also came under fire.[14] Reductions in funding were so severe that mainstream British agricultural institutions became casualties. One high-profile loss was the Cambridge-based PBI, the birthplace of Proctor barley. Following its closure, the majority of the Institute's geneticists relocated to the John Innes Institute and private plant breeding or biotech firms.[15] Despite its essential role in regulating new plant varieties produced by British breeders, the NIAB also suffered funding cuts throughout the decade.

By the time government cutbacks began to bite, the NIAB was already suffering from serious difficulties with workload and financial solvency. Britain's 1973 entry into the EEC was accompanied by a two-tier system of variety regulation: approved crop varieties would now be listed on both EEC National Lists – a list of approved crop plants produced by each member state – and the NIAB's existing Recommended Lists, bringing increased complexity and workloads to variety analysts.[16] With the introduction of full statutory seed certification in 1973, the British government became responsible for

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[12] 'Downbeat plan for agriculture' (1986): 299. In earlier decades, the British government had similarly felt that basic research in agriculture did not translate into practical gains with enough frequency. See Agar (2011).
[13] Hadlington (1988): 6.
[14] McGourty (1989): 401.
[15] Edward Dart, interview with author 02 April 2015. Edward Dart was employed as a research director in ICI Seeds (later Zeneca), a leading biotech company. Zeneca was one of the private firms which attempted to purchase the genetics arm of the PBI following the Institute's closure.
[16] Silvey and Wellington (1997): 117.

seeing EEC directives carried out. That same year MAFF negotiated a new contract with the NIAB, which directed the Institute to undertake scientific and technical work on behalf of the government.[17] This contract brought about dramatic changes in how the NIAB was funded. In the late 1960s, the NIAB possessed a largely independent income from farmers' fees and charged for its services, with direct payments from MAFF covering twelve percent of the Institute's expenditure. A decade later the situation had been reversed. MAFF payments for statutory EEC testing comprised sixty-eight percent of the NIAB's expenditure.[18] The late-twentieth century saw the NIAB move closer to government control and greater dependence on public funding, in line with other British agricultural organisations.

The impact of the EEC transition in variety regulation was still evident in the NIAB's activities during the early 1980s. The Official Seed Testing Station of England and Wales (OSTS) – a body charged with ensuring seed quality, nominally directed by the MAFF but operating under the auspices of the NIAB – had come under the greatest pressure as a result of European membership. By 1980 MAFF had informed the NIAB council that only seed testing services specifically required by legislation or international trade regulation would be commissioned. Yet in the spirit of the age, plans were simultaneously made for a concentration and reduction of the OSTS Cambridge laboratories, as seed certification tests were outsourced to satellite stations elsewhere.[19] Further MAFF meetings saw attempts to reduce the number of publicly-funded crop trials – the field testing of new crop varieties – in favour of those conducted under private contracts.[20] General cuts across government departments were passed directly on to the NIAB. Correspondence with MAFF reveals that a two and a half percent reduction in manpower costs imposed on the Ministry would also apply to the NIAB in the 1980 to 1981 financial year.[21] The NIAB faced a crisis on two fronts: the heavy workload demanded by EEC regulations and reductions in MAFF funds which had become foundational to the everyday work of the Institute.

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[17] H.A. Doughty to P.S. Wellington, 11/09/1975, Box C-3, Paper no. 668, NIAB.
[18] P.S. Wellington, 'Director's notes for Fellows on the annual report and accounts for 1978', NIAB Fellow's Newsletter 76, July 1979, Folder N1-11, NIAB.
[19] 'General developments in 1980', Sixty-first report and accounts 1980, NIAB.
[20] 'Crop priorities', 26 Nov 1981, Box C-3, Council Paper No. 754, NIAB.
[21] 'Manpower policy', 5 June 1980, Box C-3, Executive Committee Paper No. 734, NIAB.

An alarming restriction of public funding for agricultural science did not seem an ideal situation in which the NIAB could begin its transition from technical to research work. Nor was the Institute particularly well equipped or orientated within the British agricultural research system for such a move. Yet the funding restrictions posed by government during the 1980s contained their own incentives for efficiency savings. Automated laboratory machinery could provide such savings, whether through more efficient processing of crop varieties or elimination of manpower. At the increasingly commercialised NIAB, the allure of laboratory machinery proved irresistible. Trends in wider biological work suggested that such machinery would quickly find practical, perhaps even lucrative, uses. In the early years of molecular biology, 1960 Nobel Prize winner Donald Glaser had introduced devices such as the 'dumbwaiter' and 'Cyclops' into commercial firms for analysing cell cultures.[22] A move towards molecularization in the biological sciences, combined with new laboratory equipment, suggested a future without traditional variety analysis by eye. At the NIAB, this trend was announced to its staff as part of a 'modernisation plan' involving 'computerization of data capture and reporting, the automation of chemical analysis techniques and the development of new chemical methods for varietal identification.'[23]

Despite the esteem and efficiency brought by new means of varietal classification and analysis, the NIAB struggled with funding shortfalls throughout the decade. A 1987 MAFF review of the Institute's statutory work announced significant falls in government funding to occur in 1992. Staff numbers were predicted to be further reduced, while the Institute was forced to focus its resources upon private variety testing contracts (VARTEST) and other 'sponsored research'.[24] By the later years of the 1980s, the NIAB's own 'near-market-research', including Recommended List work, had government support removed following the Barnes Review.[25] Yet the Institute continued with its modernisation programme. In 1988 the NIAB took on a new Computer Unit, complete with analyst, programming and operating staff. Elsewhere in the Institute, everything from glasshouses to field trials experienced automation

[22] Vettel (2006): 188.
[23] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.
[24] 'The Need to Increase Income-Earning', Sixty-ninth report and accounts 1988, NIAB.
[25] 'The Effect of Government Cuts on the Institute's Work', Sixty-ninth report and accounts 1988, NIAB.

through computerisation.[26] The 1980s ended as they had begun at NIAB: with calls for automation to counter MAFF cuts and speed up the Institute's alignment to the research and commercial sectors.

The 1980s brought numerous incentives for the NIAB to move towards biochemical research and laboratory machinery. The Institute required new markets to counter the scale of MAFF cuts, while improving the efficiency and accuracy of its variety identification and testing. Advances in molecular biology and biotechnology implied that future agricultural research would need to be conducted on the micro-level, with future analysis of genetically-altered crops another factor to consider. Yet significant obstacles, besides from financial pressure, could derail the NIAB's research programmes. Research-focused departments in the Institute, namely the Pathology and Chemical and Quality Assessment (C&QA) branches, traditionally held a lower status than the crop trials and variety evaluation services. The latter were considered uppermost in the Institute's strict hierarchical departmental structure.[27] Significant competitors in agricultural research existed, including the John Innes Institute, Rothamsted Experimental Station and Cambridge University. Of all the taxonomic techniques to be discussed in this chapter, electrophoresis proved the NIAB's most successful venture, despite an uphill struggle from meagre beginnings.

## 2. Reinventing Electrophoresis as an Agricultural Biotechnology

In 1982 Robert J. Cooke, a young biochemist, arrived at the NIAB's C&QA branch, fresh from a postdoctoral research fellowship at the University of East Anglia. Given a single assistant, he was confronted with two empty rooms, comprising his new "laboratory". Yet encouraged by the Head of C&QA, fellow biochemist Simon Draper, Cooke focused his attention on applying biochemical techniques to the NIAB's traditional areas of strength, namely variety identification and testing. Earlier work on a method of protein fingerprinting carried out by researchers at the NIAB had created a standardised

[26] 'Progress Report' Sixty-ninth report and accounts 1988, NIAB.
[27] Cooke interview, 2015.

method of starch gel electrophoresis applicable to cereals.[28] Put simply, electrophoresis works thanks to the different electric charges held by proteins. If a prepared plant sample is placed in a gel and an electric current is run through it, then proteins separate into a pattern. This pattern can identify a crop plant by indicating the proportion of different proteins present. The NIAB rapidly established itself as a premier organisation for agricultural electrophoresis during the 1980s. The Institute was well placed to make this move, drawing upon its established reputation for independent arbitration in crop variety disputes.

Electrophoresis was by no means a new biochemical technique. Nor was it initially intended for agricultural purposes. Historians of biology have traditionally associated electrophoresis with Lewontin and Hubby's research into molecular evolution. Electrophoresis was deployed in this field to break a theoretical impasse in population genetics in the late 1960s.[29] Yet the technology has a much longer theoretical and experimental history in biochemistry.[30] The taxonomic implications of electrophoresis were recognised as early as the mid-twentieth century. Based on an address given to the Botanical Society of America in 1949, an article in *The Scientific Monthly* associated the presence of certain proteins in plant tissues with infection by plant viruses. This finding raised the possibility of empirical diagnosis of plant viruses by electrophoresis of diseased samples. Scarcely a year later and the possibility had become reality, as comparison of virus components in electrophoresis apparatus allowed for their accurate identification.[31] By the late 1950s, zoologists in the United States were harnessing electrophoresis to identify wildlife, repeating the mantra 'blood will tell'.[32]

[28] Draper and Craig (1981). Other crops, including vegetables, were analysed by the C&QA team and found to be just as amenable to electrophoresis.
[29] Lewontin (1991); Lewin (1999): 93-94.
[30] Kay (1988); Putman (1993); Chiang (2009).
[31] Wildman and Bonner (1950); Singer, et al. (1951).
[32] Johnson and Wicks (1959): 88.

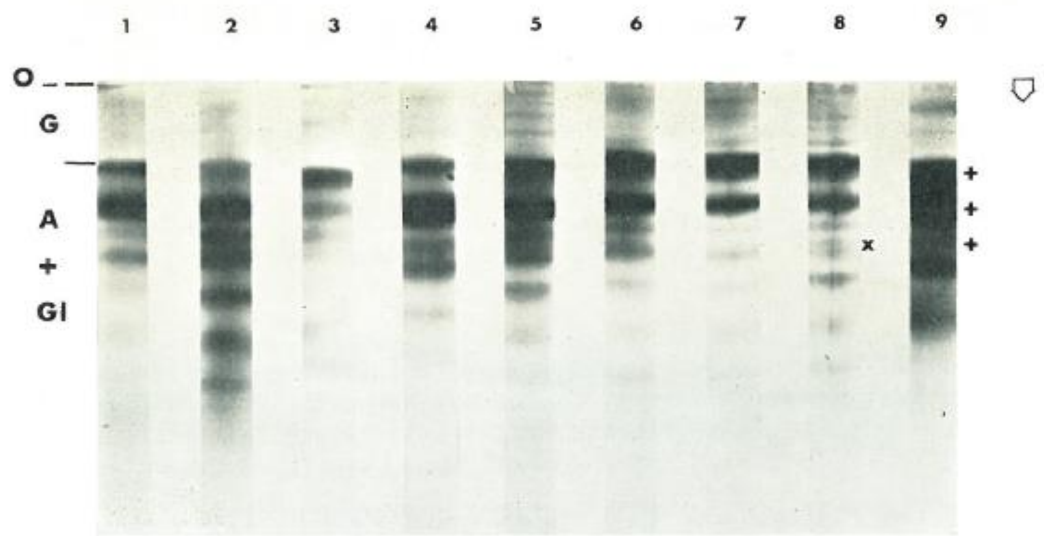


Figure 4.1: Electrophoresis Chart. An early depiction of gel electrophoresis in the NIAB's journal. The 'bands' on the image indicate the presence of different proteins. From Ellis (1971): 223–35.

The NIAB's C&QA staff had therefore hit upon a fresh application for an old technology. The race was on to further develop electrophoresis for technical work in agriculture. Following a literature review, the NIAB's biochemists embarked on a campaign of publication and promotion of their work in electrophoresis. The NIAB's approach was subsequently described by Cooke as 'fairly aggressive' and even 'ruthless', aiming to 'do the research, get the results and publish as quickly as possible'.[33] At the same time, other British organisations demonstrated less vigour in pursuing electrophoresis work, leaving the Institute with an open playing field. This was fortunate for the NIAB, considering the prestigious agricultural organisations the Institute routinely operated alongside. The NIAB was not a premier research organisation, a fact that staff from organisations such as the John Innes Institute and University of Cambridge apparently never failed to point out to Cooke.[34]

[33] Cooke interview, 2015.
[34] Cooke interview, 2015.

Electrophoresis possessed some significant advantages over morphological identification of crops by eye. Morphological analysis required crops to be grown in special ‘control plots’ and carefully observed over a long period of time.[35] Conducting detailed observation and measurement of maturing crop plants was a long and laborious process. Advocates of electrophoresis therefore argued that identification could be carried out much more quickly by analysing grain samples through electrophoresis apparatus rather than measuring mature plants.[36] The shortcomings of morphological analysis became readily apparent from the early 1970s, when warnings that additional staff and workspace would be required for the NIAB to cope with an influx of crop varieties following EEC membership appeared.[37] Following this predicted varietal influx, the NIAB was forced to hire more staff and plant more test plots: hardly a sustainable solution for an institution under financial pressure.[38] Electrophoresis provided a way out.

New technological developments in electrophoresis fortuitously encouraged the NIAB’s new-found interest. By the end of 1982, a new analytical method, termed polyacrylamide gel electrophoresis (PAGE), had been successfully applied by the NIAB to barley varieties on the EEC National List of approved varieties.[39] This represented another significant breakthrough, as barley was an economically important crop, particularly for the British brewing industry. The successful use of an improved form of electrophoresis opened commercial possibilities on a European-wide scale. The NIAB’s research standing also improved in collaboration with the International Seed Testing Association (ISTA), although electrophoresis methods developed at the NIAB did not become standard reference methods for ISTA until 1989. Cooke gave a keynote address to the International Electrophoresis Society meeting in London in 1986, and published a chapter in ‘Advances in Electrophoresis’ in 1988. Promotion in scientific circles enhanced the NIAB’s reputation outside the Institute’s usual constituency of plant

[35] Kelly and Bowring (1990): 149.
[36] Ellis (1971): 233.
[37] ‘Additional Resources Required for Implementing EEC Directives on Marketing of Seed’, October 1971, Box E-3, Executive Committee Paper No. 380, NIAB.
[38] Kelly and Bowring (1990): 148.
[39] Quarterly Report to Council, June to August 1982, Document No. 763, Box C-3, NIAB.

breeders, seed traders and farmers.[40] Commercial gains also came from the new technology, at a time when the Institute's financial stability was in serious doubt.

A lucrative service provided by the C&QA branch, electrophoresis was a welcome success story in hard times. The NIAB's director Graham Milbourn declared in 1987 that great demand existed for laboratory tests in both the Plant Pathology and C&QA branches.[41] Yet a greater impetus to electrophoresis research may have been provided by an association of automated machinery with efficiency savings, as described in the Institute's modernisation plan. In this sense, the MAFF's financial crackdown may have inadvertently aided the NIAB's electrophoresis programme. The Institute sought to appeal to an array of audiences and markets with its biochemical research. These included domestic growers, international bodies and foreign agricultural science institutions. Electrophoresis was certainly successful on the transnational scale. As a leading centre in the application of electrophoresis to crop identification, the NIAB received visitors from overseas, trained several people in the use of electrophoresis and was invited to participate in a series of development projects with the Division of Seed Technology in New Delhi, as a technical and scientific consultant.[42] Closer to home, Draper visited the Bundessortenamt (essentially the German equivalent of the NIAB) in 1982 to discuss electrophoresis and its possible 'DUS' applications ('DUS' refers to the criteria of diversity, uniformity and stability by which varieties could enter National or Recommended lists).[43] Cooke later mused that the readiness of overseas partners to work with the NIAB may have been in part due to the Institute's lower research status among British agricultural science institutions.[44] In other words, the NIAB was seen as more approachable and practically-orientated.

An obsession with new laboratory machinery permeated the NIAB's publications throughout the 1980s. In the process, the efficiency of biochemical methods of crop identification was favourably contrasted against established practices in agricultural botany. A charged narrative of scientific (and hence economic) triumph through biochemistry and technology emerged. By the mid-1980s, an outside observer might

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[40] Cooke interview 2015.
[41] Graham Milbourn, 'Income-earning', Sixty-eighth report and accounts 1987, NIAB.
[42] Cooke interview 2015.
[43] Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[44] Cooke interview 2015.

suppose that the botanically-trained eye of the NIAB Field Officer had been replaced by the new field of chemotaxonomy. The Institute's 1982 report represented this transition through the visual medium. Photographs of laboratory equipment rested alongside those of wheat fields, with electrophoresis favourably compared to traditional botanical techniques of identification.[45] New levels of standardisation were also achievable through automated biochemistry. In 1982, the C&QA branch was asked by the Intervention Board for Agricultural Produce to act as an independent reference laboratory for cases requiring electrophoresis analysis to settle arbitration.[46] By the mid-1980s, the NIAB found itself actively involved with the European Brewery Convention and ISTA to decide on a standard reference method for the identification of wheat and barley varieties by electrophoresis.[47] Electrophoresis came to represent efficiency, modernity and reliability.

As the 1980s wore on, demand for electrophoresis only increased. In 1986 the C&QA branch conducted 13,512 'separations' on individual grains, a figure which rose to 28,986 in 1987.[48] Molecularization and mechanisation were interlocking movements, growing in importance for the biological sciences and agriculture throughout the 1980s. Plant pathology, a major concern of the NIAB, focused upon the molecular level during the same period.[49] Molecular biologists also approached plant breeders during the 1980s, although the formers' early attempts at variety production fared poorly in the eyes of British breeders.[50] Advances in biotechnology and molecular-level examination implied new and additional forms of work for the NIAB's analysts. Electrophoresis was simultaneously part of a move towards molecularization and a reaction to its approach. Historians have called for an understanding of the 'molecularization movement' that extends beyond the confines of DNA.[51] When this new history is applied to agriculture, techniques such as electrophoresis will likely play a far more significant role. Yet their uptake in agriculture was clearly driven by wider economic and political incentives, rather than innate superiority over traditional classification techniques.

[45] Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[46] Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[47] 'Chemotaxonomy', Sixty-sixth report and accounts 1985, NIAB.
[48] 'Workload', Sixty-Eighth Report and Accounts 1987, NIAB.
[49] Steven Turner (2008).
[50] Webster (1990): 189.
[51] Kay (1996): 447–50; Steven Turner (2008): 235.

## 3. Modernity and Molecular Analysis

The triumphal narrative of electrophoresis at the NIAB ultimately rests on firm foundations as numerous and successful applications of electrophoresis were made throughout the 1980s. Yet contrary to the straightforward account of its advocates, the story of late twentieth-century taxonomic methods does not begin and end with protein fingerprinting. Under the umbrella term of chemotaxonomy, other potential methods of variety identification were investigated by the NIAB's C&QA branch. Although electrophoresis remained the NIAB's flagship variety identification technology for much of the 1980s, various forms of spectroscopy and chromatography were trialled by the Institute throughout the 1980s. Investment in a variety of labour-saving technologies appeared to be a sound decision, in the wake of revelations from the MAFF that requirements for government departments to reduce manpower costs would apply to the NIAB. Collaboration with European testing stations was also sought by the Institute as different laboratories developed separate techniques in taxonomy.[52]

New variety analysis technologies included near infra-red spectroscopy (NIRS) – for analysing crop constituents – and various forms of chromatography. From the early 1980s, the application of NIRS technology to variety analysis became a reality, albeit in an initially limited sphere. NIRS bombards samples with infrared radiation, to identify specific molecules via the presence of particular bonds or atoms and their place on a resulting spectrum.  NIRS is extremely versatile and can be applied to a wide range of samples, including organic materials.[53] Analysis with NIRS can therefore provide valuable information about the molecular makeup of a crop plant, for instance its carbohydrate content or nutritional quality.

NIRS methods had been developed for use on grasses and forage crops by 1982. In the same year, the NIAB obtained vital calibration equations for the application of NIRS to the nitrogen and carbohydrate content of these crops. Rapid development of NIRS techniques at the NIAB was made possible through close ties with the Scottish Crop Research Institute, which possessed its own NIRS instrument. NIAB staff, including

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[52] Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[53] Rabkin (1987): 31.

Simon Draper, arranged multiple visits to their Scottish counterpart.[54] Yet calibration work and the application of new equations did not mean quick results. It was expected that the application of NIRS equations to nitrogen and water-soluble carbohydrate content would take up to a year. In the meantime, special plant samples for NIRS analysis were obtained from test plots at the NIAB's headquarters in Cambridge.[55]

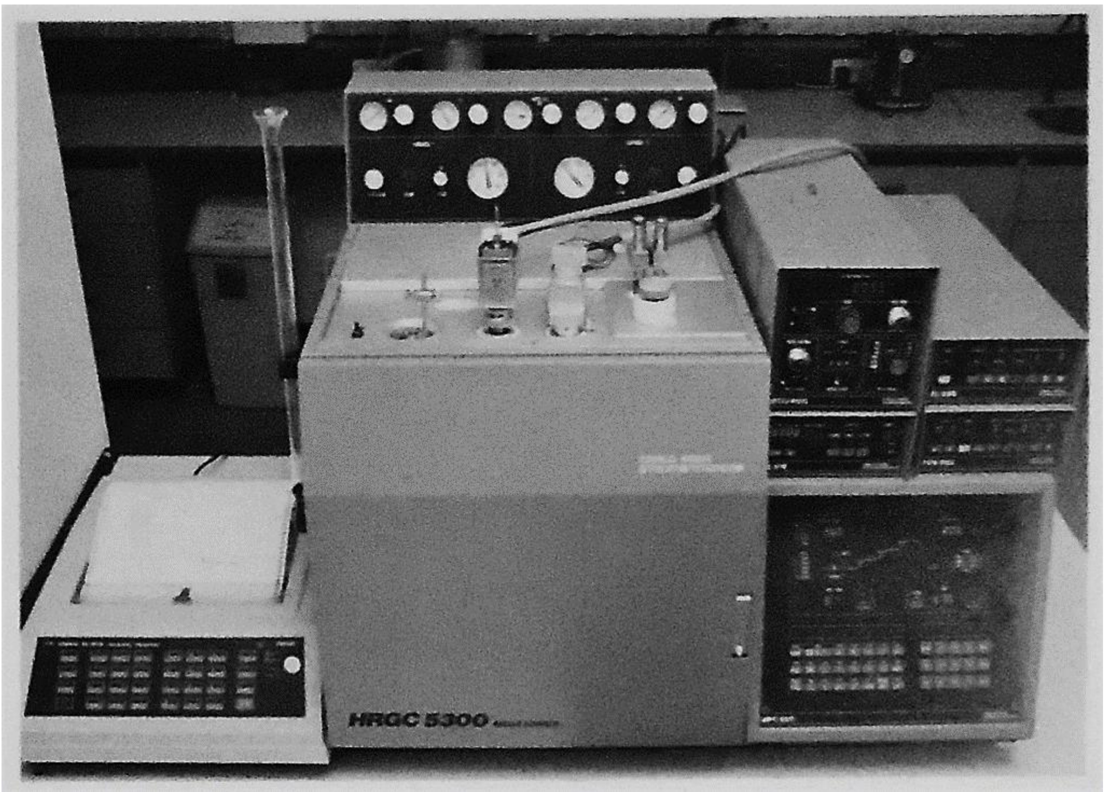


Figure 4.2. Chromatography Apparatus. A HRGC 5300 gas chromatograph at the NIAB. The Institute invested in new laboratory equipment throughout the 1980s, seeking more efficient methods of analysing and classifying crop plants. From 'NIAB and the environment', Annual Report 1990, NIAB.

[54] Quarterly Report to Council, March to May 1982, Box C-3, Document No. 761, NIAB.
[55] Quarterly Report to Council, June to August 1982, Box C-3, Document No. 763, NIAB.

Despite ongoing advances in the use of electrophoresis and NIRS, other methods of variety analysis were also tested at the NIAB during the 1980s. The Institute's 1986 annual report declared that the C&QA branch had made new advances in the 'automation' of chromatography, via an automatic injection system and data capture facility, capable of carrying out unattended analytical techniques overnight, to the benefit of 'cost-effectiveness' and 'improved efficiency'.[56] Draper considered chromatography to possess potential for variety identification, although this would not be fully realised until the late 1980s.[57] The relative unimportance of chromatography in comparison to electrophoresis at the NIAB can be explained through developmental speed. By the time chromatography featured in the day-to-day running of the Institute, electrophoresis was an established and successful method. Yet the same explanation cannot be given for NIRS, which emerged in tandem with the electrophoresis programme.

Different forms of variety analysis technology emerged at the NIAB to occupy various niches. Measuring the moisture content of cereals (which determines the storage life of seeds) was one example of a practice where new approaches were in demand. Moisture measurement had traditionally been conducted by oven drying cereals, a time-consuming and expensive process. Alternative methods, including NIRS and commercial moisture meters were introduced during the early 1980s. Yet an empty "technological niche" was provided by the desire to measure intact, rather than milled grain: a task NIRS analysis struggled to achieve. In 1984 a NIAB research team instead suggested the use of nuclear magnetic resonance (NMR) instruments.[58] The range of work conducted at the NIAB allowed multiple research programmes to flourish. Moreover, the workload demanded by the Institute's various activities drove these research programmes in the direction of efficiency and automation.

Although NIRS has been overshadowed by the success of electrophoresis in agricultural botany, the technique cannot be dismissed as a failed innovation. In fact,

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[56] 'Chemistry and quality assessment branch', Sixty-seventh report and accounts 1986, NIAB. This 'automation' involved glucosinolate analysis of oilseed rape by high performance liquid chromatography (HPLC).

[57] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.

[58] Morley, et al. (1984): 437.

multiple technologies aimed at variety analysis operated concurrently in the NIAB's laboratories during the 1980s. This was made possible by applying different technological methods to different aspects of variety analysis. Analytical work on potatoes during 1982 saw electrophoresis used for standard variety identification, while NIRS analysed the contents of potato varieties. Both methods were considered successful. Staff input to analysis work remained at a minimum, despite an influx of new varieties for testing from 1977 to 1982. 'Substantial benefit' was therefore seen to have resulted from new methods and experimental design, keeping manpower costs low at a time of government austerity.[59] Chemical analysis conducted through NIRS, when combined with variety identification via electrophoresis, created an efficient system for dealing with new crop varieties.

The rationale behind the introduction of 'modern methods of [variety] analysis' at the Institute was summarised in 1982 as meeting growers' requirements for additional information on the nutritional quality of breeders' varieties, while overcoming 'current economic pressures for cost-effective methods'.[60] NIRS and electrophoresis were introduced during a similar timeframe at the NIAB to counter financial pressures and increasing demand from industry. Both programmes allowed the Institute to expand its research work and interact with other prestigious agricultural research institutions. Yet infrared spectroscopy was a tried-and-tested technology by the time of its uptake by the NIAB, just as electrophoresis was similarly a decades-old method of analysis in the biological sciences. Due to falling equipment costs and the relatively low level of expertise required to operate the machinery, infrared spectroscopy had become a routine tool in organic and inorganic chemistry by the 1960s.[61] Industrial applications had begun even earlier, with fuel companies utilising spectroscopy for 'fingerprinting' compounds from the late 1930s.[62]

The NIAB saw significant financial returns and savings from NIRS, electrophoresis and other variety analysis techniques. By 1985 the Institute had announced the launch

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[59] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.
[60] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.
[61] Rabkin (1987): 32.
[62] Rabkin (1987): 40.

of a five-year development plan, aimed at countering stringent government cuts. The role of new techniques in variety analysis was plainly laid out. Resources were allocated for 'automation and modernisation', which included 'the automation of chemical analysis techniques and the development of new chemical methods for variety identification'.[63] Multiple techniques of automated analysis were investigated by the NIAB's researchers during the 1980s under the banner of "modernity". This policy was justified in 1986 as broadening the base of the Institute's income by increasing the volume of contract work that staff could undertake.[64] The attempt to modernise crop classification and analysis techniques was a repercussion of the NIAB's search for new sources of funding in the wake of government cuts. The widespread and rapid nature of the Institute's research into varietal analysis were symptomatic of this search.

Two points of interest emerge from the Institute's development of varietal analysis programmes. Firstly, existing technology was adopted from other fields in biology or biochemistry for use in agricultural botany. Methods of electrophoresis and spectroscopy were then presented as cutting-edge and a force for modernisation within the NIAB and the wider agricultural community, regardless of their actual age. Secondly, NIRS and electrophoresis were ultimately able to operate alongside each other, in what was fast becoming a crowded field, as each was directed towards a different aspect of variety analysis: electrophoresis to classification, NIRS to obtaining information on crop quality. Yet the final example discussed in this paper directly competed with electrophoresis in the sphere of crop classification. The arguments made in favour of machine vision systems at the NIAB demonstrate how taxonomic technology was not a simple move to the molecular, but was shaped by a combination of scientific, commercial and intellectual property considerations.

## 4. Scientific Objectivity and Automated Classification

A 1988 article in the NIAB's journal described an unusual device assembled at the Institute by Simon Draper and P.D. Keefe, the latter a member of the OSTS. The pair created a custom-built 'image analysis facility', designed to measure the size and shape

[63] 'Future developments', Sixty-sixth report and accounts 1985, NIAB.
[64] 'Future developments', Sixty-sixth report and accounts 1985, NIAB.

of plant samples submitted to the NIAB.[65] The prototype device consisted of a motorised camera gantry and image analysis computer, loaded with measurement software. By comparing quantitative data on samples collected by the camera with an existing database, the system could potentially classify varieties based on machine-generated observations of their morphology. For historians of science and technology, the term 'machine vision' brings to mind attempts to mechanically reproduce scientific

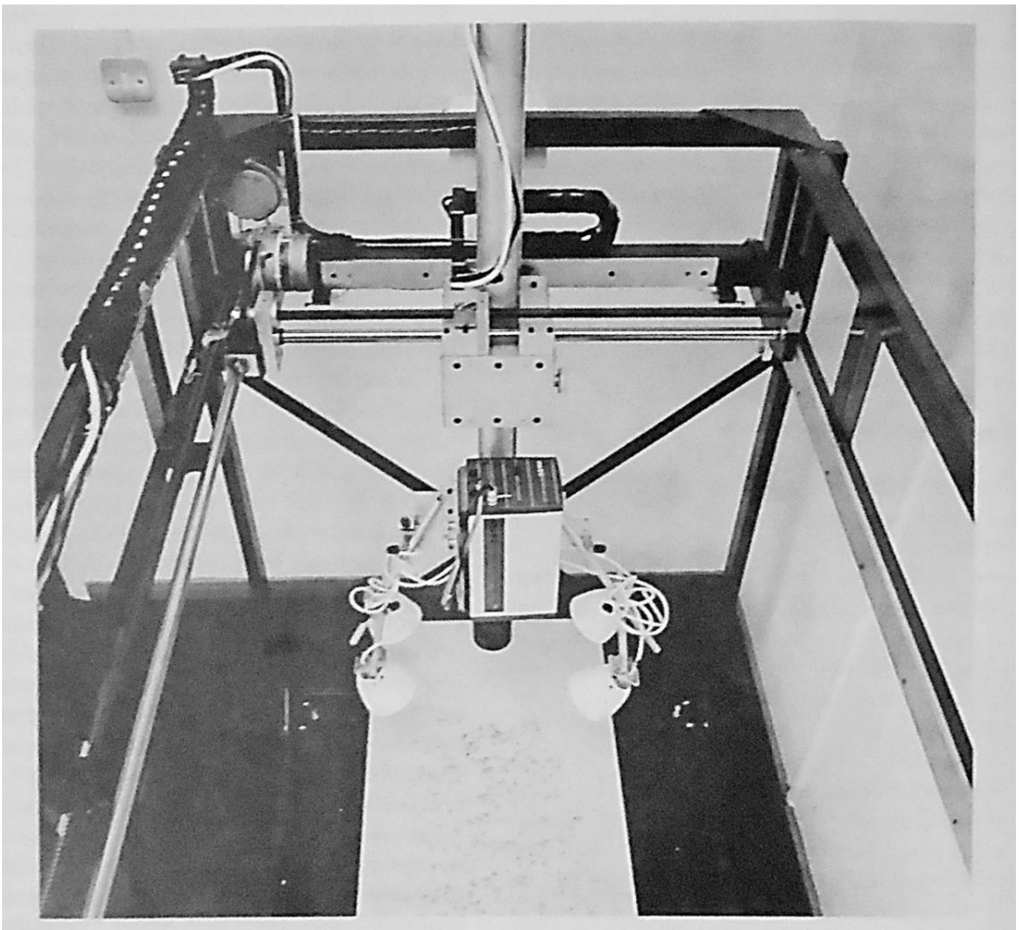

Figure 4.3. The Machine Vision System. A prototype machine vision system, produced by staff at the NIAB and OSTS in 1988. New machine vision systems were developed and tested at the Institute throughout the 1990s. From Keefe and Draper (1988): 1-11.

[65] Keefe and Draper (1988): 1. *Plant Varieties and Seeds* was the new title given to the *Journal of the National Institute of Agricultural Botany*.

images during the early-twentieth century. Mechanical objectivity had then involved the use of new image technologies, supplemented by new scientific attitudes. Yet scientists ultimately despaired of extirpating subjectivity, whilst others sought objectivity in mathematics and logic, rather than images.[66] The existence of a modern machine vision system at the NIAB during the 1980s possesses points of interest for both the history of scientific objectivity and the socio-economic influences behind the selection of taxonomic technology.

For its advocates, machine vision offered a means of eliminating the subjectivity associated with individual scientific practitioners. Describing the benefits of their machine, Draper and Keefe explained that physical traits of seeds and cuttings which had previously been subjectively measured by eye could now be objectively recorded by machines. In fact, human input could be avoided altogether once their automated machine vision system was up and running. The devices would introduce savings of staff time and effort, automatism avoiding errors arising from operator fatigue.[67] It is clear that bypassing human operators possessed potential economic benefits for the NIAB, lessening staff workload or cutting the Institute's workforce. Scientific objectivity and efficiency savings were not necessarily incompatible. During the 1970s, the OSTS had struggled under an increased workload, partly as the consequence of new regulations following Britain's entry into the EEC. While the OSTS was subject to the same financial pressures as other departments at the NIAB, the role of the former's Field Officers had always been made notoriously difficult by the range of expertise required of them. Candidates had to possess a thorough grasp of the demands of farmers and potential input of breeders and seed merchants, while simultaneously keeping abreast of scientific progress in a number of relevant disciplines.[68] Meeting breeders' demand for rapid variety identification while maintaining high scientific standards presented the NIAB's Officers with a formidable challenge.

The machine vision system represented an interaction between members of the NIAB's disparate branches, which Cooke had considered separated by institutional

[66] Daston and Galison (2010): 115-190.
[67] Keefe and Draper (1988): 8.
[68] Sells (1978): 105.

cultures and a strict hierarchy.[69] Much of the OSTS's struggle to meet demand during the 1970s was due to the increasingly complex nature of disease-resistance testing. As the NIAB's Plant Pathology and C&QA branches embraced new research programmes, the Institute's variety analysts followed the modernisation and automation drive seen in other branches. Machine vision was initially justified in much the same language as electrophoresis, an unsurprising coincidence given that Draper was heavily involved in both research programmes. A common purpose in developing the machine vision system came from outside the NIAB. Both Keefe and Draper perceived their machine vision system as dealing with high, unmet demand for variety analysis. Despite the NIAB's successful electrophoresis programme, examination of morphological characteristics remained necessary for field certification on the international level. Bodies such as the International Board for Plant Genetic Resources (IBPGR) continued to issue standardised morphological descriptions for crop species throughout the 1980s. Unlike electrophoresis, machine vision could mechanise and streamline identification, while complying with the morphological descriptions required by regulatory bodies.[70]

Investigations into the practicability of machine vision systems and image analysis technology were not confined to Cambridge. The NIAB's 1989 journal carried an article by two Perth-based engineers, describing a preliminary study on the application of 'pattern recognition techniques' to Australian wheat.[71] Visual identification of Australian wheat was difficult, as there was little genetic difference between cultivars. While gel electrophoresis was successful, facilities and techniques were not as highly developed in Western Australia. Preparation time was substantial and samples could only be analysed in specialist laboratories by experienced personnel. Digital image processing, with a proven track record in robotics and industrial inspection, had the advantages of being easily deployed, non-destructive to samples and providing inexpensive, real-time analysis. Yet by this time only the 'broad structural properties' of grains were subject to analysis, with finer details beyond the capabilities of existing technology.[72] The interest of Australian engineers in the NIAB's machine

[69] Cooke interview, 2015.
[70] Keefe and Draper (1988): 1-2.
[71] Myers and Edsall (1989): 109.
[72] Myers and Edsall (1989): 109.

vision work reveals that the technology attracted diverse audiences, possessing significant advantages over its competitors in certain contexts. Furthermore, machine vision was promising enough to combine engineering and biological interests, in the same manner as biotechnology spans both fields.[73]

In a 1989 paper, Draper and Keefe favourably compared machine vision with biochemical methods - including electrophoresis – in a similar manner to their Australian counterparts. Apart from its alignment with existing national guidelines, machine vision was quick and inexpensive. Cameras and databases could potentially penetrate new markets, where electrophoresis had failed. Cultivar registration by organisations such as ISTA had proven largely resistant to PAGE electrophoresis, despite standardised electrophoresis methods laid out by that association in 1986.[74] Breeders also objected to electrophoresis and similar technologies because they feared 'biochemical piracy'.[75] Electrophoretic methods and charts could be open to manipulation by unscrupulous breeders. An alteration or tweak of an electrophoresis experiment could therefore see a variety produced which appeared dissimilar from existing types based on an electrophoresis chart, but was in reality phenotypically identical to an existing crop variety.[76] In other words, traditional morphological identification made sense from a legal and commercial standpoint.

Yet changes to the practice of varietal identification and analysis could only occur in concert with other developments. Accounts of computerisation for data management purposes first emerged at the NIAB around the mid-1970s.[77] Yet an early attempt to computerise cereal identification and analysis in voluntary schemes at the NIAB collapsed under the number of options and flexibility required of it.[78] By the mid-1980s, the arrival of microcomputers at the Institute had improved basic work in the NIAB's Seed Handling Unit (SHU), including label printing and record keeping.[79] Elsewhere in the biological sciences, computerisation played a more sophisticated role

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[73] Bud (1991): 418-419.
[74] NIAB developed a standard method of PAGE electrophoresis which was approved by the ISTA for wheat and barley in 1986. In the same year, the European Business Council (EBC) approved electrophoresis for barley only. 'Electrophoresis', Sixty-seventh report and accounts 1986, NIAB.
[75] Draper and Keefe (1989): 53-54.
[76] This fear of variety theft or fraud was articulated to the author at the NIAB Seminar, 09 February 2016.
[77] Patterson and Talbot (1974).
[78] Silvey and Wellington (1997): 133.
[79] 'Seed handling unit', Sixty-seventh report and accounts 1986, NIAB.

in the development of, for example, protein sequencing from the 1950s.[80] Yet computing power and sophistication remained inadequate for machine vision systems. Machine vision came with technical challenges which persisted well into the 1990s. Creating computer programs capable of interpreting complex, natural structures remained a major obstacle in further development of the technology.[81]

Despite breeders' protests against electrophoresis and other biochemical methods of varietal analysis, machine vision was slow to develop beyond the prototype stage at the NIAB. By the late 1980s, the Institute may have had far too much invested in the CQ&A branches' lucrative and longstanding electrophoresis programme and other techniques in chemotaxonomy to fully embrace machine vision systems. Furthermore, if crop variability could not be accurately interpreted by existing computers, applying machine vision to high-volume variety identification systems would clearly be problematic. Multiple "high-tech" solutions were deployed in the NIAB's variety analysis work during the 1980s, with the ultimate aim of securing the Institute's finances. Their success depended upon technological viability, commercial applicability and conforming to existing values in contemporary scientific and legal systems. These factors were of greater importance to the embattled NIAB than whether the technology was capable of manipulating samples on the molecular level or not.

## Conclusions

In this chapter, we have seen how the development and uptake of taxonomic techniques at the NIAB during the 1980s was heavily reliant upon social contingencies. New methods of crop classification and analysis were investigated by the Institute in response to economic pressures, as more crop varieties were submitted to the NIAB at the same time as government cutbacks to agricultural institutions began to bite. When it came to deciding between different technologies, a myriad of factors came into consideration: speed, cost, objectivity and intellectual property rights. At the NIAB, technologies also existed side by side, either working on different aspects of crop

[80] Strasser (2010).
[81] Taylor, et al. (1997).

analysis or deployed in different contexts. Crop classification at the Institute during the 1980s also offers two points of further interest to the historian: firstly, as an example of the application of 'vintage' technology in action, and secondly as a demonstration that twentieth-century crop taxonomic techniques did not inevitably follow the path of molecularization. Just as the uptake of hybrid or mutation-bred crops by growers and food manufacturers was dependent on a number of economic, political and ideological factors, so molecular classification techniques were beholden to such factors.

Nicholas Jardine has noted that it takes a great deal of work for scientists to finish off old questions and theories: so much so, that what we might expect to be obsolete or outdated ideas can form an integral part of science. Moreover, our telling of intellectual history tends not to move at the 'textbook level', leaving historians ignorant of what ideas and practices were commonplace at a given time.[82] 'Vintage' ideas and practices can therefore successfully operate within certain fields. Historian of technology David Edgerton also argues that technologies of varying vintages can similarly occupy the same institutional space: in other words, the old can happily exist alongside the new.[83] Vintage technologies can persist in fields such as agricultural botany for longer than we might expect, fulfilling specific social contingencies. At the NIAB, the move from morphological analysis to molecular techniques was portrayed as a process of modernisation. Yet electrophoresis and spectroscopy were long–established techniques in biochemistry by the 1980s, just as hybridization and mutation breeding were long–established plant breeding technologies. The use of electrophoresis and spectroscopy at the NIAB therefore represents a further example of the successful uptake and application of vintage biotechnologies in a new context.

Molecular techniques like electrophoresis and spectroscopy did not immediately replace traditional methods of recording morphological characteristics of crops by eye at the NIAB. A 1985 article in the Institute's journal listed morphological characteristics used to differentiate hybrid wheat-rye from bread wheat. Visual representations of these characteristics were included to aid readers.[84] Botanical expertise persisted as a relevant technical practice at the Institute. Although there was some initial hostility

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[82] Radick, (2012): II.
[83] Edgerton (2006).
[84] Wilson and Eade (1985).

from traditional 'technical' branches within the NIAB, physiology and biochemistry ultimately ended up covering different aspects of plant science.[85] It was not problems with morphological analysis, but external pressure from trading standards and industrial demands for more information on crop quality which forced the NIAB to reconsider its existing methods.[86] Ultimately, multiple taxonomic practices, old and new, existed side by side within the Institute during the 1980s and beyond.

Neither was the move towards the molecular techniques at the NIAB uncontested or inevitable. Elsewhere in the biological sciences, molecularization was consciously chosen and pursued: the adoption of molecular techniques 'represented no natural or inevitable path for biological research'.[87] Within the NIAB, morphological analysis was not simply replaced by electrophoresis or NIRS. Instead, molecular techniques were adopted by the Institute for pragmatic reasons of economy and efficiency. As the testing of machine vision systems show, the NIAB did not blindly follow the path of molecularization. During the 1990s, ever more advanced machine vision systems were created and tested by the Institute's Image Analysis Group.[88] Image analysis now plays an important role in variety classification at the NIAB.[89]

Even as Cooke, Draper and others conducted their research and promotion of electrophoresis, NIRS and machine vision systems, new methods of crop classification and analysis were emerging. A 1989 article in the NIAB's journal described yet another means of varietal identification: DNA probes. Its authors hit upon a number of themes which had occupied the NIAB, including the need to reliably and rapidly screen an ever-expanding number of crop varieties following the introduction of plant variety rights and the 'need to protect genotypes'.[90] Electrophoresis was fast approaching its technical limits—varieties would eventually become indistinguishable as breeders selected for key protein types. With improvements in molecular biology, 'variation at the DNA level' could now be detected.[91] The NIAB's researchers were aware of advances in DNA sequencing and its implication for electrophoresis. Yet other

[85] Cooke interview, 2015.
[86] 'Cereals', Sixty-seventh report and accounts 1986, NIAB.
[87] Kay (1993); Steven Turner (2008): 255.
[88] Warren (1997).
[89] Discussion following the NIAB Seminar, 09 February 2016.
[90] Ainsworth and Sharp (1989): 27.
[91] Ainsworth and Sharp (1989): 28.

developments in DNA-level technology also concerned them, namely recombinant DNA technology, which was finally coming to fruition after years of promise.[92]

This chapter has described a shift towards molecular classification of crop plants in British agriculture during the 1980s. It has detailed the development of three competing taxonomic technologies at the NIAB during the 1980s, linking the need for new methods in variety analysis to falls in government funding and available manpower. Electrophoresis and NIRS were also linked to an institutional rhetoric citing the benefits of modernity and automation. Machine vision systems were justified on wider grounds, including improvements in scientific objectivity and dealing with the intellectual property concerns of plant breeders. The adoption of molecular crop classification and analysis techniques at the NIAB was by no means a straightforward or inevitable process. The 1980s had been marked by a struggle for financial survival, resulting in dramatic shifts towards private funding sources and schemes to automate and computerise the Institute's work. To ensure its survival, the NIAB pursued diverse techniques in crop classification and analysis on the basis of practicality and utility. Molecularization at the NIAB was not a deterministic process but one driven by pragmatic responses to its changing circumstances. Yet if even the most basic of assumed transitions in the biological sciences – from the morphological to molecular level – can be called into question, what does this imply for the wider history of biotechnology? In the next chapter, we shall see how this transition was not even inevitable in the world of plant breeding.

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[92] Cooke interview, 2015.

# 5. Graft Hybridization: British Horticulture as a Cold War Battleground

> If we admit as true M. Adam's account, we must admit the extraordinary fact that two distinct species can unite by their cellular tissue… in short, resembling in every important respect a hybrid formed in the ordinary way by seminal reproduction. Such plants, if really thus formed, might be called graft hybrids.
>
> – Charles Darwin, *The Variation of Animals and Plants under Domestication* (1868).[1]

In the last chapter we saw that, at least in certain institutional contexts, there was no guarantee that molecular biotechnology as we know it today would emerge from a plethora of competing technologies. More broadly, throughout this thesis we have seen how 'vintage' biotechnologies – hybridization, mutation breeding and electrophoresis – have persisted in certain contexts, or have been reinvented to fit new ones. Electrophoresis was revitalised by its application to agricultural botany long after its invention. Mutation breeding experienced a mid-twentieth century surge following calls to develop peaceful uses for atomic energy. Around the same time, hybridization, an age-old breeding technique, was overhauled and expanded to meet the demands of British industry. In this chapter, we are faced with perhaps the most remarkable and most contested example of a plant biotechnology which has been revived time and time again: graft – or vegetative – hybridization.

During the 1960s and 1970s, we saw that practitioners of plant cell fusion were careful to demonstrate that their botanical creations were not the result of grafting, but of true cellular fusion. After all, the consequences of claiming that a hybrid plant could be produced by grafting – the physical joining of one plant's tissue to that of another – could potentially be dire for biologist or breeder. Respectable sources of botanical authority, including the 1965 *Encyclopaedia of Plant Physiology*, insisted that graft hybrids did not exist and never would.[2] Graft hybridization was relegated to the realm

[1] Darwin (1868): 390.
[2] Constabel (1976): 743.

of folklore, a superstitious relic of the pre-Mendelian world of Shakespeare and Bacon.[3] The gradual removal of graft hybrids from the world of modern science was only accelerated when graft hybridization took on overtly political connotations during the mid-twentieth century.

In what Stephen Jay Gould called 'the most chilling passage in all the literature of twentieth-century science', Trofim Denisovich Lysenko (1898-1976) addressed the Lenin Academy of Sciences in 1948, with a speech reportedly pre-approved by the Central Committee of the [Bolshevik] Party.[4] Lysenko unveiled his new Soviet biology in its entirety: the rejection of Mendelian genetics; the denial that the chromosome was the seat of heredity; the inheritance of acquired characters; and supposedly new agricultural techniques, including the vernalisation of wheat. Lysenko also used the address to attack his opponents, including the botanist P.M. Zhukovsky. 'As becomes a Mendelist-Morganist', Lysenko exclaimed, '[Zhukovsky] cannot conceive transmission of heredity properties without transmission of chromosomes… He therefore does not think it possible to obtain plant hybrids by means of grafting'.[5] At this point, Lysenko purportedly gestured towards wax models of potato-tomato hybrids obtained through grafting.[6] The graft hybrid had taken on a new political life. Just as traditional hybrids had been used as a practical demonstration of the truth of Mendelian genetics, so graft hybrid plants were portrayed as living examples of the truth of Soviet biology, including the inheritance of acquired characters.

We might expect a ringing endorsement by Lysenko to mark the end of the any mainstream support for the graft hybrid as a plant breeding technology in British agriculture. After all, throughout this thesis we have seen how industrial hybridizers and mutation breeders all marketed their new plant biotechnologies to a wider public by demonstrating how their technologies undermined Lysenko. Yet it is simply not the case that Lysenko found no support among the British agricultural community, nor that graft hybridization was abandoned as a means of breeding new plant varieties in Britain.[7] This

[3] Cook (1932).
[4] Gould (1983): 135.
[5] Lysenko (1954 translation): 545-546.
[6] Cook (1949): 184. Lysenko's use of wax models led some in the Western press to accuse him of fraud. However Lysenko was – in this instance – defended by British biologist Julian Huxley, who argued that the use of wax models for botanical displays was normal practice.
[7] For an existing account of the reception of Lysenko in Britain, see Paul (1983).

chapter demonstrates that support for the graft hybrid was present in British horticulture well into the twentieth century. This support can be – at least in part – understood due to a previously untold history of graft hybridization spanning the late-nineteenth to mid-twentieth century.[8] During this period, the graft hybrid was associated with strong experimental and practically-orientated traditions in botany, animal physiology and plant physiology. Although belief in the possibility of graft hybrids had largely fallen out of favour among most biologists by the 1930s, graft hybridization remained popular among horticulturalists and continued to count members of the British scientific establishment among its supporters. Until this stage in the thesis, much of our attention has been on the difficulties involved in moving plant biotechnology from an experimental concept to practical technology for farmers and breeders. The graft hybrid instead demonstrates the difficulties faced by biologists in dislodging an established form of plant breeding.

This chapter explores three distinct periods in the life of graft hybridization in Britain. The first period begins in 1868, when Charles Darwin first coined the term graft hybrid in his *The Variation of Animals and Plants under Domestication*. Throughout the first half of the twentieth century, numerous grafting experiments were carried out across the Western world on both plants and animals. Yet the majority of botanists and plant physiologists had turned against the graft hybrid hypothesis by the mid-twentieth century, preferring to label conjoined plants as chimeras. By the time Lysenko unveiled his graft hybrids at the 1948 Lenin Academy of Sciences, graft hybridization had fallen from the peak of its scientific popularity. However, as the second section of this chapter explains, the graft hybrid did not vanish from British agriculture. Organisations such as the Commonwealth Agricultural Bureau continued to promote Soviet studies of graft hybrids, while some British breeders and growers remained sympathetic to the inheritance of acquired characters. In the third section of this chapter, we jump forward in time to the present day where the concept of graft hybrid plants has been lent a new lease of life by molecular studies. It is now accepted that heritable material can be carried across grafts and that cell fusion can occur at graft junctions. For some, these findings suggest that transgenic plants have long inhabited our gardens and orchards: a

[8] Scattered references to graft hybridization exist in the history of science literature, but to the best of my knowledge there exists no thorough history of the graft hybrid.

major rethink is therefore required on what we define as a genetically modified organism (GMO). For others, the graft hybrid presents an opportunity to reinvent biology and its history within a Marxist framework: casting aside Mendelian genetics and placing graft hybridization at the centre of modern plant breeding programmes.

## 1. The Graft Hybrid Contention before the Cold War

It is no mere coincidence that none other than Charles Darwin first coined the term 'graft hybrid' and chose to draw attention to supposed examples of the phenomenon in his 1868 *The Variation of Animals and Plants under Domestication*.[9] Since the mid-nineteenth century, the existence of graft hybrids has been bound up with fundamental questions on the true nature of heredity. After all, *The Variation* is better known as the means by which Darwin introduced his own theory of heredity – pangenesis – to his Victorian peers. Put simply, pangenesis states that each organ, or cell, of the body throws off a minute copy of itself. These copies, or gemmules, congregate in the sexual organs and are the means by which the physical characteristics of parents are passed onto their offspring.[10] If it is true that the units of heredity reside within the cells of living bodies, a graft hybrid would offer powerful evidence in favour of pangenesis. By taking the body part of one organism and surgically grafting it onto the body of another, the appearance of any characteristics resembling the grafted part in the offspring of the host organism would indicate that the wider body – not just the sex cells – can influence heredity. For Darwin, a successful instance of graft hybridization 'represented the most effective method of advancing his theory.'[11]

Darwin knew of numerous examples of grafted plants, which produced offshoots (or sports) seemingly consisting of a combination of characteristics from both host and graft. One of the most famous was the aptly-named Florentine Bizzarria.[12] The unusual plant had its origins in 1674 with the Florentine gardener Pietro Nati.[13] Apparently his incompetence managing the plants at Panciatichi House allowed an

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[9] Darwin (1868): 390. Darwin was able to cite a number of examples of breeders who claimed to have created graft hybrids. He is therefore best thought of as the originator of the term, not the concept.
[10] Explanation from Geison (1969).
[11] Schwartz (1995): 289.
[12] Darwin (1868): 391-392.
[13] Frank and Chitwood (2016): 3.

unwanted shoot to flourish on a grafted fruit tree. When the resulting fruits were examined, they were found to be an unappetising mix of citron and orange.[14] Darwin was also able to draw upon more recent findings, including accounts of graft hybrid apples and roses. Although compelling, these anecdotal stories of graft hybridization were not enough. Darwin admitted that 'it is at present impossible to arrive at any certain conclusion with respect to the origin of these remarkable trees'.[15] It would far better for Darwin and his theory of pangenesis if he could conduct his own experiments, to produce and raise his own graft hybrids under more scientifically rigorous conditions.[16]

An elderly and increasingly frail Darwin enlisted the aid of a young and enthusiastic naturalist, George John Romanes (1848-1894), to help him carry out graft hybrid experiments. Like many other Victorian gentlemen engrossed by pangenesis, Romanes had been busy testing the theory by removing the ears of rabbits and other mammals for surgical grafting. A more sensitive Darwin encouraged him to abandon this approach and conduct grafting experiments on plants, particularly potatoes.[17] From 1875 to 1880 Romanes grafted numerous species of plant together: potatoes, beets, onions, dahlias, peonies and carrots.[18] Yet success was not forthcoming. Plants were lost to disease, grafted plants decayed or separated from their hosts and all resulting seeds only displayed the characteristics of one parent.[19] Results from other thinkers in the life sciences also spelt bad news for Darwin's theory. In 1871 Francis Galton had found that transfusing blood from one variety of rabbit to another resulted in no 'alteration of breed' in their offspring, demonstrating that 'the doctrine of Pangenesis, pure as simple, as I have interpreted it, is incorrect.'[20]

The fall of pangenesis as a theory of heredity did not spell the end of attempts to create graft hybrid plants or animals. In the early years of the twentieth century, C.C.

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[14] Ragionieri (1927): 527.
[15] Darwin (1868): 397.
[16] Such experiments may well have given graft hybridization greater legitimacy, but would not have been given a free pass by Darwin's critics. See De Chadarevian (1996).
[17] Schwartz (1995): 289-290.
[18] Schwartz (1995): 291-292.
[19] Schwartz (1995): 293. Following Darwin's death in 1882, Romanes reverted back to animal experiments. His efforts to graft hybridize animals were as unsuccessful as his efforts with plants.
[20] Galton (1871): 403-404. Darwin protested against these findings on the grounds that he had never claimed the gemmules were located in the blood. Galton tactfully backed down from the controversy.

Guthrie, based at the Physiological Laboratory of Washington University Medical School, conducted his own experiments on the ovaries of chickens and their function. Taking two lines of pure-bred Single-Comb Black Leghorn and Single-Comb White chickens – one with entirely black feathers, one with entirely white – Guthrie removed the ovaries of one line and grafted them into the other over the course of August 1906.[21] When Guthrie bred his chickens to find if their grafted ovaries were still functional, he found something quite remarkable. When a black-feathered male was crossed with a white-feathered female with transplanted ovaries from a black-feathered female, the

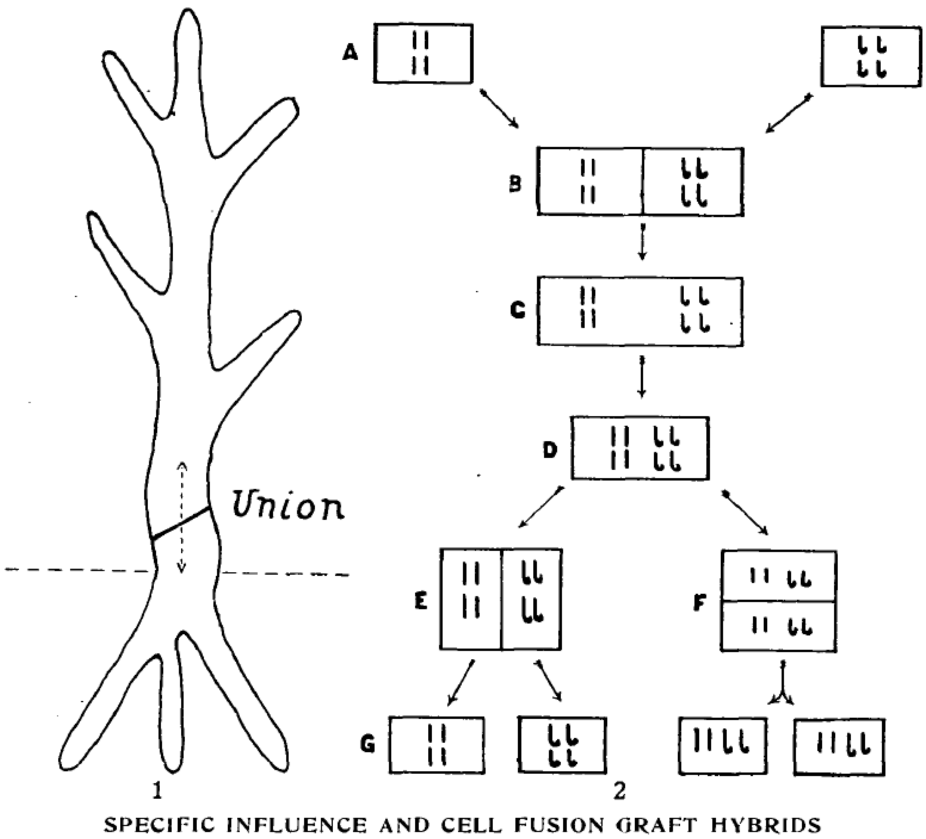


Figure 5.1. A Hypothetical Graft Hybrid. A theoretical diagram showing the movement of chromosomes across the graft junction. The graft hybrid goes on to show all the characteristics of a normal sexual hybrid, including hybrid degeneration back into its parental types over the generations (boxes E, F and G). From Swingle (1927): 77.

[21] Guthrie (1908): 563.

offspring were a mixture of black and white. The same combination of colours occurred in the feathers of offspring born of a union between a white-feathered male and a black-feathered female with ovaries from a white-feathered female. These results seemed to suggest, contrary to Mendelian theory, that the body of the hen with engrafted ovaries had 'exerted an influence on the colour of the offspring.'[22] Guthrie was understandably intrigued by his findings, which seemed to call into question the by now-established principle that heredity was a matter confined to the sexual organs.

Yet by 1911 Guthrie declared that 'One should not consider animal offspring from engrafted ovaries as identical with the graft hybrids of plants described by Darwin'.[23] He did not expand much upon why he had reached this conclusion, but did suggest that nutrition was 'of prime importance' from a 'physiological standpoint'.[24] Guthrie had probably been convinced – or convinced himself – that the mix of black and white feathers on the offspring of his "graft hybrid" hens were probably the result of exposure to certain environmental factors during their upbringing. Diet can induce noticeable changes in chickens. In an attack on Lysenko in 1949, British biologist Julian Huxley noted that, if fed a diet of corn, the feet of some fowl take on a yellow tinge. However such environmentally-induced changes are not heritable and are entirely compatible with Mendelian principles.[25] Similar experiments on guinea pigs to those conducted by Guthrie were raised in the third volume of the *Biological Monographs and Manuals* series on animal genetics in 1925. Its author Francis Albert Eley Crew (1886-1973), Director of the Animal Breeding Research Department at the University of Edinburgh, drew upon experiments with the ovaries of guinea pigs. If the ovaries of a white-furred guinea pig were transplanted into a red-furred guinea pig prior to crossing with a white male, the resulting offspring would be largely white: albeit with a few red hairs here and there.[26] Crew used this data as part of a wider argument allowing for the inheritance of acquired characters, although graft hybridization could at best produce heritable changes of a 'very restricted character'.[27]

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[22] Guthrie (1908): 569.
[23] Guthrie (1911): 369.
[24] Guthrie (1911): 371.
[25] Huxley (1949): 6-7.
[26] Crew (1925): 340.
[27] Crew (1925): 339.

Widespread belief in the possibility of graft hybrids among botanists and plant physiologists proved far more persistent than in animal physiology and genetics. Introducing his readers to the graft hybrid debate in 1914, Richard Benedict Goldschmidt – geneticist and editor of the American *Journal of Heredity* – remarked that the 'mystery' surrounding the existence of plant graft hybrids had been a 'bone of contention among horticulturalists for several centuries.'[28] After all, seemingly spectacular plants could be relatively easily created by grafting two or more varieties or species together: the results of which had so impressed Darwin back in 1868. Yet in the first decade of the twentieth century Hans Karl Albert Winkler (1877-1945), Professor of Botany at the University of Hamburg and best known for coining the term "genome", discovered that grafted plants did not fuse on the cellular level. New growths on a grafted plant showing a mix of characteristics were instead the result of distinct tissues from both graft and host plant growing side by side: an organism which Winkler called a "chimera".[29] Further experiments by Erwin Baur (1875-1933), Director of the Kaiser Wilhelm Institute for Breeding Research, showed how arrangements of different tissues could arise in grafted plants.[30] From the early twentieth century, plants which were once thought to be graft hybrids – including the Florentine Bizzarria – were labelled as chimeras.[31] In modern terminology, these chimeras were single organisms containing two or more distinct genomes.

Yet the emergence of Baur's chimaeral hypothesis did not stop some botanists hoping that genuine graft hybrids still existed. Part of the reason the graft hybrid hypothesis maintained a respectable following in botanical circles was due to further work from none other than graft hybrid debunker Hans Winkler. Over some six years Winkler carried out 268 grafts, with only five chimerical plants to show for his efforts by 1910.[32] Four of these plants, following microscopic examination by Winkler, were shown to be chimeras of the sort described by Baur. Yet a fifth plant, the result of a graft between tomato and nightshade, was different. A chromosome count of the plant, named *Solanum darwinianium*, showed that its cells contained forty-eight

[28] Goldschmidt (1914): 521.
[29] Winker (1907).
[30] Baur (1909).
[31] Tilney-Bassett (1986); Frank and Chitwood (2016).
[32] Goldschmidt (1914): 530.

chromosomes: double the number one might expect in a normal plant. This finding elicited great excitement, as forty-eight chromosomes seemed to indicate that some sort of fusion had occurred on a cellular level to create *Solanum darwinianium*. 'It claims', wrote Richard Goldschmidt in 1914, 'to be the only genuine, out-and-out graft hybrid in the world.'[33] But with the outbreak of the First World War, disaster struck. At some point, whether through neglect or disease, the *Solanum darwinianium* perished in wartime Germany and was forever lost to science. Even if Winkler had been inclined to carry out hundreds of nightshade and tomato grafts once again, there would be no guarantee that a forty-eight chromosome graft hybrid would result. An expected monograph on graft hybrids never emerged from Winkler.[34] Instead the botanist took a darker path, joining the National Socialist German Workers' Party (NSDAP) in 1937 before his death in 1945.

A lingering ambiguity therefore surrounded the possible existence of graft hybrid plants, in part caused by the unfortunate loss of the *Solanum darwinianium*. This ambiguity left enough intellectual room for members of the European scientific community to maintain their belief in plant graft hybrids, seemingly without ridicule, well into the twentieth century. One example of such an actor was Lucien Louis Daniel (1856-1940), Professor of Applied Botany at the University of Rennes. Daniel had been a longstanding advocate of graft hybridization and had developed his own technique for the production of graft hybrids – 'le greffe mixte' – which allowed shoots just below a graft junction, instead of being removed, to fully develop. Yet by the 1930s it was clear that Daniel's views on graft hybridization 'would not meet with general acceptance among botanists'.[35] One supporter of Daniel in Britain was William Neilson Jones, Hildred Carlile Professor at the University of London, who in 1935 authored a Methuen monograph entitled *Plant Chimeras and Graft Hybrids*.[36] Jones's support of graft hybrids produced through cell fusion did not meet with favourable reviews. Writing in the *Journal of Heredity*, Hiram M. Showalter, based at the University of Virginia's Blandy Experimental Farm, did praise the book as 'appeal[ing] both to the botanist and to the

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[33] Goldschmidt (1914): 532.
[34] Swingle (1927): 87.
[35] Jones (1934): 31.
[36] Methuen was a London-based publisher which issued a series of textbooks devoted to 'biological subjects' during the early twentieth century.

layman'. Yet Showalter was not convinced by the 'graft hybrid hypothesis', which he claimed lacked 'conclusive evidence' and could largely be explained by Baur's chimaeral hypothesis.[37] The general lesson to take away from Jones's monograph and its reception is that belief in the graft hybrid was, by the mid-1930s, unusual but still respectable. It appears that most botanists and plant physiologists in the United States and Europe had either abandoned the hypothesis or at least given up on the possibility of ever proving it.

A very different take on graft hybridization existed among horticulturalists. For the owners of orchards, it had always been evident that the stock of a fruit-bearing tree would exercise some kind of influence on a branch (scion) grafted onto it. Jones noted that the 'Horticultural literature is full of instances of the effect of stock and scion and *vice versa*.'[38] As an advocate of graft hybridization, we might expect support from the horticultural community to have been welcome news for Jones. Instead, Jones was sceptical of the evidence produced by horticulturalists. It was necessary to 'exercise caution' when interpreting grafting experiments. He gave the example of the branch of a green-leaved variety grafted onto the stock of a red-leaved variety, which sometimes produced red leaves on the grafted branch. A 'hasty deduction' would lead one to assume that 'the faculty for producing red pigment had been transferred from stock to scion.' Further experiments, however, would show that red leaves would still emerge from time to time when a green-leaved branch was grafted onto a green-leaved stock. The true explanation for the phenomenon was that environmental factors, including availability of water and poor healing of the graft junction, could produce such changes.[39] As Guthrie recognised with his graft hybrid chickens back in 1911, environmental influences could replicate the results once attributed to graft hybridization.

By the time Lysenko launched his attack on Zhukovsky at the Lenin Academy of Sciences congress in 1948, graft hybridization had already entered a seemingly terminal decline among biologists. Thus Lysenko's gesture to his potato-tomato hybrid models as proof that chromosomes alone did not determine heredity was quickly dismissed.

[37] Showalter (1935): 247.
[38] Jones (1934): 5.
[39] Jones (1934): 56-7.

Reacting to reports of the meeting, American geneticist Robert C. Cook argued that Lysenko's supposed graft hybrid plants were no different 'from earlier chimeras of this kind reported in the literature of "reactionary" biology.'[40] In Britain, as in much of the Western World, Lysenko's theories were generally met with scepticism by the scientific establishment. One critique was produced by P.S. Hudson and R.H. Richens, members of the Cambridge-based Imperial Bureau of Plant Breeding and Genetics. Intended as an 'impartial assessment' of Lysenko's work, their critique was nonetheless damning.[41] Hudson and Richens did, however, state that the question of whether or not graft hybridization could occur was one of biology's most long-standing problems.[42] In fact, the graft hybrid was the only area where solid evidence existed to counter the standard understanding of inheritance. When pressed to 'provide minimal empirical support of Lysenkoism', Haldane – who we encountered clashing with Darlington over Communism in Chapter 2 – also pointed to graft hybridization.[43] As poorly received as Lysenko was in the Western World, the graft hybrid was the most well-received – or at least un-refutable – part of his biology.

The long history of graft hybridization since the mid-nineteenth century presents us with three important lessons. Firstly, it is apparent that the graft hybrid was considered a serious scientific problem in Europe and America for much of the twentieth century. Until the mid-twentieth century, the graft hybrid was still an intellectually respectable hypothesis with advocates including respected botanists. Moreover, those who chose to investigate the graft hybrid possessed a strong practical and experimental orientation. This orientation was doubtlessly part of what made the graft hybrid an attractive plant breeding tool in the Soviet Union. Secondly it should be noted that, although graft hybridization became associated with Lysenko's biology during the 1940s, the graft hybrid did have a life independent of Lysenko. It was therefore possible to point to what appeared to be compelling evidence in favour of graft hybridization without ever mentioning the work of Lysenko or his disciples. Finally, it appears that strong support for graft hybridization came quite naturally from the

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40 Cook (1949): 184.
41 DeJong-Lambert (2012): 60-61.
42 Hudson and Richens (1946): 45-51.
43 Roll-Hansen (2011): 85-86.

breeders and growers of horticultural plants. As the passage from Jones in 1934 indicates, this community was used to the idea that the stock of one plant could somehow influence the characteristics of another through a graft junction. So prevalent was this idea that, to Jones's despair, graft hybridization was readily invoked to explain any observed change in grafted plants. Even into the 1950s and beyond, horticulturalists considered graft hybridization a real and valid means of altering crop plants.

## 2. Lysenko in Britain and a British Fruit Grower in the USSR

'Dog breeding is full of pitfalls and dog breeders are full of folklore', complained Cyril Darlington in 1953, who was using his time after the John Innes Symposium on Chromosome Breakage to uphold the integrity of Mendelian genetics.[44] Darlington's target was a recent monograph on dog breeding by Marca Burns, a member of the Commonwealth Bureau of Animal Breeding and Genetics at the at the University of Edinburgh's Institute of Animal Genetics.[45] According to Burns, 'The most controversial question in all the history of the science of genetics has been whether or not peculiarities acquired by an individual during its lifetime can be passed on its descendants.'[46] She claimed that British breeders of livestock and working dogs had apparently never been disabused of the notion that acquired characters could be inherited. The theories of Lysenko had therefore 'aroused much interest among farmers.'[47] Darlington was outraged that such views 'still held by illiterate people all over the world' were being expounded 'coupled with the name of Lysenko' by a division of the state-funded Commonwealth Agricultural Bureaux.[48] Yet Darlington was unsurprised that this had occurred in Edinburgh, which had long been sympathetic to such theories.[49] As we have seen, Francis Crew – Director of the Animal Breeding

[44] Darlington (1953a): 141.
[45] The Bureau was 'founded in 1930 to disseminate information through reviews and bibliographies.' An outline of its founding and history can be found online at: http://ourhistory.is.ed.ac.uk/index.php/Animal_Genetics.
[46] Burns (1952): 85.
[47] Burns (1952): 86.
[48] Darlington (1953a): 142.
[49] Darlington (1953a): 141. Darlington claimed that a sympathy for the inheritance of acquired characters had existed at the University since the time of Professor James Cossar Ewart (1851-1933).

Research Department and founder of the Institute of Animal Genetics – had written in support of non-Mendelian means of heredity back in the 1920s, using graft hybrid guinea pigs as experimental evidence.

Animal Breeding and Genetics was not the only branch of the Commonwealth Agricultural Bureaux which might be accused of erring in favour of Lysenko. In 1963 Robert L. Knight of the Commonwealth Bureau of Horticulture and Plantation Crops, based at the East Malling Research Station in Kent, issued a list of papers published on horticulture since 1900.[50] Like Burns's dog monograph, this technical publication was intended to update breeders – in this case breeders of common fruit trees – with information on 'breeding, genetics and cytology.'[51] So far, so orthodox. Yet Knight also included a number of papers which proclaimed the truth and utility of graft hybridization. Somewhat disingenuously, graft hybrids were placed under the label of 'graft chimaera' in the index of Knight's *Abstract Bibliography of Fruit Breeding and Genetics to 1960.*[52] These papers included a number of accounts of graft hybridization for plant breeding in the Soviet Union. A 1948 contribution by S.I. Isaev explained how the 'root mentor effect' had been used to transfer 'hardiness' across a graft junction to produce apple varieties suited for central Russia.[53] Experiments in Leningrad were reported as transmitting heritable changes from scion to stock in 1954.[54] The most recent contribution from the Soviet Union dated to 1960 and described the breeding of dwarfed apple trees using a combination of 'vegetative [graft] hybridization' at Kinel Agricultural Institution, followed by a series of hybrid crosses.[55] Through the work of the Commonwealth Agricultural Bureaux during the 1960s, graft hybridization was presented to British fruit growers as a genuine means of breeding new plant varieties.

Resistance to the graft hybrid in Britain came not just from leading biologists like Darlington, but also from leading members of the horticultural community. A two-pronged assault on Lysenko and graft hybridization came from the Royal Horticultural Society (RHS) during the 1950s and '60s.[56] In the pages of its journal, members and

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[50] Interestingly the East Malling Research Station has recently been acquired by the NIAB.
[51] Knight (1963): Foreword.
[52] Knight (1963): 511.
[53] Knight (1963): 199.
[54] Knight (1963): 251.
[55] Knight (1963): 408-409.
[56] On the history of the RHS, see Fletcher (1969).

admirers of the Society promoted the myriad benefits of foundational techniques in modern plant breeding – hybridization and mutation breeding – while critiquing work friendly to Lysenko. An outsiders' perspective on the relationship between the RHS and plant breeding was provided by M.J. Sirks, Professor of Genetics at Government University Groningen in the Netherlands, in 1955. The RHS, claimed Sirks, had long been in the business of clearing up misunderstandings and falsehoods in the horticultural literature. This business was continued, from a 'genetical point of view' and to the 'great credit' of the Society, by cytologist E.K. Janaki Ammal in the RHS laboratories at Wisley Gardens.[57] Ammal was a regular contributor to the RHS journal, where she promoted the value of work on the chromosome and its benefits for plant breeders. 'The number of chromosomes in a plant', she wrote in 1951, 'their shape and other morphological characters seen during germ formation, tell us not merely what is going on in the living plant but also what has happened in the course of its history'.[58] The manipulation of chromosomes using substances like colchicine were seen by Ammal as possessing 'vast' potential for the improvement of 'economic and ornamental plants': vital in a 'world which is yearly finding it more difficult to feed itself.'[59]

The RHS did not only set itself against the graft hybrid by indirect means, such as endorsing the importance of chromosomes and the value of mutation breeding. Lysenkoist thinking in British horticulture could also be tackled by attacking both its philosophical roots and supposed benefits. The opportunity to do just that emerged in 1949, when an English translation of Ivan Vladimirovich Michurin's (1855-1935) *Selected Works* was published by the Foreign Languages Publishing House in Moscow. A review in the RHS journal by M.B. Crane appeared the following year. A self-taught and self-made fruit grower, Michurin was often cited by Lysenko and his followers as the basis of the new 'progressive' Soviet genetics.[60] Crane noted that Michurin discussed the 'influence of the stock upon the scion' and gave an account of his creation of a 'so-called vegetative [graft] apple-pear hybrid' in 1898. Crane was sceptical, arguing that 'I cannot accept this as an example of vegetative hybridisation nor can I find anything in

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[57] Sirks (1955): 216.
[58] Janaki Ammal (1951): 236.
[59] Janaki Ammal (1951): 239.
[60] Crane (1950): 369.

the book which proves there is such a thing as vegetative hybridisation.'[61] Michurin's discussion on the inheritance of acquired characters was also dismissed as 'mainly philosophical' and lacking proof. Yet to Crane's surprise there were 'some accounts in this book which most biologists, at least most of those outside Russia, can accept.'[62] Michurin did not deny Mendelian laws, or their usefulness, but only sought to introduce various amendments and additions to them. For Crane, this level of inclusiveness aroused suspicion. 'One is bound to ask', he wrote, 'whether Lysenko or his colleagues have really been honest with Michurin.'[63]

Despite the best efforts of some members of the Commonwealth Agricultural Bureaux, by the mid-1950s Lysenko – and with him, the graft hybrid – seemingly held no weight at the RHS. Yet if we step forward into the 1960s, we find that there were two clear avenues by which British horticulturalists could be tempted back into the graft hybridization fold: extra chromosomal inheritance and the apparent health of Soviet agriculture. In 1964 John Leonard Jinks (1929-1987), Professor of Genetics at the University of Birmingham, argued that 'No sooner had chromosomal heredity, with its Mendelian laws of inheritance, been defined and techniques for its recognition developed, than exceptions were described.'[64] Such exceptions, according to Jinks, had included the realisation that cell organelles could be passed down by plants using heredity mechanisms which did not involve chromosomes.[65] The following year, *The Times* reported that ongoing experiments from Peter Michaelis (1900–1975), geneticist at the Max Planck Laboratory of Breeding Research near Cologne, had demonstrated 'a form of non-Mendelian inheritance' in plants by altering their morphological characteristics without recourse to their nuclei.[66] This, claimed the Science Correspondent of *The Times*, was the only the latest example of an 'overshadowed' part of genetics with 'a long and respectable history, little related to the extreme position

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[61] Crane (1950): 369. Writing on the inheritance of acquired characters in 1934, Michurin wrote that for 'us fruit growers our entire case [in favour of acquired characters] is usually based on propagation of new hybrid varieties by the vegetative method of grafting or cutting.' Yet Michurin also acknowledged that the heritable changes induced by grafting were slight, echoing the 1925 conclusions of the Edinburgh-based Francis Crew. See Michurin (1952): 54-55.
[62] Crane (1950): 370.
[63] Crane (1950): 370. Crane's suspicions were well-founded. Weiner (1985) situates Lysenko in a much older tradition in Russian biology, stretching back to the mid-nineteenth century.
[64] Jinks (1964): 1.
[65] Jinks (1964): 31-24.
[66] 'Heredity Mechanisms and Evolution' (1965).

adopted by Lysenko and those in Russia who followed him.'[67] Under this wider view of genetics, graft hybrids were entirely possible: although an exact explanation as to why 'phenotypic differences' were 'graft-transmissible' was lacking.[68]

The promises of Soviet agriculture provided another possible source of temptation for growers to embrace graft hybridization. Nothing demonstrates this better than the extraordinary account of a British fruit grower, Ben Tompsett, and his travels through the horticultural landscape of the Soviet Union in May of 1967. Under a 'cultural exchange agreement', Tompsett visited the Soviet Union with the intent of studying commercial-fruit growing. He reported that, despite having previously 'visited the major fruit-growing areas of the world', he had nowhere before seen 'development proceeding on such a scale. The facilities, resources, and vast areas of land available to research and experimental workers are beyond anything I have seen before.'[69] The first stop of Tompsett's visit was the Research Institute of Pomology at Skierniwice in Poland, at the invitation of a Professor Pieniazek. Strawberry production in Poland, Tompsett reported, had boomed from 8000 to 150,000 tonnes per annum from 1950 to 1966. 'The rapid expansion in production' he explained, 'has been due to the introduction of virus-free stocks, which have remained free of virus because the winters are too cold for the vector to survive.' Likewise, apple production had also benefited from the introduction of frost-resistant rootstock.[70] However, none of these techniques, despite their emphasis on the importance of stock-scion relationships and the environment, would have been alien to a British fruit grower.

Tompsett's second visit was to Professor V.A. Kolesnikov, Head of the Horticultural Department at the Timeriazev Agricultural Academy near Moscow. Astonishing statistics were once again heaped upon the foreign visitor: the area devoted to fruit production in Russia had leapt from 1,625,000 acres in 1917 to 8,750,000 in 1966. Yields of fruit had also risen thanks to 'improved methods of cultivation.' Tompsett reported spending much of his time in the rootstock section of the Academy, 'where the emphasis is on the study of root systems and the effect of the

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[67] 'Heredity Mechanisms and Evolution' (1965).
[68] Jinks (1964): 72.
[69] Tompsett (1969): 354.
[70] Tompsett (1969): 355.

Figure 5.2. Lysenko and the Graft Hybrid. Lysenko promotes his botanical productions, which included grafted plants. These graft hybrids had supposedly been created thanks to the insights of Michurin. From Cook (1949): 171.

environment on them, linked with the study of the whole tree.'[71] In other words, the interaction between stock and scion was still a live subject of inquiry, despite Lysenko's fall from grace after the death of Stalin in 1953. Tompsett moved on to visit more institutions and collective farms in Moldova and Ukraine. In the latter, he was intrigued to see the use of hydroponics to grow apples at the State Farm Technicum in the Crimea.[72] Tompsett also visited the Steppe Sub-Station near Simferopol, where 'large-scale production of clonal rootstocks' occurred.[73] The production and distribution of

[71] Tompsett (1969): 356.
[72] Tompsett (1969): 358.
[73] Tompsett (1969): 358-359.

different stocks had not only increased fruit production in the Soviet Union, but had apparently allowed orchards to be grown in what were previously considered to be inhospitable environments. In the North Caucasus, known for dust storms, saline subsoil and extreme weather, the State Farm Krasnoje covered 10,000 acres of land with orchards, vineyards and nurseries, thanks to the use of plant stocks 'able to withstand heat, drought and frost.'[74]

Summarising his visit in an account which appeared in the RHS's journal in 1969, Tompsett was clearly impressed by the Soviet Union as a whole. Forests were preserved, parks and roads were immaculately clean and 'Conditions of employment are not hard.' People had 'freedom to change their jobs and to travel.'[75] Turning back from the wider Socialist project to horticulture, Tompsett was not without criticism, but felt that there was 'a high level of efficiency on the farms' and that new orchards would obtain high yields.[76] Like a number of carefully-handled Western visitors, Tompsett had apparently been won over by the Soviet Union. He admittedly did not express outright support for Soviet biology, nor endorsed graft hybridization as a valid plant breeding technique. Yet Tompsett was clearly taken aback by the scale and productivity of a horticultural system which placed great emphasis on the stock-scion relationship: the essence of graft hybridization. Given his reaction it was perhaps a relief for the RHS, Ammal, Darlington and others that more British fruit growers were not able to venture to the Soviet Union on cultural exchange visits.

The first section of this chapter showed us that graft hybridization had a history of its own well before Lysenko: engaging breeders and botanists from at least the nineteenth century onward. As the travels of Tompsett in the Soviet Union demonstrate, the horticultural infrastructure and institutions which backed graft hybridization continued to flourish and impress after Lysenko's fall from grace. Back in Britain, belief in graft hybridization had stagnated, although the necessary conditions for its existence continued to manifest themselves among amateur horticulturalists. At a 1970 lecture, Hilary M. Hughes, a Regional Fruit Advisor at the National Agricultural Advisory Service (NAAS), noted that 'Insufficient attention is often paid to the choice of

[74] Tompsett (1969): 359.
[75] Tompsett (1969): 361.
[76] Tompsett (1969): 361-362.

the right combination of rootstock/scion'.[77] Amateur gardeners in particular 'demand a large tree and they frequently bud [graft] for the amateur trade, apple cultivars on strong-growing rootstocks' which invariably proved 'entirely unsuitable for garden use.' Hughes claimed this unsuitability stemmed from the amateur gardeners to underestimating the extent to which their chosen stock would invigorate their grafted cultivars.[78] Just because a large and strong stock induced vigorous growth in grafted scions and emerging sports does not mean anything like graft hybridization had occurred. It does, however, indicate why the idea of graft hybridization proved a compelling idea among horticulturalists who were keenly aware of how grafted plants could influence one another. If such powerful and permanent influences could be seen in real-time, it seemed no great leap to assume some trace of such influence might persist across the generations.

There is still no denying that the graft hybrid, despite a few notable exceptions, had been pushed to the margins of British plant science and horticulture by the final decades of the twentieth century. The battle for the heart of heredity and plant breeding had largely been won by those who espoused methods of plant biotechnology such as hybridization and mutation breeding, which were perceived as firmly rooted in Mendelian principles. Support for graft hybridization did persist throughout the latter stages of twentieth century, whether from Lysenko sympathisers at the Commonwealth Agricultural Bureaux in the 1950s or with John Jinks and other geneticists intrigued by instances of extra chromosomal inheritance during the 1960s. Support for graft hybridization among fruit breeders and growers is of course harder to gauge. The impact of extra-chromosomal inheritance and the influence of Soviet horticulture on this community was limited. Yet there does appear to have been a longstanding tradition among British horticulturists and gardeners – from at least the time of Darwin onwards – that placed great emphasis on the stock-scion relationship. The belief that physiological characteristics and/or heritable elements could be transmitted across graft junctions, which persisted throughout the twentieth century, has only recently found the support of mainstream biology.

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[77] Hughes (1971): 223.
[78] Hughes (1971): 223.

## 3. Michurin and McLaren in the Biotech Age

As cytologists and agricultural advisors clashed over the existence and utility of graft hybrids in horticulture during the mid-twentieth century, similar contests were occurring elsewhere in biology. One such instance was recalled by Anne Laura Dorinthea McLaren (1927-2007), zoologist and first female Officer of the Royal Society, at the 1953 International Congress of Microbiology in Rome. At the Congress, McLaren met with Jaroslav Sterzl, a microbiologist at the Department of Experimental Biology and Genetics at the Biological Institute of the Czechoslovak Academy of Sciences in Prague. Sterzl informed McLaren that one of his colleagues, Milan Hašek, had found some unexpected results during his work on parabiosis – when two organisms are surgically attached and share physiological systems such as the circulatory system – in chicks. Intrigued, McLaren and her then-husband Donald Michie approached Peter Medawar (1915-1987), science writer and future Nobel Prize winner, at University College London, who appeared 'very interested' if 'somewhat disconcerted' by Hašek's findings. Medawar subsequently wrote to Hašek and arranged for him to be published in the *Proceedings of the Royal Society* in 1956.[79]

What had Hašek learnt that so disconcerted Medawar, the renowned father of transplantation who both J.B.S. Haldane and Stephen Jay Gould described 'as the cleverest man I have ever known'?[80] Hašek's experiments had involved connecting the circulatory systems of different species of domestic fowl whilst his subjects were still in the embryonic stage. If a turkey and a chicken were grafted together, following their separation, evidence of this connection in the form of foreign blood cells would disappear: a turkey once connected to a chicken, for instance, would lose the chicken blood cells in its system after a matter of weeks.[81] Yet in some turkeys, chicken blood cells were detected for as long as eight weeks following separation. Hašek concluded that their presence could only be explained by the turkey releasing new chicken blood cells into its circulatory system during 'post-embryonic development' making such birds 'interspecific chimera[s].'[82] When Hašek injected chicken blood into these turkey

[79] McLaren (2003): 1425.
[80] Gould (2001): 305.
[81] Hašek (1956): 67.
[82] Hašek (1956): 68.

chimeras, the usual immunological reaction which occurs in the presence of foreign blood did not arise. In Hašek's words, 'Embryonic parabiosis brings about an immunological tolerance which persists for a long time, sometimes perhaps throughout the individual's life.'[83] Contrary to the findings of Galton, it seemed that permanent modifications could be passed on through blood from one organism to another.

Although these findings were interesting – perhaps even worrying – from a medical or ethical point of view, they seem somewhat distant from the world of plant breeding. Just because physiological changes were induced when one plant or animal was grafted onto another did not mean hybridization – similar to that of cell fusion – had occurred. Yet Hašek had originally interpreted his findings through a Michurinist framework, claiming that just as Lysenko had demonstrated the possibility of vegetative or graft hybridization in plants, so his experiments had created an animal graft hybrid through parabiosis.[84] In 1954 Medawar and fellow immunologist Leslie Brent met Hašek and persuaded him that his findings could instead be interpreted through 'acquired immunological tolerance'.[85] This meeting had a profound effect on Hašek: his 1956 paper couched his discoveries in terms of Western immunology and dropped all reference to Michurin, Lysenko or graft hybridization. Despite the conscious reframing of Hašek's results in a style compatible with Western biology by Medawar and Brent, his immunologically tolerant turkey has 'never been adequately explained.'[86]

McLaren, herself a Marxist and member of the Communist Party of Great Britain, did not seek to align Western biology with Czech parabiosis. She instead interpreted Hašek's results in much the same way as he had originally done. McLaren thought that 'combining the characteristics of two strains vegetatively (e.g., by grafting or parabiosis) is analogous to combining them sexually by crossing.' In her view, Hašek's turkey-chicken chimeras were a 'type of vegetative [graft] hybrid', while embryonic parabiosis was effectively 'analogous to combining them [the chickens and turkeys] sexually by crossing.' In her own research McLaren had predicted that heterosis – hybrid vigour – would be observed in mice chimeras, or, as she termed them, 'another

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[83] Hašek (1956): 67.
[84] Hašek originally published his results in two papers in a 1953 Czech journal, which was not accessible to Western biologists. Brent (1997): 192.
[85] Brent (1997): 193.
[86] Brent (1997): 201.

type of vegetative hybrid'.[87] McLaren reportedly felt 'irritation at the neglect of the role on environmental influences' in biology and in 1959 moved to the Institute of Animal Genetics at Edinburgh. As we have seen, the Institute was something of a hub for unorthodox approaches to genetics and had long hosted supporters of graft hybridization. McLaren reportedly found a 'wonderful scientific atmosphere' at the Institute and remained there for fifteen years.[88] She returned to University College London before moving to the Wellcome Cancer Research Centre (later the Gordon Institute) in Cambridge.[89]

Given her Marxist orientation and support for graft hybridization since (at least) the 1950s, it is not altogether surprising to find that McLaren was drawn into the world of plant biotechnology. In the early 2000s Yongsheng Liu, a plant breeder based at the Henan Institute of Science and Technology in China, wrote to McLaren for advice. Liu, who had been 'taught both Mendelian genetics and Michurinist genetics', had been attempting to write an article reviewing the scientific literature on graft hybridization. However, early drafts had been rejected by several journals. Liu recalled that McLaren was sympathetic: 'She knew that there is convincing published literature on heritable changes induced by grafting. She suggested that I write a longer review article, with more of the published evidence.'[90] The end result of their collaboration was a 2006 article in the reputable journal *Advances in Genetics*, which 'reconsiders the subject of graft hybridization in light of our present understanding.'[91] Graft hybridization, Liu declares, 'is compatible with concepts of molecular genetics' and that 'graft hybridization and sexual hybridization can coexist comfortably in the universe of Darwin's Pangenesis and molecular biology.'[92] The paper invokes a number of the historical actors mentioned in this chapter – Darwin, Daniel, Winkler and Michurin – to support the validity of graft hybridization.[93] The paper also draws upon evidence from

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[87] McLaren (2003): 1425.
[88] Franklin (2007): 856.
[89] Franklin (2007): 858.
[90] This account was written by Liu on an online obituary notice: http://www2.gurdon.cam.ac.uk/anne-mclaren.html. Accessed 10/11/17.
[91] Liu (2006): 103.
[92] Liu (2006): 103.
[93] Liu (2006): 105-107.

Lysenkoists from the 1940s to 1970s, including French Michurinists.[94] Ultimately Liu arrives at two key conclusions:

1) *Darwin's pangenesis is our most compelling theory of heredity to date:* In 1865 Gregor Mendel presented his famous paper on experiments in plant hybridization to the Natural History Society of Brünn. Ignored in its own time, Mendel's paper was "rediscovered" at the turn of the twentieth century, with Mendelian genetics subsequently emerging as a cornerstone of modern biology: or so the textbook story goes. Yet Liu argues that Mendelian laws of inheritance are inadequate as they cannot explain how heritable material can cross graft junctions to form graft hybrids: a phenomena which also allows for the inheritance of acquired characters. Our best explanation for graft hybridization, Liu argues, is found by looking beyond Mendel and (re)embracing Darwin's theory of pangenesis. Liu's favoured mechanism for the formation of graft hybrids is messenger RNA: molecules made up of a sequence of nucleotides, which are supposedly capable of travelling between grafts.[95] Liu argues that messenger RNA and Darwin's hereditary particles – gemmules – are analogous. Back in a 2004 paper Liu argued that Darwin's gemmules now have a biochemical basis. In Liu's own words: 'Once most geneticists have recognized the existence of graft hybrids and Darwin's so-called gemmules, Pangenesis needs to be reconsidered.'[96]

2) *We would be better off with a Michurinian take on plant breeding:* As we have seen, the Russian plant breeder and horticulturalist Michurin was one of the key proponents of graft hybridization during the early decades of the twentieth century. Faced with the longstanding problem of why grafted fruit trees produced an inferior crop, Michurin theorised that unreliable fruiting occurred when cultivated trees were grafted onto wild stock: unwanted characteristics were, unknown to horticulturalists, being exchanged across graft junctions.[97] Michurin went on to develop the 'mentor-grafting' method, attaching cuttings from mature fruit trees to the branches of a young seedling, by which

[94] Roll-Hansen (2011): 85.
[95] Liu (2004): 118.
[96] Liu (2004): 120.
[97] Michurin (1949).

he claimed to have developed several graft hybrids. Michurin's work possesses many attractive qualities for Liu: Michurin was a firm believer in the graft hybrid and announced that Mendelian laws – while useful in many aspects of breeding – could not be applied to fruit trees.[98] Liu is also sceptical towards most modern forms of genetic biotechnology, including recombinant DNA technology, protoplast fusion, tissue culture and mutation breeding. He declares that graft hybridization offers the best means of effecting 'quantitative characters' in crop plants, will reduce the amount of time needed to produce new varieties and allow breeders to transfer select genes from 'relatively distantly related species.'[99] In other words, graft hybridization is 'a simple and powerful means of plant breeding' of great practical benefit and can accomplish anything that other forms of plant biotechnology can do.[100]

A combination of the graft hybridization tradition in Britain and China has, quite remarkably, resulted in an overt call for the restoration of Marxist biology and Michurinist plant breeding in the twenty-first century. Unsurprisingly Liu is not without his critics: Nils Roll-Hansen has questioned the historical link between 'Darwin's pangenesis and modern molecular genetics' and criticised the attempted 'rehabilitation of work by Lysenko's followers'. He ultimately labels Liu's history of graft hybridization as a 'long shot' and 'inadequate and misleading.'[101] On the other hand, Liu's work does present us with one example of 'how ideology has constrained the freedom of scientific research in the West.' In the rush to counter Lysenko, 'legitimate scientific work that tasted of the inheritance of acquired characters', including graft hybridization, has been condemned.[102] The graft hybrid has moved from the world of British biomedicine to Chinese plant breeding through the collaboration of Liu and McLaren. More recent events have now moved graft hybrids towards the centre of the controversy over genetic modification (GM) in Europe.

Liu's call for the reinstatement of graft hybridization as a plant biotechnology may well have faded into the scientific wilderness if not for a series of recent findings. In

[98] Michurin (1949).
[99] Liu (2006): 122.
[100] Liu (2006): 125.
[101] Roll-Hansen (2011): 85.
[102] Roll-Hansen (2011): 85.

2009 Sandra Stegemann and Ralph Bock of the Max Planck Institute of Molecular Plant Physiology in Potsdam overturned assumptions that genetic material could not be exchanged between two grafted plants. By generating two varieties of transgenic tobacco with specific genetic markers, they were able to show that chloroplast genes were able to move across the graft junction.[103] Stegemann and Bock claimed that this form of genetic exchange did 'not lend support to the tenet of Lysenkoism that "graft hybridization" would be analogous to sexual hybridization.'[104] Gene transfer between the tobacco plants had only occurred in the area immediate to the graft junction, restricting heritable change to plant shoots emerging directly from the junction. However, Stegemann and Bock argued, their findings did mean that reported instances of heritable changes in plants induced by grafting did 'warrant detailed molecular investigation.'[105] The established tools of the biotech age – recombinant DNA technology and molecular analysis – had been repurposed to resurrect a once discredited means of manipulating the heredity of plants through grafting.

Further work by researchers at the Max Planck Institute and the Department of Molecular Biology at the John Paul II Catholic University of Lublin in Poland brought more intriguing findings. In 2014 experiments grafting transgenic tobacco plants found that 'nuclear gene transfer across the graft junction had occurred.'[106] The transfer was not insignificant. When the cells of plants arising from a grafted parent were examined, they were found to be larger than usual, indicating the presence a large number of chromosomes. While the cells of the parent tobacco plants usually contained forty-eight chromosomes, some of their offspring contained up to ninety-six.[107] Chromosome doubling, a highly-valued goal of many of the biotechnologies discussed in this thesis – hybridization, mutation breeding and cell fusion – had occurred through grafting. 'We have demonstrated', declared the study's authors, 'that grafting results in the transfer of entire nuclear genomes between species.' Grafting, which can occur in nature, therefore presents us with 'a potential asexual mechanism of speciation'. Artificial grafting also provided a new means of creating new crop species through polyploidy,

[103] Stegemann and Bock (2009): 650.
[104] Stegemann and Bock (2009): 651.
[105] Stegemann and Bock (2009): 651.
[106] Fuentes, et al. (2014): 233.
[107] Fuentes, et al. (2014): 233.

thereby conferring 'the superior properties of modern crops over their diploid progenitor species. This has significant potential in breeding and agricultural biotechnology.'[108] Graft hybridization had finally been recognised as a real phenomenon, capable of producing new crop plants.

'We have been accidentally genetically engineering plants – and eating GMOs – for millennia', announced Michael Le Page, a reporter at *New Scientist*, in March 2016.[109] Le Page was referring to recent studies on the movement of genes between grafted plants, including the recent finding by Pal Maliga, at the Waksman Institute of Microbiology of Rutgers University in New Jersey, that mitochondria can be exchanged across graft junctions.[110] Maliga's study now demonstrated that all three genomes present in plants – in chloroplasts, cell nuclei and mitochondria – could move between grafted plants to produce heritable changes. Such exchanges are not simply symbolic vindication of the truth of graft hybridization. Le Page noted that graft hybridization 'could provide plant breeders with new tools to create novel traits and crops. Bock is already trying to use grafting to create new species, such as a tomato-chilli mix.'[111] The transfer of mitochondria across the graft junction also offered a promising development for plant breeders. Grafting now 'offers a way to transfer traits encoded by mitochondrial genes, such as male sterility, to plants that lack them.'[112] As we saw back in Chapter 1, inducing sterility in plants would make it possible to greatly extend the range of crop plants we are currently capable of hybridizing. Le Page clearly envisions a future where graft hybridization plays a prominent role in plant breeding. In this future, however, the graft hybrid is stripped of all its former connections to Lysenko and Marxist biology.

Modern adoption of graft hybridization as a future plant biotechnology does not mean that the technique will finally be stripped of all political connotations. Le Page also quoted Maliga and Bock in his article as stating that 'it is highly likely that some of the plants we eat were created by this kind of unintentional genetic engineering by

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[108] Fuentes, et al. (2014): 235.
[109] Le Page (2016).
[110] Gurdon, et al. (2016).
[111] Le Page (2016).
[112] Le Page (2016).

farmers'.[113] In Britain and Europe, as we shall explore further in Chapter 6, the growing and consumption of transgenic crops is a highly-charged issue. Movement of genes across crop varieties and species is seen by many as undesirable, or unnatural. Le Page has declared that 'The idea that we have been unintentionally modifying plants by grafting will not be welcome to those who like to claim that grafting is very different to genetic modification.'[114] In other words, for as long as humans have been grafting, we have been moving genes between plants to create transgenic organisms. Just as graft hybridization has seemingly emerged triumphant from nearly two centuries of scientific and political controversy, it seems likely that some – whether Liu or Le Page – will seek to plunge the biotechnology back into politicised debate once more.

## Conclusions

The history of graft hybridization presents us with two takeaway lessons, which relate to the broader goals of this thesis. The first confirms the hypothesis developed throughout the course of this thesis: namely that the twentieth-century history of plant biotechnology is far broader and more complex than we might expect. Graft hybridization presents us with an example of a historically under studied form of plant breeding with significant bearings on the transnational history of genetics and heredity. Moreover, to understand the extent and length of mid-twentieth century debates surrounding graft hybridization, it has been necessary to trace its contested history from the mid-nineteenth century. The second lesson involves the innovation and uptake of plant biotechnology. For the majority of this thesis, we have seen how biotechnologies such as industrial hybridization and mutation breeding were embraced by biologists, breeders, farmers and the general public for a number of practical and ideological reasons. Graft hybridization offers us an insight not into what it takes for a biotechnology to gain general acceptance, but what it takes to remove an established biotechnology from agriculture.

During the late-nineteenth and early-twentieth centuries, the reality of graft hybridization was widely accepted among breeders and growers. Charles Darwin found

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[113] Le Page (2016).
[114] Le Page (2016).

numerous examples of what breeders declared to be graft hybrids in 1868, and over sixty years later William Neilson Jones felt the need to counter what he saw as fallacious examples of graft hybridization among horticulturalists. Support for the graft hybrid among both zoologists and botanists became increasingly rare over the course of the twentieth century. The graft hybrid was still an intellectually respectable hypothesis into the 1930s, with its advocates possessing a strong practical and experimental orientation. Yet thanks to the discovery of plant chimeras and general acknowledgment that environmental – especially nutritive – factors play an important role in animal morphology, the graft hybrid hypothesis had already begun to lose popularity among the scientific community by the time it became associated with Lysenko's biology. This long history shows us how graft hybridization was essentially an entrenched form of plant biotechnology within the horticultural and botanical community. The controversy over the graft hybrid in Britain during the 1950s and '60s, which involved established centres of support for hybridization such as the University of Edinburgh, is in part a reflection of this history.

The survival and modern revival of graft hybridization also speaks to the fundamental question of what characteristics are required for a biotechnology to endure. We can all agree that graft hybridization has proven to be a highly resilient form of plant biotechnology. In part this resilience is a reflection of how the graft hybrid has been adopted across a number of different disciplines and domains: horticulture, dog and livestock breeding, botany, cytology, embryology and medicine. This broad uptake is in part because graft hybridization points to the exciting prospect of an unknown mechanism of heredity unknown to Mendelian laws: as noted by actors as diverse as C.C. Guthrie and Peter Michaelis. As we have seen with the case of Anne McLaren and Yongsheng Liu, there is also a strong element of Cold War politicisation to graft hybridization.[115] The persistence of graft hybridization in the Western world and its enthusiastic uptake in the Soviet Union is in part because grafting is a simple and practical method used by amateur gardeners and horticulturalists worldwide.[116] Graft

[115] These political connotations may have led to graft hybridization being widely attacked during the mid-twentieth century, but they may have also contributed to its enduring appeal among those sympathetic to Marxist biology.
[116] A similar appeal was possessed by the use of colchicine in twentieth-century America. See Curry (2014).

hybridization may well have continued to appeal to growers and breeders on a more intuitive level: given what they saw during their daily work in the orchard, it simply made sense that some kind of exchange went on between grafted fruit trees. In a similar manner, Marca Burns argued that the embrace of Lysenko by British farmers occurred because they had never really dropped the idea of the inheritance of acquired characters. Lysenko's theories were just as capable at explaining what they saw in their livestock as Mendelian laws.[117]

In more recent times, graft hybridization has been vindicated thanks to the development of transgenic plants which have allowed us to trace the movement of genes across the graft junction. Its advocates now hope that graft hybridization – what we could well class as a vintage technology – may become a powerful tool in modern plant biotechnology. Yet graft hybridization has also seen its role as political point-scorer revived. Liu wishes to maintain the graft hybrids' Cold War legacy, while Stegemann and Bock would presumably prefer that the graft hybrid lose such connotations and be seamlessly integrated into the world of molecular biology and genetic biotechnology. It is testament to the resilience and potential power of graft hybridization that a plant breeding technique first identified by Charles Darwin in 1868 has now been called upon by Le Page to influence one of the great scientific controversies of our time: the clash over genetically modified crops.

[117] Burns (1952): 86.

# 6. Genetic Modification: A Transatlantic Divide in Attitudes to Nature

> Genetic engineering is the single most important development in biology since Charles Darwin's exposition on the origin of species by means of natural selection in 1859. Both concepts, evolution by natural selection and the modification of genotype to achieve phenotypic goals, have evoked great controversy.
> – Robert Pickard, *GM Crops: Understanding the Issues* (2001).[1]

As noted in the Introduction, the thesis has up until this point placed technological development in the foreground. Public attitudes to plant biotechnology and its uptake in agriculture have, with the odd exception, remained very much in the background. Growers and breeders of crop plants have appeared throughout the thesis, voicing their admiration or concern towards various forms of biotechnology. Yet the voices of the wider public who actually consume the end products of plant biotechnology have been strangely absent, save for a few publicly aired concerns regarding mutation breeding and cell fusion. In this chapter, we will bring public attitudes to the foreground, using a case study of the British GM controversy from the late 1980s to early 2000s. With this change of direction we explore why the British public are so opposed to the transformation of agriculture through plant biotechnology, and why it took so long for this opposition to openly erupt into the public sphere.

One of the most immediate and striking facts about the British GM controversy is that public controversy erupted against a biotechnology largely derived from elsewhere. The latter half of the twentieth century had seen crop plants crossed, irradiated, fused and anatomised in the pursuit of improved agriculture. Yet in the late 1980s the first crop plants altered using recombinant DNA technology, a method largely developed in the United States, arrived in Britain. As the histories of plant cell fusion and graft hybridization have shown us, new genetically modified (GM) crops were –

[1] Robert Pickard, in 'GM Crops: Understanding the Issues', 2001, Bob Fiddaman collection of GM material [hereafter shortened to 'Fiddaman papers'], Science Museum Library and Archives [Wroughton], Box 1.

from a technological standpoint – not especially unique. Yet GM crops were subject to an immense and unprecedented pushback from a wary public. Hostility to GM crops in Britain is an unfolding drama, which has even engaged members of the country's royal family. Genetic engineers, according to the outspoken Prince of Wales, have started what could be the 'biggest disaster environmentally of all time.'[2] His sister, the Princess Royal, has taken the opposite stance, arguing that 'GM is one of those things that divides people but surely if we are going to be better at producing food of the right value, then we have to accept that genetic technology is going to be part of that.'[3]

Against this background, a definitive answer to why consumers in Britain and much of Western Europe turned against GM crops during the course of the 1990s and early 2000s is invaluable. Yet those historians and sociologists who are bold enough to attempt to create this account are faced with a seemingly insurmountable problem: why are attitudes to GM so different in the United States and Europe? In the most general sense, both blocs appear very similar: developed Western nations, with no major variations in technological development or attitudes towards science. This contrast is all the more puzzling if we compare the United States with Britain. Both countries appear culturally close, with Britain once regarded as one of the most promising markets for agricultural biotechnology outside the United States.[4] The situation is rendered all the more confusing by the strong social and economic forces we have seen at work throughout this thesis, which favoured the uptake of radical forms of plant biotechnology in Britain: a sense of economic decline, Malthusian population fears and Cold War technological optimism. Some plant breeding technologies like cell fusion have also had a strong internationalist component, engaging like-minded researchers on either side of the Atlantic. So with these factors in mind, why did the British not accept GM?

Arguments and theories abound. Such is the intractability surrounding the GM debate that some scientists have despaired of the British public, declaring that rejection

[2] Randall (2008).
[3] On 'Farming Today: Princess Anne on Food and Farming Post-Brexit', BBC Radio 4, 23 March 2017. With growing political turmoil and a new wave of plant breeding technologies inbound, public controversy over the growing of GM crops in Britain may well reignite.
[4] Toke (2004): 1.

of GM was the result of 'a witches' brew of anti-science agendas.'[5] A far more acceptable and compelling explanation is found in the history of food safety scares in Britain, with a particular focus upon the BSE (bovine spongiform encephalopathy) – popularly known as mad cow disease – scandal. The argument goes that a succession of food scares in Britain knocked consumer confidence in those charged with food production and the regulatory ability of government and scientists.[6] Other arguments in the fields of sociology and science and technology studies have focused upon the role played by regulatory differences across the Atlantic and the global anti-GM movement.[7] Yet others, including those directly involved with the British GM controversy, have sensed deeper, more fundamental causes at work.

Alan Ryan, head of a GM working party formed by the Nuffield Council of Bioethics, gave voice to these feelings in a 1997 interview with *The Times* newspaper. Ryan recognised that 'anxieties of a kind they [the British public] cannot quite put a name to' generated a general feeling of unease surrounding GM. Philosopher Mary Midgley has argued that the idea of genes crossing the boundary between distantly related species invokes a feeling of disgust in us, or the 'yuk' factor.[8] Yet if this is the case, why did the British consumer feel disgust at genetic engineering in agriculture, while the American consumer did not? Ryan did not address why this transatlantic divide existed, but did admit to being intrigued by the distinction between the natural and unnatural:

> I am deeply curious about what people feel is natural and unnatural and whether it matters and if so how it matters. Why is it that we do not care about some sorts of obvious tinkering with nature, while some tinkering with nature seems to unnerve us? What is behind the unnerving and what can government do to address it?[9]

This chapter provides one possible answer to Ryan's questions. In a sidebar to an article on exotic species in the United States, environmental philosopher Mark Sagoff has argued that very different ideas of what is natural and what is unnatural exist in Europe

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[5] Lachmann (2005): 153.
[6] Ardent support for the role of BSE in the GM controversy is found in Petts, et al. (2001): 35.
[7] For the main example of the former, see Jasanoff (2005). On the latter, see Schurman and Munro (2010).
[8] Midgley (2000).
[9] Midgley (1997).

and the United States. This contrast is a consequence of history, as – surprisingly, given their many similarities – attitudes to nature have developed in very different ways on different sides of the Atlantic. In the United States, wilderness is synonymous with nature. Yet in Britain, which lacks a wilderness tradition, pastoral landscapes and farms are considered to be part of nature. Transgenic crops are therefore seen as interfering with the natural order. These diverging histories now manifest themselves in very different attitudes to GM crops. This chapter subjects Sagoff's claims to historical inquiry and argues that attitudes to nature have played an important role in the British rejection of GM. Although attitudes towards GM crops are extremely complex, cultural attitudes to nature can contribute to our understanding of opposition to transgenic crops.

This chapter begins with a brief account of existing arguments used to explain the transatlantic divide over GM and explains how a renewed focus on cultural attitudes to nature can help supplement existing accounts. In the second section of the chapter, Sagoff's thesis is subject to thorough treatment, particularly his claims regarding the cultural power of wilderness in the United States. Using the British GM controversy as a case study, Sagoff's thesis is then tested in the remaining two sections of the chapter, harnessing public surveys, interviews and previously unexamined archival material.[10] The chapter firstly demonstrates that the British public did consider GM unnatural, or alien, and that this perspective played a major role in their rejection of recombinant DNA technology. It then provides evidence that this stance has deep cultural roots, examining the post-war emergence of British nature conservation and the longstanding pastoral ideal in British culture. This historical analysis lends a level of credence to Sagoff's thesis, revealing that British hostility to GM is in part the result of an established cultural heritage which values a pastoral and – some would say – idealised view of the traditional countryside.

[10] Since 2008, efforts have been made to gather material belonging to scientists, academics, industry, farmers, campaigners and others embroiled in the GM controversy. The end result is an extensive 'GM Archive' housed at the Science Museum's Wroughton site, near Swindon. It is these archival resources that this chapter draws extensively upon (the author having been granted early access to the collection). The archive was originally planned to be global in scope, until it became clear that this was overambitious. The archive therefore confines itself to Britain, where there has been substantial debate over GM crops and 'a large amount of material is available.' Moses (2016): 139.

## 1. Public Opposition to GM: Existing Explanations

As a major political and scientific controversy, the public pushback against GM in Britain, Europe and elsewhere has attracted no shortage of scholarly comment. Rather than attempting to do justice to a vast and ever-expanding literature, this section of the chapter briefly considers four sets of common arguments which may account for the public rejection of GM in Britain, before examining some equally common rebuttals of these arguments. By examining these arguments and counter-arguments, a space emerges for something like the Sagoff thesis – emphasising the importance of our historically-deep, culturally-laden visions of nature – to helpfully contribute to our understanding of why GM was rejected by the British public.

*I. Ignorance and/or rejection of science*

Public rejection of GM has often been blamed on either ignorance of science, or deliberate attempts by those in the media to undermine it. Peter Lachmann, British immunologist and co-producer of the Royal Society's 1998 report on GM crops, has argued that the 'Pusztai affair' – when an experiment suggesting GM potatoes had damaged the health of lab rats was released into the public sphere – demonstrated that 'the GM-food debate had abandoned the arena of scientific discourse for that of a media circus.'[11] Other advocates of GM crops have pointed towards studies which indicate a lack of knowledge of both genetic modification and genetics in general among the public. Molecular geneticist Alan McHughen, an ardent supporter of GM crops, noted that one particularly damning survey found that only forty percent of British respondents knew that conventionally-bred crops contain genes.[12] Others have gone even further, to blame a wider anti-science culture as the reason behind public rejection of GM. Klaus Ammann, head of the Bern University Botanical Garden, was cited in a Monsanto publication in 1997 as stating that the United States 'has a trans-logic spirituality; its culture builds upon science': whereas in Europe 'people have a pre-logic spirituality; we look backward and have a longing for nature as an unharmed

[11] Lachmann (2005): 158.
[12] McHughen (2000): 9.

system.'[13] With such a worldview, it would certainly come as no surprise to find that Europeans would be hostile to biotechnology, or indeed any form of agricultural innovation. These narratives depict the public as uninformed and irrational, bamboozled by scare stories from environmentalist organisations and media groups. This interpretation has very real implications: public attention, at least among some European genetic engineers, has been regarded as harmful to their science.[14]


Figure 6.1. Rejecting GM. A Greenpeace logo portraying GM crops as a risky 'genetic experiment' conducted on consumers and the environment. From Greenpeace International letter, Tait papers, Science Museum Library and Archives, Box 2.

[13] Monsanto, 1997 report on sustainable development including environmental, safety and health performance, Merritt papers, Science Museum Library and Archives, Box 1.
[14] Rabino (1994): 27.

Yet this equation of the public rejection of GM with rejection of science as a whole has been critiqued, not least on the grounds that it gives advocates of GM an excuse to avoid addressing specific concerns about genetic engineering. To avoid awkward questions, researchers or biotech firms may instead cite ignorance or rejection of the scientific enterprise as the primary factor behind hostility to GM. Yet surveys seem to suggest that the public is not hostile to the scientific enterprise as a whole. It is only certain areas of science, including GM, which have faced sustained criticism.[15] Even then, particular uses of genetic engineering seem to attract far less criticism than GM crops. Meta-surveys from the late 1990s show that Europeans were far more supportive of biotechnology for medical purposes, either genetic testing or treatment, than its application to agriculture.[16] It is agricultural biotechnology, a 'seemingly innocuous field', which has become a major source of contention.[17] To put rejection of GM crops down to ignorance or rejection of all forms and applications of biotechnology misses an important point. Farming, food and countryside – not the human body – have proven most impenetrable to genetic engineering.

Despite these problems, overcoming a perceived lack of knowledge became a priority in overturning negative attitudes towards GM in Britain. Following the introduction of GM foods to the UK market in 1996, members of the Institute of Grocery Distribution and Policy Issues Council (IGD/PIC) Biotechnology Advisory Working Group – which included major supermarkets, food manufacturers and even the British Society of Plant Breeders – organised focus groups on GM and concluded that 'consumers had a low awareness and understanding of genetic modification.'[18] GM was confused with existing forms of biotechnology and food processing, including irradiation, cloning and even traditional breeding. However, some members of the focus groups expressed a desire for more information and responded in a positive manner to a basic explanation of how recombinant DNA technology is used in plant

[15] Turney (1998): 3-4. On changing public understanding and engagement with science in the UK, see Gregory and Jay Lock (2008).
[16] Gaskell, et al. (2000): 936.
[17] Newell-McGloughlin and Re (2006): 119-120.
[18] IGD/PIC Biotechnology Advisory Working Group, 'Consumer Attitudes to Genetically Modified Foods: Results of Qualitative Research', Merritt papers, Science Museum Library and Archives, Box 1. The IGD is a charitable body founded by grocery retailers. The PIC is one of its working groups, where industry leaders discuss strategic challenges.

breeding.[19] Such feedback doubtlessly reinforced the belief that basic communication of scientific principles would overthrow public resistance to GM. The latest manifestation of this belief in Britain can be found in a recent policy project conducted on GM plants by the Royal Society, which was released in May of 2016. [20]

It may well be the case that information and education can change the attitudes of those formerly sceptical of GM. Yet the wider claim that the British public is somehow uninformed, or holds anti-science beliefs, seems like flawed reasoning. When applied to the GM controversy, for instance, this claim raises more questions than answers. If true, we might expect the years of information released by bodies such as the Royal Society to the public to have resulted in a radical shift in attitudes to GM. Ignorance or mistrust of science and scientists also fails to account for the different attitudes displayed towards GM in different contexts: why is genetic engineering accepted in the medical laboratory, but not on the farm? It seems that attitudes towards the use of GM in food and agriculture are more charged and negative than elsewhere. This fact alone indicates that cultural attitudes to nature, or what belongs on the farm and what does not, must figure in our understanding of the British rejection of GM.

### *II. Food scares*

One of the more compelling explanations for British rejection of GM is the turbulent history of twentieth-century food safety scares. As we saw back in Chapter 1 of this thesis, Britain experienced a post-war drive for agricultural production. This may have resulted in 'cheap and plentiful food', but came at a cost in terms of reduced 'food quality and [growing] environmental concern.'[21] By 1988 British attitudes to food were reliant on the so-called 'managerial myth', the commonplace idea that government and

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[19] IGD/PIC Biotechnology Advisory Working Group, 'Consumer Attitudes to Genetically Modified Foods: Results of Qualitative Research', Merritt papers, Science Museum Library and Archives, Box 1. The explanation consisted of a 'concept board' and the following paragraph: 'Plants contain hundreds of genes. Genes are like the instructions in a recipe book. This plant has got a gene which makes it resistant to insects. You can select a desirable gene from one plant and transfer it to a second plant. The second plant is now modified so that it is resistant to insects. So you are moving a gene from one plant that has it naturally, to a second plant that doesn't normally have it.'

[20] See https://royalsociety.org/topics-policy/projects/gm-plants/.

[21] Marie Roslyng (2011): 163.

other authorities were fully capable of ensuring food safety: hence the tremendous damage caused to the agricultural industry when, in 1988, Junior Minister Edwina Currie said in a televised statement that most egg production in Britain was badly affected by salmonella. A collapse in confidence and egg sales followed.[22] Salmonella in eggs was only the first of a number of food safety scandals to rock post-war Britain. These scandals undermined the managerial myth and made consumers far more sceptical of their food, how it was produced and existing safety standards.

When referring to the impact of these scares upon public attitudes to GM, however, the most significant and commonly cited example is that of the BSE scandal.[23] 'Within a decade', wrote American bioethicist Gregory Pence, 'Europeans and especially the English went from a gullible trust in their food system to a deep cynicism.'[24] The British government faced heavy criticism over its handling of the BSE crisis. Its priority was public reassurance, not protection: an attitude which moved officials' priorities from protecting the public to protecting industry.[25] It is undeniable that BSE marked a profound shift in how Britons thought about their food.[26] A lengthy study of British consumers by the Media Research Unit at the University of Glasgow indicated that 'attitudes to food have been radically altered by the BSE crisis'.[27] A member of a Bristol-based focus group interviewed for the study summarised participants' feelings:

> 'Nothing will ever be the same again, I think, we are now in a post-BSE world and that means that what you may have ignored or not thought much about before has become central… and I don't just mean about the actual food, I think this issue highlighted quite radically how our political institutions work and who they are most concerned about, and what came out is that this isn't us [the consumer].'[28]

Yet criticisms have also been directed at the simplistic linking of anti-GM feeling with earlier food scares. The Glasgow Media Research Group also found that the salmonella

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[22] Marie Roslyng (2011): 163.
[23] Petts, et al. (2001): 35.
[24] Pence (2002): 51.
[25] Blay-Palmer (2008): 96.
[26] Scepticism of traditional authorities' ability to manage GM is not confined to Britain. A 1997 survey of European consumers revealed that industry, political parties and even universities were not trusted to 'tell the truth' about GM food. By contrast, environmental and farmers' organisations were rated highly. Bauer, et al. (1997): 846.
[27] Reilly (2006): 208.
[28] Reilly (2006): 216.

in eggs scare was 'seen most clearly as a cooking or storage problem', and there 'was no real sense in which it was perceived as being a problem of industrialised agriculture.'[29] The dialogue and sense of blame surrounding food scares has therefore differed from one case to the next. When it came to GM crops, a lack of choice, issues of 'unnaturalness' and economic implications permeated discussions among focus groups.[30] Industrialised agriculture and its imposition on consumers took centre stage. While the BSE scandal may have led the British public to mistrust official pronouncements on the safety and utility of GM, it does not explain why the public chose to resoundingly reject GM as a particular method of plant breeding.[31] Moreover, GM crops not intended for food – but for pharmaceutics or fuel, for example oilseed rape – did not escape controversy. This would indicate that the very existence of GM crops, rather than just their use in food – sparked controversy.

Multiple studies show that food scares were a significant force in the British GM controversy. However, it is questionable to what extent food scares were the primary, driving factor in the rejection of GM: not least because all GM crops were criticised by Britons for a whole range of reasons, whether they were destined for the dinner plate or not. Furthermore – as Section 3 of this chapter explains in more detail – surveys seemed to indicate that food scares and the BSE scandal grew in prominence as reasons to reject GM among the British public grew over time. By the early 2000s, government mismanagement of BSE was the most common justification given by respondents for their rejection of GMOs.[32] Public hostility to GM in Britain did not emerge from a twentieth-century history of food scares. Instead, these scares – and the failure of government to handle them – were introduced as another reason to reject GM at a later date. It is therefore pertinent to look to the early years of the GM controversy, at a time when issues of what was natural and unnatural, native and alien, were live issues among members of the British public.

[29] Reilly (2006): 223.
[30] Reilly (2006): 223.
[31] Toke (2004): 63-64.
[32] Petts, et al. (2001): 35.

*III. National politics*

Although the transition of recombinant DNA technology from the laboratory to agriculture was by no means a simple feat, in the United States the uptake of agricultural biotechnology was aided by 'friendly' intellectual property laws and regulation.[33] Yet in Europe, the situation was perceived as being very different. A 1986 conference on the prospects for biotechnology in Europe held at the Wembley convention (just outside London), saw leading figures in the world of genetic biotechnology air their concerns. Interviewers from the *Bio/Technology* journal encountered both optimism and scepticism from leading European scientists and industrialists. One example of the latter was Gerard H. Fairtlough of Berkshire-based Celltech Ltd. Fairtlough considered biotechnology an enterprise unique to specific areas of the United States, such as California and Massachusetts. Not only did Europe lack an 'enterprise culture', but links between industry and universities were not well developed, despite a high density of 'scientific resources' in Europe, including major research institutions.[34] Yet far more pressing to other attendees were the political complexities associated with biotechnology in Europe and the continents' restrictive regulatory policies.

Salomon Wald, director of the Organisation for Economic Co-operation and Development's (OECD) Biotechnology Unit was wary of European food and health markets. Both were 'totally dominated by political concerns' and 'privileges'.[35] Bringing biotechnology to European growers and consumers was generally considered a political, rather than economic, matter by the Wembley gathering. Robbert A. Schilperoot, from the University of Leiden's Department of Plant Molecular Biology, was irritated by what he perceived to be key political shortcomings. Europe lacked an 'open and free market… uniform regulatory regimes' and a 'good patent policy'.[36] In 1991 the NIAB's R.J. Jarman and A.G. Hampson attempted to explain the patenting challenge faced by producers of

[33] Curry (2016): 11.
[34] McCormick and Dixon (1986): 772.
[35] McCormick and Dixon (1986): 772.
[36] McCormick and Dixon (1986): 773.

GM crop plants to members of the Institute. Patents were already available in Britain for bacteria, yeasts and 'microbiological techniques including genetic components'.[37] Yet plants were another matter. Patenting could not apply to plants, as classical breeding techniques could not 'repeat the results of a breeding programme from a written specification and produce the same variety'.[38] GM varieties were considered under the same criteria. European patent protection was simply 'less good for the biotechnology inventor' than those of Japan or the United States.[39]

The 1986 conference represented an outpouring of frustration from those in the biotech industry at the complexities of politics and intellectual property faced by their community in Europe. During the 1980s a 'distinctively European form of politics and policymaking took shape', in contrast to the 1970s when 'U.S. biotechnology policy led Europe's'.[40] Molecular biologists and members of biotech firms had clearly not taken to this change of tack, arguing that European political attitudes, intellectual property laws and regulation dampened innovation in biotechnology. Sheila Jasanoff, based in the field of science and technology studies, has argued that state policies towards biotechnology reflected attempts at 'nation-building' or 'reclaiming nationhood at a critical juncture'.[41] These different national identities and the policies derived from them led to different attitudes towards GM in different countries. In Britain the Thatcher government sought to harness a 'rising green sentiment' prior to the 1988 election, partly by altering the regulatory procedures governing the release of agricultural biotechnologies. Thus research on GM bacteria during the late 1980s moved with considerable caution: involving 'small, incremental steps' and moving to reassure the public through consultation with environmental groups, notices in newspapers and information films.[42]

Jasanoff argues that political portrayal of the release of GMOs as a process 'deserving special concern' had a number of consequences, highlighting the unpredictability of field experiments, the lack of accountability for their consequences

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[37] Jarman and Hampson (1990): 161.
[38] Jarman and Hampson (1990): 161. Crop plants were instead covered under Plant Breeders' Rights, which in the case of cereal varieties, granted monopoly protection for twenty years.
[39] McCormick and Dixon (1986): 775.
[40] Jasanoff (2005): 5.
[41] Jasanoff (2005): 7.
[42] Jasanoff (2005): 101-102.

and scientists' growing hostility to the regulatory process.[43] Alteration of regulatory procedures during the 1980s also altered how the public would be informed and reassured when GM crops were released into agriculture. In Britain, 'expert judgement' was called upon to assure the public that GMOs posed little risk, in contrast to the United States where it was claimed that "science" had demonstrated that GM was safe.[44] As we have already seen, public opinion on experts in food and agriculture deteriorated rapidly in Britain following the BSE scandal. Likewise, expert judgement on the safety of GM crops would be greeted with a similar degree of scepticism. A picture therefore emerges of Europe as a place where biotech firms and molecular biologists struggled to do business, with the biotech community lashing out against what they perceived as restrictive regulations, poor intellectual property law and obstructive politics.

Can political systems and manoeuvring therefore be blamed for the British rejection of GM? Political and regulatory systems certainly led to GM being viewed in a less-than-favourable light by a public increasingly sceptical of expert pronouncements on food and environmental safety. However, we must still consider initial public reaction to GM and why much of this reaction was framed in negative terms, even before the BSE scandal reached its peak. Cultural attitudes to nature and the power of the pastoral ideal present us with one possible explanation. Jasanoff has noted that the 'theme of nature's unpredictability' played a major role in 'official British policy' towards GM on the farm.[45] She speculates that this may be 'a legacy of Britain's colonial past', in which the transfer – deliberate or unwitting – of plants and animals across the globe had 'unpremeditated and unpredictable' consequences.[46] Even when we closely examine the inner workings of twentieth-century British politics, there still remains a sense that deeper, more fundamental historical factors were also at work in the British rejection of GM.

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[43] Jasanoff (2005): 112.
[44] Jasanoff (2005): 117.
[45] Jasanoff (2005): 57.
[46] Jasanoff (2005): 57.

*IV. The 'yuk' factor*

Back in Chapter 1, we saw how hybrid plants were initially treated with a degree of hostility by those who considered their creation and existence unnatural or impious. Such feelings are not some relic of centuries gone by. As we saw in Chapter 3, similar controversy was aroused in the twentieth century by cell fusion. Hybrid animal cells raised fears that unnatural chimeras, biological slaves, or "super soldiers" would be the end result of scientists tampering with life. Why such fears emerge is also a question pertinent to the GM controversy. Mary Midgley has argued that the idea of genes crossing the boundary between distantly related species invokes a feeling of disgust in us, or what she terms the 'yuk' factor.[47] Genetic biotechnology is not 'compatible with our existing concepts of nature and species', as new advances in genetic engineering envisage 'species as unreal and nature as infinitely malleable.' [48] GM therefore threatens long-established and dearly held concepts of species fixity. Similar argument has been put forward by Ernst Mayr and Stephen Jay Gould, who argued that the notion of fixed species leads to difficulties in understanding the theory of evolution.

Midgley goes on to argue that it is misleading to divide those who object to GM into those who think it intrinsically wrong versus those who consider its consequences unwanted or dangerous. In the GM controversy, both sets of objections – emotional and rational – work side by side. For instance, recombinant DNA technology can be objected to on the grounds that it leads to a view of organisms as machines and allows the biotechnologist to play God. These upsets, at once concerned with questions of the natural and fears of real-world consequences, lead Midgley to argue that those opposed to GM are 'moved by strong emotion and not necessarily being merely irrational and negative.'[49] The 'yuk' factor presents us with two areas of reflection. Firstly, seemingly rational objections to GM – based on political leanings, mistrust of authorities following the BSE scandal and so on – may work in tangent or be the result of instinctive revulsion at the technology. Secondly, we must consider the possibility

[47] Midgley (2000): 8.
[48] Midgley (2000): 15.
[49] Midgley (2000): 15.

that revulsion towards GM is innate, rooted deep in either human psychology or culture.

A historical explanation for instinctive rejection of transgenic technology is offered by Keith Davies of the Entomology and Nematology Department at IACR-Rothamsted.[50] Like Midgley, Davies argues that the Western world has traditionally perceived species as fixed entities: a worldview which originally stems from the philosophy of Plato and Aristotle. In the case of the GM controversy, Davies argues that a shared conception of species as distinct and fixed means that the idea of transferring genes between species is abhorrent to many. This essentialist view of life supposedly suffered a blow with the coming of the Darwinian age. Davies claims that Darwin's 'population thinking' emphasises the uniqueness of organisms while reducing the species to a 'statistical abstraction'. After Darwin, 'holistic thinking had to change its form to survive', re-emerging in the shape of vitalism and anti-reductionism.[51] Thus two millennia of established thought, albeit somewhat upset by the arrival of Darwin, supposedly influence our attitudes to GM.

Longstanding instinct or historical values give us one possible explanation for the widespread rejection of genetic engineering. Davies claims that Greek essentialism explains why a 'significantly large number of educated people believe that moving genes around between species is intuitively wrong'.[52] This argument certainly helps to explain ethical resistance to both hybrid plants and cell fusion. Yet Davies's history of biological thinking fails to account for the different attitudes to GM in Europe and the United States, which presumably share the same Greek essentialist heritage. A similar problem is also faced by Midgley's 'yuk' factor. If it is the case that GM and the breaching of the species barrier invokes disgust on some instinctive level, why is it the case that some feel this disgust and others do not? There must be more recent factors at work which mean that the British consumers feel disgust at genetic engineering in agriculture, while the American consumer does not.

Both Midgley and Davies appear to step too far back to account for different perceptions of GM in different nations. To fully account for the British rejection of GM,

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[50] Davies (2000); Davies (2001).
[51] Davies (2000): 135.
[52] Davies (2001): 424.

an explanation is needed which is rooted in more recent – relatively speaking – history. This explanation must, on the one hand, account for distinctive public attitudes to GM on either side of the Atlantic. It must also account for why GM crops are so fiercely challenged in Britain. Sagoff's thesis claims to do exactly that.

## 2. Attitudes to Nature in Europe and the United States

In a 1999 report from the Institute for Philosophy and Public Policy at the University of Maryland, Sagoff addressed the European exclusion of GM crops as part of a larger discussion on attitudes towards exotic species. Sagoff noted that while Europe has imposed a '*de facto* moratorium' on GM crops, Americans 'regard with near indifference the conversion of the nation's farmland to GM corn and soybeans.'[53] Sagoff attempts to explain contrasting attitudes to GM in the Old and New worlds by invoking different cultural attitudes towards nature. In the United States, there has been a sharp turnabout in attitudes towards wilderness. When the first European settlers found themselves in the Americas, their attitude towards their environment was infamously hostile. The frontier of unconquered wilderness was pushed back, before disappearing entirely. Yet during this time, romantic visions of untouched nature emerged, exemplified by areas of natural beauty such as Yellowstone and Yosemite.[54] Untouched nature and the idea of wilderness is what Americans consider natural. By contrast, 'farms do not belong to Nature but to commerce and industry.'[55]

This 'splitting off' of farmland from nature in the United States is backed by leading environmental historian William Cronon in his classic 1996 article on the American wilderness. Cronon has argued that wilderness is a relatively recent cultural invention, created by urban elites who had never had to work the land for a living. In fact, there was 'nothing natural about the concept of wilderness at all', with the movement to set aside 'virgin' or uninhabited land for national parks and wilderness

[53] Sagoff (1999): 10.
[54] Here Sagoff cites historian Perry Miller in full: 'The more rapidly, the more voraciously, the primordial forests were felled, the more desperately poets and painters — and also preachers — strove to identify the personality of this republic with the virtues of pristine and untarnished, of "romantic", Nature.' Miller (1956): 207.
[55] Sagoff (1999): 11.

areas displacing Native American populations.[56] Regardless, wilderness areas are now seen as means to escape the stresses and artificiality of modern life and enjoy nature. Cities, suburbs and farms are therefore no longer seen as part of nature. In fact, Sagoff declares that in the United States, GM is even seen as a positive step for the environment, as intensifying agricultural production will leave more space for wilderness.[57] This positive was unsurprisingly embraced by Robert Horsch of the chemical giant-turned-biotech firm Monsanto. In a paper published by the UK's Royal Society, Horsch announced that 'the more productive we can be with good crop land, the less natural habitat (which is usually poor farm land anyway) will need to be cleared and ploughed for farming.'[58]

Yet this interpretation is a clear oversimplification of complex attitudes towards nature and wilderness in the United States. As Cronon himself has stated, the idea of wilderness 'is a more problematic part of our environmental politics and cultural values than we commonly recognize.'[59] Historians therefore 'enter difficult waters when they seek to explore the deepest of human cultural values, those grounding principles and faiths so central to people's collective and personal being that we label them with words like Nature or God.'[60] Sagoff's vision of wilderness can therefore be critiqued on a number of grounds. Wilderness takes on a myriad of meanings in the United States and is not confined to pristine national parks. Some wilderness devotees have defined wilderness not as untouched land, but where 'human intrusion is [only] relatively unnoticeable'.[61] Others have argued that wilderness is something that can be repaired and restored.[62] Although the cultural attitudes described by Sagoff are undoubtedly oversimplified, it is undeniable that wilderness has acted as an important social and cultural force in American ideas about nature.

[56] Cronon (1996): 16. For Cronon's immediate response to critics of his article, see Cronon (1996a).
[57] Sagoff (1999): 11.
[58] Horsch (1993): 288.
[59] Cronon (1996a): 47.
[60] Cronon (1996a): 54.
[61] Hays (1996): 30.
[62] Hall (2001).

By contrast, Sagoff argues that 'the idea of pristine nature has little spiritual or cultural force' in Europe. A wilderness tradition is therefore not present in Britain.[63] Hence there is no conflation of wilderness and nature as one and the same. Instead the British image of nature might include somewhere like the Lake District, in northwest England. Famed for its natural beauty, the Lake District is nonetheless a managed landscape, with herds of sheep owned by local farmers grazing its hills.[64] For Sagoff, this 'bucolic landscape' where 'wildflowers, trees, and shrubs grow harmoniously with crops' alongside farmers and livestock, is exemplary of the wider European idea of nature. The natural landscape is synonymous with benevolent human management. Farms, at least those perceived as being in harmony with the surrounding landscape, are therefore part of the natural order. This pastoral vision leads Europeans to reject the application of the so-called 'technological treadmill' to agriculture. Attempts at agricultural improvement have been greeted with disdain and attacked as an assault on nature. Sagoff's thesis concludes that 'Europeans regard GM crops as the last stage in this process: the eradication of nature, or everything lovely and worth protecting about it, in the name of improved agriculture.'[65]

The thesis offered by Sagoff is appealing on a number of fronts. Its potential explanatory power is huge, offering a historical narrative underpinning negative attitudes to GM in Britain while explaining different attitudes to GM on a transnational scale. But does Sagoff's thesis fall under the remit of historians? Can it be tested through historical case studies and sources? This chapter argues that the Sagoff thesis can be subject to historical analysis, by identifying a series of criteria which must be present in British history if Sagoff's thesis is to be accepted as true and applicable. If British farmland and "nature" are truly synonymous, we would expect to find that GM crops would be considered unnatural or alien. Moreover, rejection of GM crops on these grounds would be a major factor in public hostility to GM. Other factors, including concerns over food safety, would play a lesser role or only become significant at a later

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[63] Sagoff (1999): 11. There are signs that wilderness may be acquiring 'greater purchase' in Britain, as organisations such as the John Muir Trust experience a rapid growth in membership. See Coates (2006): 25-26.

[64] Some recent studies on the Lake District as a foundational site of British environmentalism and sustainable thinking include Ritvo (2009); Hess (2012); Albritton and Albritton Jonsson (2016).

[65] Sagoff (1999): 11.

stage of the GM controversy. According to Sagoff, we should also find a general aversion among Britons to intensification, technological development, or any other trend threatening pastoral ideas of agriculture. Finally, the pastoral ideal would be a clear force in British history and culture, despite huge changes to farming practices since the Second World War.

## 3. Natural vs. Unnatural? British Perspectives on GM

In 1987 the UK's Economic and Social Research Council (ESRC) submitted a report to the Royal Commission on Environmental Pollution. The Commission, chaired by Lord Lewis of Newnham, was considering the impact of GMOs on the environment for its latest report. The ESRC had attempted to gauge public attitudes to the release of GMOs by collating a series of surveys and studies: all provided unambiguous results. A 1985 qualitative study had discovered that participants 'invoked profound moral judgements' against scientific 'interference' with nature.[66] Sample responses ranged from GM being cast as 'unnatural' to 'I don't think you should mix science things with food.'[67] Quantitative surveys found the same objections. Of some two hundred interviewees, seventy percent thought genetic engineering morally wrong and sixty-two percent thought it unnatural: by contrast, only twenty-seven percent found the technology 'frightening'.[68] The ESRC summarised its findings:

> It would seem that genetic engineering is not yet a major issue of popular public concern. Levels of knowledge are likely to be low – positive attitudes [towards GM] are related to the desire to explore potential benefits, negative attitudes are associated with unfamiliarity, beliefs about unnaturalness and novelty.[69]

[66] Economic and Social Research Council submission [hereafter abbreviated to ESRC] to The Royal Commission on Environmental Pollution: the release of genetically engineered organisms to the environment, Tait papers, Science Museum Library and Archives, Box 11.
[67] ESRC submission to The Royal Commission on Environmental Pollution, Tait papers, Science Museum Library and Archives, Box 11.
[68] ESRC submission to The Royal Commission on Environmental Pollution, Tait papers, Science Museum Library and Archives, Box 11.
[69] ESRC submission to The Royal Commission on Environmental Pollution, Tait papers, Science Museum Library and Archives, Box 11.

This statement provides us with a glimpse of British attitudes to GM prior to the great controversies of the 1990s. Participants in the ESRC studies clearly thought GM was unnatural, though fewer were concerned about potential dangers. The Royal Commission on Environmental Pollution released its first report on GM in 1989, which clearly considered GMOs to be "alien" or "exotic" introductions to the British countryside. To imagine the potential environmental impact of a GM plant or animal, the Commission considered the effects of non-GM releases. Although these did 'not necessarily provide an exact analogy', their 'effects helps [us] in understanding and anticipating the potential impact of GEOs [genetically engineered organisms] on the environment.'[70] The resulting roll call of exotic introductions produced by the Committee was not likely to inspire confidence in introduced GM crops:

> 4.17 An example of a controversial exotic which has altered the landscape is the spread of *Rhododendron ponticum* in woodlands and on heaths in the UK… threatening many native species and bringing about a loss of diversity of native plants and animals.
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> 4.18 Another example is Dutch elm disease. The introduction of a particularly virulent strain of this fungus, probably from America, has progressively killed most of the UK's large elm trees (*Ulmus* species). The loss of these elms has markedly affected the appearance of much of the British landscape.[71]

The list of ecological villains went on and on: the predatory Nile perch (*Lates niloticus*) in Lake Victoria, rabbits in Australia and parasitic wasps in Hawaii.[72] The juxtaposition of GM plants and animals with exotic species provided an attractive (if not flawless) model for British ecologists. A short booklet published by the British Ecological Society in 1993 considered the environmental implications of GM crops. Maybe the new arrivals would act similarly to 'traditional agricultural [crop] varieties, and pose little new risk to the environment.' Or perhaps GM crops would possess 'sufficiently different phenotypes

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[70] Royal Commission on Environmental Pollution. Thirteenth report. The release of genetically engineered organisms to the environment, 1988/89, Parliamentary Papers Online [hereafter referred to as PP], Cm 720, p. 20.

[71] Royal Commission on Environmental Pollution. Thirteenth report. The release of genetically engineered organisms to the environment, 1988/89, PP, Cm 720, p. 21.

[72] Royal Commission on Environmental Pollution. Thirteenth report. The release of genetically engineered organisms to the environment, 1988/89, PP, Cm 720, pp. 21-24.

that they cannot be regarded as varieties of native species, but rather as exotics.'[73] The Society argued that if GMOs were sufficiently different, they could well act as another wave of invasive species. GM crops could persist in fields as 'arable weeds', displace wild plants or transfer genes to 'related crops or wild species'.[74]

Concern that GM was somehow unnatural could also be found among members of environmentalist organisations during the late 1980s and early 1990s. From 1989 to 1991, an ESRC-funded project entitled 'Risks of Biotechnology and their Regulation' ran under the management of Professor Joyce Tait. Academics on the project interviewed members of Greenpeace and Friends of the Earth in the Edinburgh area. From the outset of these interviews, it was clear that neither organisation had yet considered GM as a major environmental issue. When questioned, a member of Greenpeace stated that GM was 'not something people would see as a priority environmentally.'[75] A member of Friends of the Earth noted a 'curious absence of comment at least in Friends of the Earth magazines that I've read in England and Wales or Scotland on any reference to biotechnology or genetic engineering.'[76] Contrary to what we might expect, there were even hopes from one member of Greenpeace that GM could be used to help the environment:

> I can see one of the advantages of having genetically engineered crops… the idea is that you don't need to use chemicals to combat pests. A crop that is genetically engineered aught not to suffer from pests and diseases or whatever so that's obviously as far as Greenpeace might be concerned a good point.[77]

Yet the unnaturalness of GM crops and their introduction to the British landscape proved a sticking point. As one interviewee described it, 'I think the main worry is that they're not natural, they haven't evolved like everything else has, it doesn't fit in.'[78] The

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[73] Shorrocks and Coates (1993): 9. Intriguingly, the authors of the British Ecological Society booklet were not against the concept of genetic engineering. In fact, they did not concern themselves much with genes at all. When it came to releasing new organisms into an environment, 'it is the phenotype of the organism that matters, not how it was made.' Shorrocks and Coates (1993): 36.
[74] Shorrocks and Coates (1993): 24.
[75] Greenpeace interview, 8 May 1991, Tait papers, Science Museum Library and Archives, Box 10.
[76] Transcript of meeting with Edinburgh area members of Friends of the Earth, Thistle Hotel, Manor Place, Edinburgh, 29 May 1991, Tait papers, Science Museum Library and Archives, Box 10.
[77] Greenpeace interview, 8 May 1991, Tait papers, Science Museum Library and Archives, Box 10.
[78] Greenpeace interview, 8 May 1991, Tait papers, Science Museum Library and Archives, Box 10.

alien nature of GMOs to ecosystems was a matter of concern, just as it had been a few years earlier in the Royal Commission on Environmental Pollution's report. One Greenpeace member felt that predicting the environmental impact of GM was problematic. As history had shown, 'introducing different species to different areas of the world, like rabbits to Australia' could be disastrous, as 'you can't foresee the consequences. It's the same for genetically engineered things, isn't it?'[79] Attitudes to GM were more or less identical among participants at a Friends of the Earth meeting in 1991:

> I'm not worried about the actual plant side of things, I don't think I'm particularly worried about the danger of producing unfortunate mutations through genetic engineering of animals really, but I feel that it's just that, it's almost an aesthetic thing. I'm happier with what's natural and we've got already.[80]

It is clear that, at least among some British environmentalists and nature enthusiasts, GM crops were linked to wider concerns about alien species. Environmental historian Peter Coates has compared 'saboteurs snapping the stalks of genetically modified corn' to 'parties of native plant enthusiasts… bashing away at Himalayan balsam along British riverbanks.'[81] Coates does not endorse Sagoff's interpretation of the GM controversy, but does acknowledge that 'the juxtaposition of native and non-native species is far from alien to British conservation debates.'[82] The alignment of GM crops with non-native species is clearly detrimental to British acceptance of GM. While Americans also possess an aversion to non-native exotics, GM crops produced by US biotech firms do not seem to fall into this category.

As the debate over GM raged in Britain during the course of the 1990s, there were no signs that public perceptions of GM as unnatural had changed. Public surveys conducted in southwest England from 1998 to 2000 revealed 'an intuitive unease about

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[79] Transcript of meeting with Edinburgh area members of Friends of the Earth, Thistle Hotel, Manor Place, Edinburgh, 29 May 1991, Tait papers, Science Museum Library and Archives, Box 10.
[80] Transcript of meeting with Edinburgh area members of Friends of the Earth, Thistle Hotel, Manor Place, Edinburgh, 29 May 1991, Tait papers, Science Museum Library and Archives, Box 10.
[81] Coates (2006): 25.
[82] Coates (2006): 25-26. The hostile language directed at "alien" species has uncomfortable connotations, which can make some minority groups uneasy about nature conservation. See Smout (2011): 61. Despite recent shifts in British politics, Sagoff's thesis at least offers the hopeful message that Britons share a deep cultural affiliation with their European neighbours.

moving genes between species.' Several respondents contrasted traditional breeding methods with GM: the latter a means for scientists to play God, 'messing around' or 'tampering' with nature.[83] A meta-survey of European opinion – published in *Nature* in 2000 – showed that some ninety percent of respondents agreed with the statement that GM foods 'threatened the natural order' and, despite offering some benefits, 'was fundamentally unnatural.'[84] Yet a major shift in attitudes towards the risks associated with GM had occurred. Over eighty percent of the European public thought that GM presented an unacceptable risk and posed a danger to future generations.[85] Surveys conducted within Britain indicate that by the early 2000s, the prime factor for consumer rejection of GMOs was government mishandling of the BSE crisis.[86]

What we can take from these cases is that the British public, including members of environmental organisations and royal committees, were initially sceptical of GM crops on the grounds that these organisms were unnatural or alien to the British landscape. The British regard their countryside as natural and aesthetically pleasing. Changes to this landscape via the planting and growing of GMOs are unwelcome, particularly given existing suspicion surrounding the detrimental ecological effect of introduced or invasive species. Other issues, such as health risks and mistrust of government, only emerged as the primary factors in British rejection of GM after years of controversy. This outcome fits with the Sagoff thesis: clearly GM was seen as a form of interference in nature and specific safety concerns only emerged as a major force some years after GM was first trialled in Britain.

Yet this observation alone is not enough to confirm Sagoff's thesis. A feeling that genetic engineering is unnatural or immoral could also be taken as evidence of the 'yuk' factor, religious objections or public suspicion of science. What we need is evidence that a particular view of what is and is not natural exists in Britain. According to Sagoff, this should revolve around the pastoral landscape, a concept supposedly integral to European conceptions of nature. In the following section, this chapter therefore moves on to examine the twentieth-century history of the British conservation movement and

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[83] Shaw (2002).
[84] Gaskell, et al. (2000) 937.
[85] Gaskell, et al. (2000) 937.
[86] Petts, et al. (2001): 35.

more recent evidence of the pastoral ideal in British thought. This investigation tests two of Sagoff's claims: firstly, that a natural and worked landscape are one and the same in Britain and secondly, that the British are highly sensitive to technological developments seen to threaten traditional conceptions of agriculture.

## 4. The Pastoral Ideal and the British Imagination

Can we draw meaningful parallels between the well-established British conservation movement and GM protest groups? If British hostility to GM crops does stem from deep cultural values aimed at preserving the countryside – as Sagoff suggests – there seems to be no reason why this should not be the case. We should also ask the broader question of how the British have viewed technological development in agriculture and whether such developments have been perceived as a threat to the pastoral ideal. According to Sagoff, glimpses of British affiliation with the pastoral farm and countryside can be found throughout the nation's cultural and artistic history, from the idealised paintings of rural life by John Constable (1776-1837) to John Stuart Mill's (1806-1873) ardent rejection of a future where 'every natural pasture is ploughed up, and scarcely a place left where a wild shrub or flower could grow… [all] in the name of improved agriculture.'[87] The pastoral ideal, however, would have to have survived into more recent times to validate its application to the GM controversy. Intriguingly, aspects of the late twentieth-century history of agriculture and conservation in Britain does suggest that the rejection of improvement and modernity has continued to exert a powerful force.

The twentieth-century British conservation movement was confronted by drastic changes to the countryside. Following the Second World War, a 'silent revolution' occurred in British farming, which manifested itself in ever-increasing levels of agricultural production.[88] Intensified farming had a visible impact upon the landscape. By the 1980s, Des Wilson, Chairman of Friends of the Earth in Britain, could write that 'Britain's countryside, with all its historic beauty and diversity, is slowly being

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[87] Cited in Sagoff (1999): 11. Intriguingly John Ruskin (1819-1900), another cultural icon of English nature, rebelled against Darwin's intervention in botany and his interest in plant hybridization. See Smith (2008).
[88] Plumb (1977): 363. For a historical treatment, see Blaxter and Robertson (1995).

desecrated.'[89] Hedgerows, ancient woodland and wild species were all seen as under threat from powerful, subsidised farmers and landowners. Conservationist Chris Rose noted overwhelming public support for environmental action during the 1980s and argued that this upsurge was the result of 'total political inactivity among conservation groups from 1947-1979', which were more concerned with 'creating a cosy, cloistered world of [nature] sanctuaries' than protecting the 'wider countryside'.[90]

Wilson's critique of the post-war conservation movement, however unfair, demonstrates that the environmentalists of the 1980s were not content to see the British countryside ravaged by industrialised agriculture. Nor were they content with an American model of natural spaces confined to reserves, parks or sanctuaries. The eco-activist groups which first emerged during the 1960s were different to their predecessors, wanting 'not only to preserve certain animal species and woodland habitats but also to redirect Britain along paths of development that would be more in harmony with the needs and limitations of the natural environment.'[91] In other words, modern environmentalism strives to both protect nature and change society. It is therefore easy to see how the pastoral ideal – which envisions the natural world and its human inhabitants in equilibrium – would appeal to the 'holistic vision' possessed by many eco-activists.[92] Similarly, political scientist John McCormick has stated that '[both] the countryside and the rural ethic hold a place in the British psyche that is comparable to the position of forests in Germany or wilderness in the United States.'[93]

Holistic visions which married environmental, social and political activism were also characteristic of anti-GM organisations in Britain. The anti-GM movement evolved a dialogue consisting of 'social justice critique[s]', technological risk and nature conservation discourse.[94] GM crops, with their perceived unnaturalness and commercial leanings, interfered with the vision of the British countryside held by the anti-GM movement.[95] There are of course similarities between the goals and activities of anti-

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[89] Wilson (1984): 7.
[90] Rose (1984): 32-33. Reports produced by the Nature Reserves Investigation Committee and the British Ecological Society in the early 1940s drew heavily upon the American model of nature reserves. See Bocking (1993): 98-99.
[91] Veldman (1994): 210.
[92] Veldman (1994): 210.
[93] McCormick (1991): 69-70.
[94] Purdue (2000): 62.
[95] Purdue (2000): 62.

GM groups and their predecessors. Yet these similarities are not merely superficial: established conservationist organisations also weighed in on the GM controversy. As we have already seen, the British Ecological Society – founded in 1913 – attempted to interpret the introduction of GM crops using established notions of introduced or invasive species.[96]

Other conservationists went on to draw an explicit link between GM resistance and preserving the integrity of the British countryside. The effects of agricultural intensification continued to make themselves felt in the countryside during the 1990s as biodiversity, particularly birdlife, declined. To some members of organisations, such as the Royal Society for the Protection of Birds (RSPB) and the British Trust for Ornithology (BTO), the environmental hazards posed by GM would simply 'be painted onto a biodiversity landscape that is already severely damaged by the intensification of agriculture.' The 'Introduction of new crop types' could pose a danger to British wildlife, but was listed on equal footing with activities such as 'Land drainage' and 'Hedgerow removal'.[97] For British environmentalists of all stripes, there has often been little distinction between protecting the countryside from hedgerow removal and GM crops: both upset the pastoral ideal.

All this suggests that the pastoral ideal has played an important role in the British conservationist movement and its attempts to preserve the wider countryside. However, this leaves the question of whether the pastoral ideal was confined to conservation organisations and groups, or was instead part of a wider culture. Membership of such groups provides the most straightforward method of gauging their popularity. In 1970, conservationists held the European Conservation Year, and a rush to join voluntary organisations seeking to protect nature began. Membership of the RSPB grew sevenfold to over 300,000 members by the end of the 1970s, while membership of the Society for the Promotion of Nature Conservation (SPNC) more than doubled in the same period.[98] The idea of nature conservation was therefore reaching more and more Britons in the decade prior to the arrival of GMOs.

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[96] Shorrocks and Coates (1993).
[97] Krebs, et al. (1999): 611-612.
[98] Evans (1992): 137.

Other communities concerned with agriculture were also aware of the pastoral ideal. Some in the food industry were alarmed by what they saw as a growing discord between the countryside of the British imagination and the realities of modern agriculture. Addressing members of the NIAB in 1993, Dr. Geoff Spriegel, the Research Director of Sainsbury's supermarket chain, described how 'urban populations [were] becoming increasingly divorced from the realities of food production.' Spriegel explained the worrying implications of what he saw as consumer ignorance to his audience:

> In this scenario, technical development has continued apace, almost without reference, or even a means of reference to the consumer. This leads to difficulties when we [in the industry] try to explain new technology to consumers as enhancements to previous production techniques, when knowledge of the techniques which are being replaced is very limited.[99]

When GM entered the public sphere, it therefore seemed like a sudden and alarming innovation. At institutions like the NIAB, which favoured the introduction of GM crops during the 1990s, the perceived distance of the majority of the urban public from the realities of modern farming and food production is a major source of frustration. Jeremy Sweet, who conducted research on the environmental impact of GM crops while based at the NIAB during the 1990s, articulated this frustration:

> People like to think that their food is natural. When you consider that most people think that supermarkets make food… If you took people to a slaughterhouse, to see how food is actually produced and processed, they would be horrified. People have no idea how their food is produced and processed and manufactured. But they can latch on to this fear that's been generated about… taking genes from one thing and putting it into another… It's really annoying, very frustrating.[100]

Yet the food industry itself is also complicit in promoting the British pastoral ideal. Traditional images of rural life project a reassuring message to potential customers. A notable example of this tactic can be found on Seed Catalogues issued by Marsters Seeds, a Norwich based-firm during the 1970s. These materials, which list the latest

[99] Spriegel (1997): 62.
[100] Jeremy Sweet (NIAB), interview with author: 09/02/2016.

crop varieties stocked by the seed company, are often fronted with romanticised country images. The seed catalogue for 1970 is fronted by draft horses drawing a plough: essentially an updated version of a Constable painting.[101] Yet only two years after the catalogue was published, Marsters merged with Milns Seeds. As we saw back in Chapter 2, Milns had embarked upon a mutation breeding programme during the 1960s, subjecting barley to gamma radiation and selecting promising mutant cultivars for further breeding: a process far from the natural and romanticised image of seed production presented by their new partners.[102]

British suspicion of technological development in agriculture and the endurance of a pastoral view of the countryside into recent history lends further vindication to Sagoff's thesis. But does a longstanding view of traditional agriculture as part of nature mean that the British are stuck with an unrealistic picture of modern farming? The answer matters for both advocates and opponents of GM. Cronon has argued that the wilderness myth has led Americans to ignore environmental damage and pollution in "unnatural" spaces, including farmland.[103] After all, why would they bother when they can simply escape to true nature in wilderness areas? In the same manner, the pastoral myth may lead to Britons rejecting beneficial technology simply on the grounds that it does not fit with preconceived notions of what the "natural" countryside should look like.

## Conclusions

Does the Sagoff thesis stand up to scrutiny? Partially yes, at least in the British context. As we have seen, the pastoral ideal has continued to hold sway over the British imagination well into the twentieth century. Instinctive rejection of GM on the grounds that such organisms are unnatural or alien has undoubtedly taken place on a significant scale.[104] These arguments suggest that the Sagoff thesis has some validity. Moreover,

[101] Marsters Seeds Seed Catalogue, Spring 1970, Gressenhall Library, GRSRM: 2002.165.286.
[102] Milns Seeds Seeds Catalogue, Spring 1967, Gressenhall Library, GRSRM: 2002.165.273.
[103] Cronon (1996): 16.
[104] At this point, we might well ask why the natural versus unnatural debate has not been subject to greater scholarly analysis. Turney (1998): 3-4 has argued that public objections to particular research avenues in genetics have often been dismissed as an irrational or instinctive reaction against science as a whole. Such objections may therefore not be taken seriously. If this is the case, it is also possible that

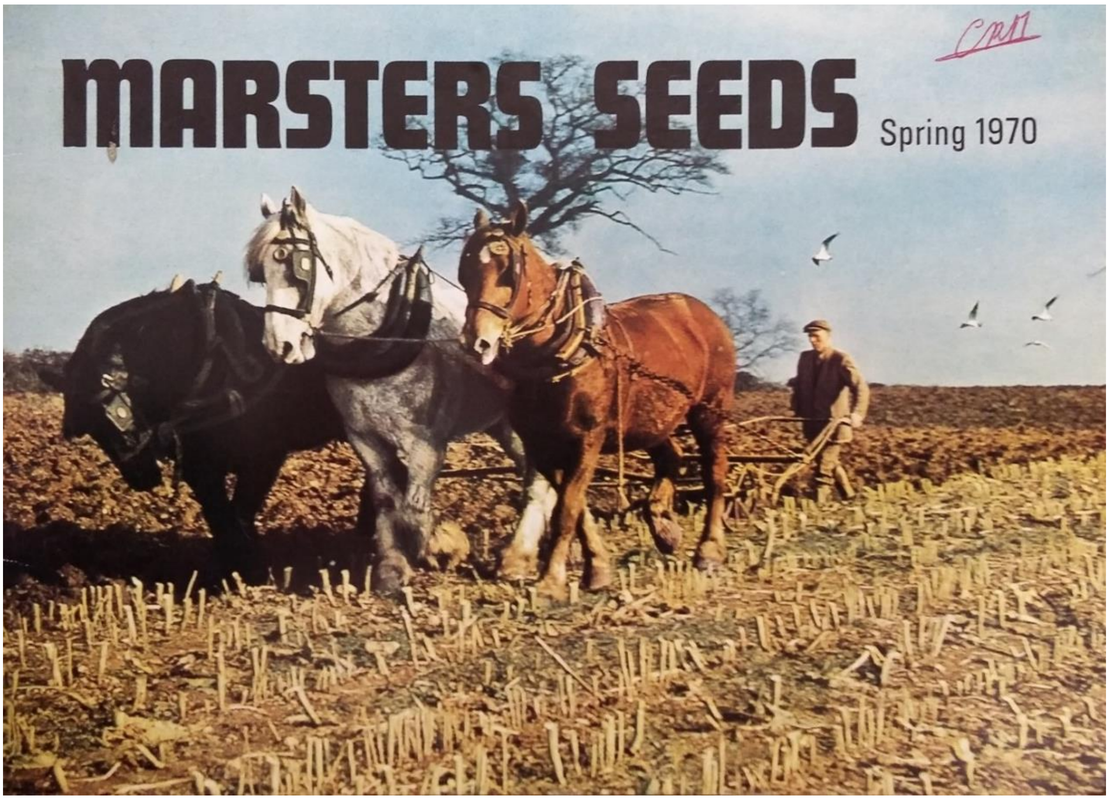


Figure 6.2. The Pastoral Ideal. An idyllic rural scene of premodern farming on the front of the 1970 Marsters Seeds catalogue. Only a few years after this catalogue was released the firm partnered with Milns Seeds, known for its mutation bred barley varieties.

accepting the thesis answers a number of problems surrounding existing interpretations of why the British rejected GM crops. For instance, debates surrounding the safety of recombinant DNA research during the 1970s apparently had little impact in Britain, in stark contrast to the later public outcry against GM crops.[105] In the Sagoff thesis, threats to established conceptions of nature and landscape are what count, not speculation about future risk from GM bacteria. Yet before we can embrace the Sagoff thesis in its

feelings of GM as unnatural or alien have either been ignored or been masked by other discussions: for example, ecological debates over whether GMOs should be classed as exotic or invasive species.
[105] Turney (1998): 197-198.

entirety, further research, particularly on attitudes to GM in other European countries and developed nations, will need to be conducted.

When taken alongside existing studies on the GM controversy, the Sagoff thesis is not some "magic bullet" capable of explaining attitudes to GM crops across the globe. It does, however, emphasise an important factor for historians to consider in their analysis of such public controversies: cultural attitudes to nature. If studied further, the thesis may also strengthen and enhance existing arguments as to why countries like Britain turned against GM.[106] For example, the emergence of different political cultures surrounding biotechnology in different nations may have been influenced by longstanding national-level sentiment about what is natural and unnatural.[107] In the British context, food scares such as the BSE outbreak formed a significant factor in public mistrust of GM crops. Part of the cynicism felt by consumers to food and agriculture may well be attributed to the realisation that pastoral farming was far more commercialised and industrialised than previously imagined.

To its credit, the Sagoff thesis does encourages scholars to further question seemingly well-established concepts, including the pastoral ideal and longstanding beliefs surrounding native and alien species. This critical process has already been extensively applied to the concept of American wilderness. But why have environmental historians felt the need to overthrow the wilderness tradition? Are there benefits to doing so? It is quickly apparent that the popular idea of wilderness in the United States is a historical construct. Yet the idea apparently informs current attitudes to environmental issues among Americans. As cities, suburbs and farms are separated from nature, there appear to be few barriers to evading our environmental responsibilities in these places. Wilderness, therefore, 'poses a serious threat to responsible environmentalism.'[108] Does the pastoral ideal also present a threat? As we have seen, a vision of a traditional, harmonious countryside has led Britons to reject

[106] The only theories the Sagoff thesis directly contradicts are those which attribute public rejection of GM to instinct or ancient cultural values, such as those posited by Keith Davies and Mary Midgley.
[107] Jasanoff (2005): 57.
[108] The creation of national parks continues to court controversy over the access of Native Americans. See Cronon (1996): 15. In the British context, a picturesque view of the "traditional" countryside also glosses over uncomfortable truths such as rural poverty and the modern industrialisation of agriculture.

new agricultural technologies, including GM. Yet many would argue, often on well-considered grounds, that this is no bad thing.

Yet there is a problem when poor arguments are made based on an invented past. We have seen some examples of agricultural and biotech firms seeking to align their products with a romanticised vision of traditional farming: a tactic which may well have sustained public ignorance of food production. Similarly, even those opposed to GM crops for reasons of food safety, environmental impact or social implications must recognise that visceral rejection of GM based on an imagined history does not allow for reasoned debate. Accepting this does not necessarily imply that GM should become part of British agriculture. Although the untouched American wilderness is a historical myth, this does not mean national parks and other wilderness spaces should be opened up to farming or extraction industries. Similarly, the knowledge that GM is part of a long history of plant breeding does not grant the technology a free pass today.[109] The pastoral ideal is not a necessary barrier against the unfettered use of GM: it simply clouds a polarised debate already steeped in mutual mistrust.

The British GM controversy can be viewed as emerging from a 'perfect storm' of long and short term factors. In the long term, the longstanding and often romanticised view of the British countryside as a pastoral ideal was threatened by the advance of intensified agriculture. Although this was by no means a new threat, by the 1990s it had become increasingly obvious to conservationists and environmentalists that many traditional aspects of the British countryside, from songbirds to hedgerows, had been badly damaged by industrialised agriculture. In the short term the 1980s and 1990s had seen a series of food scares, which undermined public trusts in scientific and governmental authorities to safely manage food and the environment. When GM crops altered through recombinant DNA technology were introduced to Britons through a clumsy public relations campaign, the plants were viewed by some as 'alien' or 'invasive' organisms. While hybrid or mutation bred crop plants were, to a certain extent, given a free pass thanks to the perceived threats of Soviet biology or global population growth, GM crops became the epitome of the worst excesses of industrial agriculture and commercial biotechnology.

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[109] For instance, see Lewontin (2001).

# Conclusion

> The history of science like the history of nations is a history of conflict. Just as nationalists often try to rewrite history to the credit of their nations, scientists with specific prejudices try to justify their intolerance of those who dissent from what they believe to be the "correct" or "true" point of view.
> – Carl C. Lindegren*, The Cold War in Biology* (1966)[1]

'US moves to sell gene-edited mushrooms fuel doubts over British ban on GM imports' announced a 2016 article headline in *The Guardian* newspaper. The article followed news that regulators in the United States had permitted the commercial release of crop plants – including white button mushrooms – modified by CRISPR, a genome editing technique.[2] Crudely put, CRISPR is a promising method of 'editing' genomes: deactivating, replacing or inserting genes. Yet in Europe, regulators have repeatedly delayed a decision on whether genome edited crops can be imported. At stake is whether such crop plants should be considered GMOs, an issue which has provoked an angry response from some British scientists. Huw Jones, Senior Research Scientist at Rothamsted Research, has argued that comparing GM with CRISPR is like 'comparing chalk and cheese'.[3] To illustrate the social and scientific controversy surrounding genome editing, *The Guardian* printed a typical picture from the height of the British GM controversy: masked protestors in biohazard suits marching through a field of GM crops. Given recent political turmoil in Britain and uncertainties over the future of agriculture and environmental regulations, a repeat of such activism is hardly beyond the imagination.

Popular articles and magazines have chosen to portray genome editing as the new standard bearer of the Biotech Age. Yet, in the malleable world of crop improvement, this focus on genome editing techniques may well be misplaced: there is

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[1] Lindegren (1966): vii.
[2] McKie (2016).
[3] Ainsworth (2015): 516.

potential for older biotechnologies to once again make their mark on world agriculture. Crop varieties produced through mutation breeding are becoming increasingly common in Asian agriculture, particularly in China and Japan.[4] Back in Britain, a firm called Azotic Technologies has moved to commercialise one of Edward C. Cocking's cell fusion innovations by inserting a bacterium capable of extracting nitrogen from the air into the cells of crop plants. Early trial results show a significant reduction in the amount of synthetic fertilisers required by these cytoplasmic hybrids.[5] It seems that the hope expressed for a fertiliser-free future by Arthur Galston back at the 1970 meeting of the British Society for Social Responsibility may finally have some basis in reality.[6] These ongoing developments leave historians of plant biotechnology in an unusual position. Not only are their histories called upon to speak to modern controversies in biology, but the very techniques, institutions and actors they study may suddenly take centre stage as the face of 'modern' biotechnology. Histories of plant biotechnology and their application to agriculture have never been timelier.

During the course of this thesis we have been introduced to six different forms of plant biotechnology, spanning from the Biological Revolution of the 1950s up to the present Biotech Age. If we think back to the Introduction of the thesis, this largely unexamined array of biotechnologies presented us with three research questions. In this Conclusion we will firstly answer these questions in light of the six case studies presented in previous chapters, while considering some of the limitations of this thesis. We will then consider some of the historiographic lessons of these answers for historians of biotechnology and historians of twentieth-century science. We will then bring this thesis to a close by presenting a series of areas for potential research, which have now revealed themselves as both timely and exciting: a thorough history of the graft hybrid, interrogation of the boundaries between research on plants and animals, and the debateable claim that the 'art' of breeding has at some point during the twentieth century evolved into a 'science'. Finally, we will look at the potential promises and pitfalls of applying the historical insights of this thesis to modern controversies.

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[4] Forster and Shu (2011): 16.
[5] Ridley (2016).
[6] Galston (1971): 158.

## 1. Evaluating the State of Plant Biotechnology in Late-Twentieth-Century Britain

At the very beginning of this thesis, we tasked ourselves with answering three basic questions about the state of plant biotechnology in Britain since 1950. (1) Which forms of plant biotechnology have been applied to British agriculture since 1950? (2) Why did some forms of plant biotechnology find a place in British agriculture, while others did not? (3) What role have Cold War divisions played in the development and uptake of plant biotechnology in Britain? To answer these questions, this thesis has covered six plant biotechnologies with agricultural applications developed or used in Britain since 1950: industrial hybridization, mutation breeding, cell fusion, electrophoresis, graft hybridization and recombinant DNA technology. Some of these biotechnologies are largely new to historians of science, while others are known but have never been thoroughly examined in the context of British agriculture. These case studies not only go some way towards answering the research questions initially set by this thesis, but offer some timely historical perspectives on current controversies in biology and biotechnology.

The Introduction to this thesis also described how the history of plant biotechnology has been presented by warring parties in the British GM controversy as a simple divide between traditional breeding and modern genetic engineering. If this account were true, we would expect to see very little change in the techniques used to manipulate crop plants for most of the twentieth century. This long period of continuity would then be suddenly interrupted in dramatic fashion by the arrival of GM crops produced using recombinant DNA technology. Certainly the uproar which accompanied the introduction of GM crops to Britain would seemed to indicate that an established way of doing things had been thrown into jeopardy. Yet the five case studies of plant biotechnology in Britain prior to the arrival of GM crops suggest that the division of plant biotechnology between traditional breeding and genetic engineering is overly simplistic. In answer to our first question then, numerous forms of plant biotechnology have been applied to British agriculture. The mid-twentieth century was replete with numerous technologies used in the manipulation of life, some of which are largely unknown today. This thesis therefore reinforces a growing body of literature on the long history of biotechnology and its many facets, which has demonstrated that the story of biotechnology and its place in agriculture is not a simple one.

Of the six plant biotechnologies examined in this thesis, three have thus far failed to find a place in British agriculture. Cell fusion did not become a widely-used tool in plant breeding, only producing commercial crop plants in Europe and North America since the 1990s. Graft hybridization may have contributed to the breeding of horticultural plants, but the extent to which it has done so remains largely unknown. No large scale research or breeding programme investigating the possibility of graft hybridization took place in twentieth-century Britain. Recombinant DNA technology, despite its widespread uptake in other parts of the world, was met with adverse public and political opinion in Britain. Throughout this thesis, crop plants have been subject to an 'enviro-tech' perspective. This standpoint essentially views organisms as technologies and crop plants as 'industrial plants': artificially modified elements in an industrial system.[7] This thesis has argued that compatibility with existing agricultural and industrial systems is a vital prerequisite for biotechnologies to result in commercial success. We quickly found a highly compatible crop plant in the form of Proctor barley, which was carefully modelled and bred through industrial hybridization to meet the demands of the British brewing industry. Conversely, one example of the issues which can arise from incompatibility between an industrial system and a biotechnology was explored in the case of cell fusion. A lack of commercially available enzymes during the 1960s meant that the production of protoplasts necessary to create somatic or cytoplasmic hybrid plants was severely curtailed in institutions like the John Innes Centre (JIC).

Yet this thesis has exposed a range of hitherto little-studied factors – economic, technological and ideological – which have also played a role in the success or failure of twentieth-century plant biotechnologies to enter British agriculture. Take the case of mutation breeding in British agriculture, which underwent a major transformation thanks to the use of radioisotopes. On the one hand, this transformation and the subsequent success of plant breeders in producing crop varieties like Golden Promise was a straightforward case of compatibility between industrial systems: those of plant

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[7] A forthcoming chapter by Dominic Berry in *Technology, Environment and Modern Britain* discusses the idea that crop plants are a form of technology.

breeding and atomic energy. Yet we also saw how Milns Seeds firm benefited from changes to intellectual property law in the form of Plant Breeders' Rights. This new level of intellectual property protection made plant breeding a far more profitable enterprise, allowing the company to take a financial risk investing in a mutation breeding programme. Similarly, new classificatory technologies like electrophoresis met an established need within British agriculture, but also benefited from a financial squeeze on institutions like the NIAB. Another finding of this thesis is that public opinion did not appear to manifest itself in Britain as a significant force in the uptake of plant biotechnology in agriculture until the GM controversy.

Our third research question asked us to consider yet another factor in the uptake of plant biotechnology in agriculture: the Cold War. The ideological division between East and West influenced almost every aspect of plant biotechnology discussed during this thesis. This influence took two forms, one indirect and one direct. Indirectly, the ever-present military threat posed by the Soviet Union drove British biotechnology and agriculture further along the path of increased crop production at all costs. We have seen instances of this pressure in calls by Kenneth Blaxter, animal nutritionist and Fellow of the Royal Society, for Britain to become self-sufficient in food production to survive future blockades. Efforts at Wantage to model the impact of radioactive fallout on the growth of common crop plants represented another instance of Cold War fear influencing agricultural research. We have also encountered the direct influence of the Cold War on British plant biotechnology via repeated references to Lysenko and the new Soviet biology. If a new crop plant was supposedly produced through a biotechnology based upon the application of the principles of Western genetics – say hybridization or mutation breeding – then an ideological blow would be struck against Marxist biology.

The need to repudiate Lysenko's theories emerged even more explicitly among plant physiologists conducting cell fusion, who were careful to avoid any association with graft hybridization and the inheritance of acquired characteristics. The graft hybrid itself languished within post-war British science. Although graft hybridization had its defenders at the Commonwealth Agricultural Bureaux, its validity was strongly opposed by authority figures like Cyril Darlington and established bodies like the Royal Horticultural Society. Only a few Marxist biologists, such as Anne McLaren, supported the existence of graft hybrids during the latter half of the twentieth century. The influence of the Cold War can be plainly seen in the field of transplant immunology, where the unexplained findings of Milan Hašek were stripped of all association with Lysenko and graft hybridization. Such is the global influence of the Lysenko controversy that even the most recent scientific papers on graft hybridization have been careful to distance themselves from Soviet biology. The divisions which existed in biology during the Cold War had a significant influence on which types of plant biotechnology were developed in Britain and how those involved in this development portrayed their work to a wider audience.

Although this thesis has considered a number of important factors in the turbulent transition of plant biotechnology from petri dish to farm, many questions remain. The majority of case studies covered in this thesis arose as the result of archival work and conversations conducted at major plant breeding institutes in the United Kingdom, chiefly the NIAB and the JIC. Although these institutions have proved invaluable, the histories of plant biotechnology they point towards have invariably been ones important in their own history or the career history of their staff. More plant biotechnologies have undoubtedly been developed with the intention of transforming British agriculture outside of these institutions. Another gap is left by the absence of farmers' voices: although meetings and debates at the NIAB and letters from the JIC archives have given us some insight into the mind-set of ordinary British growers, this has not always been sufficient.[8] For instance, it is clear that a significant gap in the perceived truth and utility of graft hybridization existed between biologists and some British horticulturalists during the 1950s and '60s. Plant breeders and growers often had very different takes on the value of biotechnology to scientists and administrators, as evidenced by the cold reception of electrophoresis during the 1980s. Greater historical understanding of these differences and their roots may well shed further light on the uptake of plant biotechnology in agriculture. For now, we can agree that this thesis is not a comprehensive account of plant biotechnology in twentieth-century Britain, although it does point us towards a far more complex and contested history of biotechnology than we might otherwise possess.

[8] On the silence of American farmers in historical accounts of plant breeding in the United States, see Palladino (1991): 513-514.

## 2. Insights for the History of Biotechnology

The case studies examined in this thesis offer historians of biotechnology two new insights into the nature of plant biotechnology and agriculture in mid-twentieth-century Britain. The first is to show that the line between traditional breeding and GM is not only blurred, but that a linear progression from one type of plant biotechnology to a more advanced one simply does not exist. At numerous points in the latter half of the twentieth century, scientists, breeders and growers were faced with very real choices between different types of plant biotechnology: each with its own merits and drawbacks. To add to the historiographical complexity surrounding plant biotechnology, some of these decisions involved 'vintage' forms of biotechnology like hybridization or electrophoresis: long-existing technologies which had been reinvented or requisitioned for new roles. Our second insight is that plant biotechnology and its application to agriculture cannot be divorced from deeper theoretical musings and political ideology. When successfully applied to crop improvement, biotechnology became part of a longstanding cycle of utility and truth in science, where practical success lends weight to the truth of theoretical principles.[9] During the first decades of the twentieth century, this cycle was vital for the promotion of the science of genetics and Mendelian laws in agriculture. Yet by the 1950s, the commercial success of plant breeding tools such as industrial hybridization and mutation breeding were seen as means of undermining Marxist biology and Lysenkoist agriculture.

A sense of plant biotechnology becoming an ever more advanced enterprise over time, with intermediate stages in-between traditional breeding and genetic engineering, has been advanced by prestigious figures like former NIAB director John MacLeod. In 1998 MacLeod proposed a three-tier history of agricultural biotechnology. This potted history of plant breeding portrayed biotechnology as progressing from the domestication of crop plants, to hybridization and finally onto genetic engineering.[10] Yet the case studies of plant biotechnology presented in this thesis do more than add additional stages to MacLeod's linear history of plant breeding. They instead indicate that the history of plant biotechnology is more of a complex, branching tree of

[9] Dear (2005): 394.
[10] Cooper and MacLeod (1998): 131.

innovation and reinvention than a straightforward line of progress. Yet simply because a new biotechnology comes into existence does not mean it will become a standard tool in agriculture. The history of plant biotechnology is therefore littered with technological failures, or technologies which have only found their niche long after their initial invention. The fine line between success and failure leads us to our second insight on the nature of plant biotechnology and agriculture.

The plethora of biotechnologies made available to British plant breeders and botanists since 1950 suggest that biotechnology as we know it today – dominated by recombinant DNA technology and private biotech firms – was far from inevitable. One of the most compelling alternatives to recombinant DNA technology was cell fusion, which for much of the 1960s and even the 1970s was thought of as the most promising biotechnological technique in plant breeding. In fact, many of the same promises now attached to recombinant DNA and even genome editing – producing more food for a hungry planet, fighting back crop disease, reducing the need for chemical pesticides and fertilisers – were once attached to cell fusion. As we explored back in Chapter 3, a new generation of crop varieties produced through somatic or cytoplasmic hybridization never materialised. Instead the development of plant cell fusion was held up by unforeseen technical difficulties and supply problems. Yet cell fusion did eventually produce some new crop varieties, while more recent work from Azotic Technologies would seem to indicate that cell fusion may soon produce highly desirable crop plants. With all this in mind, it is not too hard to imagine an alternative history of plant cell fusion where technical hurdles were overcome, or where an ample supply of enzyme existed for protoplast production at an early date. The Biotech Age as we know it today may well have taken on a very different form.[11]

Yet it was not only technology and money which was at stake when plant breeders, geneticists and physiologists explored different avenues to manipulate plant life. Their choices also raise fundamental questions about key principles in the biological sciences. Take the story of electrophoresis and other classificatory technologies at the NIAB during the 1980s: here, agricultural botanists were faced with a very real choice between different types of classificatory technologies, each based upon very different

[11] For a recent take on the value of counterfactual histories in the history of science, see Radick (2016).

principles. Electrophoresis represented the biotechnological approach, pulling apart cells with an electric current to reveal their content. Spectroscopy was a well-established method commonly used in chemistry, while machine vision systems offered a modern take on morphological analysis. The NIAB stood at a crossroads in agricultural botany, faced with an array of classificatory technologies which viewed and understood crop plants in very different ways: at the molecular or morphological level. The Institute's history tells us that there was nothing inevitable about the uptake of electrophoresis: after all, the technology only became of interest following significant reductions in government funding to the NIAB. Another example of a fundamental biological principle at stake emerges in the story of graft hybridization. Although there were compelling reasons to believe in graft hybrids, their seeming contradiction of Mendelian laws and support for Lysenkoist doctrine strictly limited their investigation and uptake in Britain during the Cold War.

This tacit suppression of biological dissent – to paraphrase biologist Carl C. Lindegren – leads us onto the second insight this thesis provides for historians of biotechnology.[12] Garland E. Allen has argued that a mechanistic view of the gene emerged in part due to the industrialisation of agriculture during the early years of the twentieth century. As 'mechanistic thinking clearly dominated the metaphorical landscape of the industrial revolution' it was no accident, Allen claims, that the genome was also seen in this light: as a series of 'separable parts' which could be removed, added or altered at will.[13] An industrial ideology of control, predictability and statistics favoured a particular view of heredity, which in turn informed the activities of breeders. Large-scale forces – urban expansion, mechanisation in agriculture and changes to intellectual property laws – provided a boost for classical Mendelian genetics. By the mid-twentieth century these same forces were still in play, but had been supplemented by another: the rise of the Soviet Union and Lysenko's biology. As we have seen, Lysenko found little support in Britain at either university biology departments or agricultural institutions. Significant actors in this thesis either attacked Lysenko, stood by Vavilov, or sought to distance their work from Marxist-endorsed techniques like graft hybridization.

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[12] Lindegren (1966): vii.
[13] Allen (2014): 25.

If we apply Allen's account of the mechanistic gene emerging from the industrialisation of agriculture to late-twentieth-century Britain, fresh links between agricultural practices, theories of heredity and political ideology emerge. We can see how a burgeoning array of mid-twentieth-century biotechnologies acted as practical demonstrations of the truth of Western genetics and more broadly, the ideals and principles on which science was conducted in Britain. Sometimes, as in the case of cell fusion, these biotechnologies could be interpreted as supporting Marxist biology and non-sexual inheritance. In such cases, their advocates carefully distanced themselves from such unwanted and dangerous interpretations: hence the Brookhaven Laboratory team which created the first somatic hybrid in 1972, taking the time to dismiss any suggestions that their hybrid could have emerged as the result of a 'graft union'.[14] The cycle of truth and utility could also run in the opposite direction: graft hybridization had become so deeply associated with Lysenko by the 1950s that the phenomenon was never properly investigated, meaning it was not given the opportunity to demonstrate its utility, or lack thereof, in British horticulture. Just as alternative theories to Mendelism attracted agronomists in early-twentieth century Europe and America, so different forms of biotechnology attracted scientists and breeders in late-twentieth century Britain.[15] The repudiation of Marxist biology was a significant, if not dominating, factor in their choices of which forms of plant biotechnology to invest in.[16]

## 3. Insights for the History of Twentieth-Century Science

A recent essay review by Joseph D. Martin has asked historians of science to look again at what defines twentieth-century science. There currently appears to be little historiographical sense of the twentieth century as a cohesive 'epoch', in the way that the scientific revolution has helped define the nineteenth.[17] In pursuit of this missing sense of cohesion, Martin reviews two books which have attempted to tackle the twentieth century in its entirety: Stephen G. Brush's *Making Twentieth Century Science*

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[14] Carlson, et al. (1972): 2292.
[15] Allen (2014): 26.
[16] Allen (2014): 26 considers a combination of the science/technology available, plus the channelling of funds, to be the determining factor in what research is pursued. Agar (2012) gives a significant role to Marxist biology in the development of biology in the inter-war period.
[17] Martin (2017): 149.

and Jon Agar's *Science in the Twentieth Century and Beyond*. According to Martin, the different approaches in these books indicate that the longstanding distinction between 'internal and external, conceptual and contextual, approaches to the history of science' still hold sway.[18] So where does this thesis fit in these broader conceptions of twentieth-century science? In this Section we will discuss the tension between 'internal' and 'external' factors in the development and uptake of plant biotechnology. On the one hand, a range of communities associated with the development and use of plant biotechnology in Britain chose biotechnologies based on their 'internal' qualities or characteristics: cost, ease of use, reliability and so on. On the other there are the 'external' factors – political, social, cultural and economic – which during the course of this thesis have manifested themselves as neo-Malthusian fears, environmental concerns and Cold War ideological divisions.

Although Brush's book restricts itself to understanding why scientific theories become generally accepted, some intriguing results emerge if we apply its logic to the acceptance of biotechnology among a range of practitioners in Britain: plant physiologists and botanists, agronomists, breeders and farmers. Ignoring the risk of gross oversimplification, Brush essentially argues that scientific theories are accepted when they fit with existing evidence: what Martin calls 'Success accommodating existing evidence'.[19] Morgan's chromosome theory of inheritance, for instance, became accepted in Britain and the United States during the 1920s and 1930s thanks to its ability to explain several different experimental results.[20] Now let us substitute a scientific theory for a biotechnological technique, while simultaneously substituting experimental evidence for commercial success. While any meaningful comparison to Brush would be a stretch, we can see that a biotechnology like mutation breeding would need to fit several existing criteria to become widely accepted in British agriculture. These criteria might include the ability to produce high-yielding crop varieties relatively cheaply: in which case the newfound use of radioisotopes during the 1950s and '60s meant that mutation breeding was broadly accepted as a plant breeding

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[18] Martin (2017): 150.
[19] Martin (2017): 151.
[20] Brush (2015): 412-414. There were, of course, other factors at work. Brush does not fail to note that Morgan's theory possessed predictive power and benefited from a number of 'social and psychological factors.'

tool in British science and agriculture. We can see that other forms of biotechnology like cell fusion would fall foul of such criteria, hampered by technical difficulties, high costs or a lack of resilience in the resulting crop varieties.

That said, the history of twentieth-century plant biotechnology also fits into the 'external' or context-driven account of twentieth-century science outlined by Agar. One example given by Agar of a scientific field shaped by external factors is evolutionary biology. Prior to the repression of genetics in the Soviet Union, ideas from that field found their way into Western biology via exchange programmes, translation of scientific works and Theodosius Dobzhansky's move to the United States in 1927. Soviet genetics, Agar claims, which consisted of the study of wild populations 'informed by natural history,' acted as a 'bridge-builder' in the creation of the Evolutionary Synthesis.[21] In a similar manner the work of Nikolai Vavilov was picked up by British plant breeders like George Douglas Hutton Bell, while Vavilov's persecution was condemned by British friends and colleagues, including Cyril Darlington.[22] Political events in the Soviet Union thereby exerted a tangible influence on British plant breeding, with some forms of manipulating life promoted based on their anti-Lysenkoist credentials. In Agar's account, the Cold War went on to form 'working worlds', which were influenced by Cold War values: including research on the biological impact of radiation at institutions like the Atomic Energy Research Establishment like Harwell.[23] As we have seen throughout this thesis, Cold War values and fears likewise played a role in support or dismissal of certain research pathways in plant biotechnology.

Yet it is not always clear where the conceptual and contextual begin and end in twentieth-century science. At several points in this thesis we have discussed the importance of plant biotechnologies being compatible with existing industrial systems. The significance of this compatibility for the uptake of a biotechnology in agriculture was most apparent in the case of industrial hybridization and Proctor barley: where a plant breeding method – hybridization – was altered to in order to meet specific demands from the British brewing industry. This case study seems to blur the distinction between the conceptual and contextual. Did industrial hybridization prove a popular

[21] Agar (2012): 203-204.
[22] Harman (2003): 149.
[23] Agar (2012): 354-356.

technique based on its integral merits? It admittedly had the ability to effectively produce 'pre-ordered' crop varieties required by brewers using a tried and tested means of crossing crop plants. Industrial hybridization was predictable, reliable and ultimately profitable. Yet were these characteristics truly internal, or did they result from outside forces? After all, it was the specific demands of the British brewing industry which drove Bell and his colleagues to develop industrial hybridization in the first place. In such cases it seems impossible to separate the conceptual from the contextual.

Another intriguing example of the blending of internal and external forces appeared during the general rejection of graft hybridization as a horticultural technique. A review of the *Selected Works* of Michurin on behalf of the Royal Horticultural Society in 1950 saw M.B. Crane attack Michurin's experiments. Crane dismissed the nineteenth-century account of graft hybridization supposedly carried out by Michurin, instead favouring the prevailing hypothesis in the West that all such plants were chimeras. On the one hand, this attack is highly-context driven. In the charged atmosphere of the Cold War, Crane was reacting to very real social pressures by rejecting Michurin's philosophy in favour of orthodox genetics and botany. Yet on the other hand, although Crane was highly critical of Michurin, he was not fixated on intellectual destruction. Crane dismissed Michurin's experiments on graft hybridization, but noted that were some claims in the *Selected Works* which 'most biologists, at least most of those outside Russia, can accept.' Michurin was far more open-minded and nuanced than his self-proclaimed disciple Lysenko, leading Crane to ask 'whether Lysenko or his colleagues have really been honest with Michurin.'[24] This level of sympathy of Michurin could be read as a context-driven move to undermine the philosophical foundations of Lysenkoism. Alternatively, it could be seen as a conceptual move. Maybe Crane was convinced by some (if not all) of the experiments carried out by Michurin, which addressed some very real problems in the contemporary understanding of heredity.

Although this thesis in no way attempts to bridge the divide between 'internal' and 'external' accounts of twentieth-century science, the history of plant biotechnology does cross the much contested no-man's land between these two approaches.

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[24] Crane (1950): 370.

Repeated movement between internal and external factors is required to adequately explain the choices made during the development of plant biotechnology and its application to agriculture in Britain. This repeated back and forth may simply be indicative of 'the inadequacy of the methodological legacy we have inherited for taming the twentieth century' identified by Martin.[25] Or it could be that biotechnology is somehow uniquely situated to bridge the conceptual and contextual divide. Support for the latter option may be found with further research into the Cold War influences on biotechnology, the ability of biotechnology to transverse scientific disciplines or the claims of its advocates to have provided a scientific basis for breeding.

## 4. Some Prospects for Further Research

In the light of this thesis, four subjects emerge which lend themselves to further historical research. The first is the highly controversial, yet largely unexplored, history of the graft hybrid. As we explored in Chapter 5, the graft hybrid has long been at the centre of fundamental questions about the nature of heredity and human ability to shape the natural world. Although the short account of graft hybridization given in this thesis has given some sense of this history, far more remains to be explored. The graft hybrid has been an object of controversy since the nineteenth century (and possibly beyond) on an international level. There are undoubtedly different national stories of genetics to be explored and retold in light of graft hybridization experiments, especially during the first half of the twentieth century. The graft hybrid was also an object of Cold War contention, one of the most important and compelling pieces of evidence available to Marxist biologists who wished to promote extra-chromosomal inheritance and the inheritance of acquired characters. Recent discoveries that graft hybrids can be formed using basic grafting techniques suggest that we may need to fundamentally rethink our basic assumptions before approaching the history of genetics.

The second is the rapidity with which ideas and techniques have moved between the worlds of plant and animal research. This is especially the case when we look at the 1960s. As more and more work was conducted on the cellular level, whether

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[25] Martin (2017): 157.

in cell fusion or electrophoresis, tools and techniques were exchanged between biologists working on plants, animals and microbes. Some manifestations of this trend included collaboration between Edward Cocking and researchers at the Microbiological Research Establishment, the uptake of electrophoresis for crop classification following its successful application to wildlife management, and the intervention of Anne McLaren in the world of plant breeding and graft hybridization. A major shift in the history of science has occurred with increased specialisation and, presumably, the separation of scientific disciplines. The growing ability of scientists to manipulate cells, with seeming disregard for the traditional boundaries of life, seems like a counterexample to this assumed trend. If the same techniques and substances could be used to alter or even fuse cells from plants, animals, humans or microbes, it would seem that this separation of disciplines on biological lines was not complete. Closer examination of collaborations similar to the ones raised in this thesis may raise new questions on the extent we can speak of distinct disciplines in biology.

A third area of future research is found in repeated claims that fundamental activities in agriculture, most notably breeding, have at some point during the twentieth century made a transition from 'art' to 'science'. It was implied that this transition has manifested itself as a new degree of control and predictability over the heredity of organisms. Often, although not necessarily, this newfound power over nature is accompanied by wresting of plant breeding away from farmers and into the hands of 'expert' breeders or geneticists.[26] Flashes of the belief that breeding was in the process of becoming a scientific endeavour have been encountered in this thesis: for instance the 1970 pronouncement by seed merchant T. Martin Clucas that the typical British plant breeder, while 'still an artist, like his predecessor', was now 'aided by science and technology'.[27] Some historical accounts of the post-war boom in British agriculture likewise imply that soaring production was the result of new scientific developments and their application to agriculture.[28] Yet such assumptions only raise questions about the extent to which standard breeding practices in Britain truly lost their artisanal qualities to the march of scientific rationality.

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[26] Fitzgerald (1993): 342.
[27] Clucas (1970): 48.
[28] Blaxter and Robertson (1995).

Finally, given the newfound examples of British plant biotechnology uncovered by this thesis, it is tempting to use this history to inform contemporary issues around biotechnology. Jane Maienschein has taken this route with cloning, a technique which aroused great public interest following the birth of Dolly the sheep at the Roslin Institute in 1996. Given that the American plant physiologist Herbert John Webber had introduced the concept of cloning back in 1903, Maienschein asks, why did Dolly create such an outcry when nothing about her 'was the result of fundamentally new science'?[29] Part of the reason was a skewed reading of the history of science. Rather than recount the numerous twentieth-century developments in cloning which made the creation of Dolly possible, media attention focused instead on the rather technical detail that an adult somatic cell, rather than an embryonic one, was used in the cloning process. Subsequent stories therefore focused on the possibility of cloning adult humans and all the thorny ethical issues that would arise in such a scenario.[30] An opportunity therefore exists for historians of biology to 'illuminate public discussion and media presentation' of the biological sciences, in the case of cloning by demonstrating that it 'is not radically new science.'[31] For Maienschein, long histories of biology can act in the public interest. While a new and diversified history of plant biotechnology could potentially fulfil this call, questions remain about how such a history could best speak to current debates and divisions.

Despite such misgivings, a sense of urgency now surrounds the future of the history of science in the public sphere. In 2014, Jo Guldi and David Armitage produced *The History Manifesto*, a book which has become a source of much discussion and soul-searching among historians of science. Its authors criticise historians for short term thinking, calling for a return to 'big' narratives of common concern.[32] Although this is by no means a new argument, it seems that calls for history to become more relevant to current debates and policy-making cannot be brushed off by its practitioners.[33] Historians of science have also been called upon to provide reasons as to why their

[29] Maienschein (2001): 423-424.
[30] Maienschein (2001): 428-429.
[31] Maienschein (2001): 431.
[32] Guldi and Armitage (2014). A 2016 issue of *Isis* (volume 107) presents a series of responses to *The History Manifesto* by historians of science.
[33] Jacobs (2016): 313.

advice can be valuable.[34] The history of plant biotechnology does provide us with such reasons. An expanded history of twentieth-century biotechnology acts as a myth-buster, helping us to overcome unhelpful conceptions of history such as the pastoral ideal or Monsanto's division of the past between traditional breeding and genetic engineering. The history of plant biotechnology is also a warning against deterministic accounts of science and technology. At no point was it inevitable that plant breeding would be inexorably marched towards the use of recombinant DNA technology. The development and uptake of plant biotechnology in British agriculture has been a fraught and contested process, where very little can be taken for granted.

## 5. Final Remarks

By uncovering a series of new accounts of biotechnological programmes and their application to British agriculture, this thesis has painted a complex and dynamic picture of how the Biological Revolution unfolded in Britain and how the Biotech Age could potentially have looked very different. By applying the concept of the 'industrial plant' to crop varieties produced by this new array of biotechnologies, this thesis has also revealed why some biotechnologies were seamlessly integrated into British agriculture, while others were hotly contested or failed entirely. Yet we have also seen how contemporary ideology and fears informed the uptake or rejection of plant biotechnology in the scientific, industrial and public spheres. The ideological divisions of the Cold War acted to block research on some types of biotechnological manipulation, while being used as a justification for research and eventual use of others. By the 1960s neo-Malthusian fears had reinforced the need to harness biotechnology in the production of high-yielding crops. By the 1970s and 1980s economic fears had been added to the mix. To fully explain the historical development of plant biotechnology and its application to agriculture, both practical constraints and conceptual worldviews must be taken into account.

By uncovering new forms of plant biotechnology and producing a new history of biotechnology in Britain, the findings of this thesis are important for a number of

[34] Heilbron (2016): 352.

disciplines. Historians of biotechnology, particularly British biotechnology, have thoroughly documented the rise of molecular biology and the development of recombinant DNA technology.[35] It may be of use for them to consider instances of plant biotechnology in largely unforeseen and unusual disciplinary and institutional contexts, whether plant physiology at British universities or crop classification at agricultural institutes. More broadly, this thesis also speaks to historians of the twentieth century and the Cold War. Rebuffing Lysenko and promoting the utility of classical genetics was a common indulgence of the biologists and plant breeders who appear in this thesis, suggesting that the Cold War seemed to exercise a pervasive power on British science and industry. The history of the NIAB has shown how fears of the global population bomb and British economic decline were very real influences on the thinking of the British agricultural community. Almost coincidentally, this thesis has also uncovered a number of areas of interest for historians of medicine, agriculture and environmental history: the influence of Marxist biology on transplant immunology, a successful mutation breeding programme used to create popular varieties of barley, and indications that US-bred GM crops were rejected on the grounds of their 'alien' nature and association with industrialised agriculture.

The history of biotechnology remains a highly contested affair. Biotech firms would prefer the public to see modern forms of genetic engineering as part of a gradual continuum from traditional breeding to the present. Green organisations instead portray GM as an untested experiment with nature, quite different from all that has gone before. How historians interpret 'precursor' biotechnologies, particularly those with agricultural applications, therefore has immediate bearing on current public debates: namely whether transgenic plants and animals have an established place in modern farming. Yet in unpicking the various strands of botanical 'Biological Revolution', this thesis has shown that plant biotechnology possesses a far more complex and nuanced history. Plant biotechnology developed in a certain way in Britain thanks to a combination of ideological and economic constraints and influences. Given a different national context, or even a different timeline, we might expect the Biotech Age to have manifested itself in a very different form.

[35] De Chadarevian (2002).

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