A Study Of European Cereal Frequency Change During The Iron Age And Roman Periods

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Volume One
Text

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To my parents on the occasion of their Golden Wedding Anniversary

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ABSTRACT

This study addresses cereal frequency shifts throughout the Iron Age and Roman Periods in seven European countries. A database of charred archaeobotanical assemblages was compiled and sample-based correspondence analysis employed to reveal chronological patterning. Findings were evaluated with respect to a range of archaeological, ancient textual and modern agronomic evidence and in relation to economic suppositions about cereal production, consumption and exchange. Three types of cereal shifts/trends were documented, which were not necessarily universal and, which varied spatially, temporally and in magnitude. These shifts/trends were: (1) an increase in the proportion of wheat relative to barley which was chronologically associated with the Roman period; (2) an increase in proportion of spelt wheat relative to emmer wheat which, having begun during the Bronze Age in central European regions, continued into the Iron Age and Roman periods; and (3) an increase in the proportion of free threshing wheat relative to spelt and/or emmer, which appears to gain momentum in some countries during the Roman Period. It is argued that social and economic factors were driving cereal change in the direction of greater choice, quality, yield, productivity and refinement. Farmers were reaching for taxa which might accommodate new and old demands in a better and more efficient manner. Differences between the timing and extent of these shifts suggest that farmers crossed over to different taxa when they had exhausted the developmental potential of traditional types. Cereal shifts were enabled by technical innovations which ameliorated environmental stress factors and market developments, which compensated farmers for taking greater risks. The shifts were driven by demands for taxa with increased versatility and the need to specialize in types of wheat which offered profitability. A hypothesis is offered which posits that there was a tendency to shift towards higher level allopolyploid wheat taxa wheat because these conferred naturally high levels of functional elasticity.

Abbreviations used in the text

Agr. = Cato, *De Agricultura*

Ann. Tacitus, *The Annals*

ARS = Agricultural Research Service of the USDA

BSTID = Board on Science and Technology for International Development

CE =Jerome, *Commentaria in Ezechielem, David in Lib. Radicum*

CP = Theophrastus, *On Plants: The explanations =De causis Plantarum*

DE = Chantraine, *Dictionnaire Étymologique de la Langue Greque*

DN = Athenaeus of Naucratis, *Deinosophistai*

DS = Diodorus Siculus, *The Bibliotheca Historica*

FAO = Food and Agriculture Organisation of the United Nations

H = Ammianus Marcellinus, *History*

HP = Theophrastus, Enquiry Into Plants = *Historia Plantarum*

LS = Lewis and Short, *A Latin Dictionary*

MAFRI = Online crop database maintained by the Manitoba Agriculture, Food and Rural Initiative

MM = Dioscorides Pedanius, *Materia Medica*

M.N.I. = Minimum number of items

NF = Galen, *On Natural Faculties*

NH = Pliny the Elder, *Naturalis Historia*

OCD = *Oxford Classical Dictionary*

OE = Xenophon, *Oeconomicus*

OECD Organisation for economic co-operation and development, Paris

OED = *Oxford English Dictionary*

OH = Palladius, *On Husbondrie*

OLD = Oxford *Latin Dictionary*

Ops et Dies = Hesiod, *Works and Days*

PD = Perseus Database

PL = *Patrologia Latina* [Database] Cambridge: Chadwyck-Healey, 1994

RR = Columella, *de Re Rustica*

RRV = Varro, *Rerum Rusticarum*

USDA = United States Department of Agriculture

VM = Valerius, *Factorum ac dictorum memorabilium*

WGD = Wildhagen, *Wildhagen English-German, German-English Dictionary*

WGRC = Wheat Genetic Resource Centre

Chapter 1
Introduction

έτος φέρει ούτι 'άρουρα

The harvest is the year's and not the field's
Theophrastus *CP* III. 23.4

1.1 The problem and its research history

In recent years archaeobotanical datasets have begun to accumulate in many European countries to the extent that it is now possible to delineate specific crop patterns within individual countries. There has been little effort, however, to compare findings across national boundaries or over long time spans. The following study sets out to evaluate changes in the composition of Iron Age and Roman charred cereal assemblages from seven different countries: Britain, the Netherlands, France, Germany, Switzerland, Italy, and Greece (Fig. 1.1). It is hoped that by comparing general patterns in each country's carbonised assemblages it may be possible to shed some light on the nature of European cereal change during this period.

The cereal taxa considered here are: barley (*Hordeum* sp.), wheat (*Triticum* spp.), oat (*Avena* sp.) and rye (*Secale* sp.), plants whose grain and vegetative plant parts have perennially constituted a highly significant fraction of Europe's food and animal fodder production since late prehistory (Hilu 2004; Evans 1993). They are members of the grass family, Poaceae (Gramineae), the fourth largest flowering plant family, one of the most recent in terms of evolution and the most important in relation to both ancient and modern societies. Food scientists recognise the small grains as important staple foods. A staple food is a basic but nutritious food that forms the core of a traditional cuisine (Young and Pellett 1985). Major changes in the production of staple foods are rare events and may be the result of (or result in) synchronous changes in social and economic fabrics (Kuhlein and Receveur 1999). Their external consequences can be considerable, creating ripple effects which produce localised changes in agricultural productivity, intensity and sustainability (Millstone and Lang 2003; *cf.* Evans, J. 1981).

1.1.1 The classic models

The study of Iron Age and Roman cereal frequency variation owes it foundation to 19th century classicists. It was, however, 20th century investigators who produced the first credible systematic studies (Jardé 1925; Schultz 1913; Cotte and Cotte 1911). These early attempts outlined the general nature of early cereal production and provided the first definitions of Greek and Latin cereal epithet meaning. Nonetheless, with the discipline of archaeobotany still in its infancy, these authors relied almost entirely on Classical literature to support their findings and their works generally display little interest in regions beyond the Mediterranean.

The mid 1940s witnessed the first serious attempts to use the composition of cereal assemblages as a means to investigate ancient agriculture. Jasney (1942), an agricultural statistician, was the first to address the subject of relative frequency directly with a pioneering article, *Competition Amongst Grains in Classical Antiquity*. Using a limited amount of archaeobotanical evidence in combination with Classical sources, Jasney distinguished two important cereal shifts which he attributed to the Classical period. Firstly, he identified a general shift from barley to wheat. Secondly, he argued a subsequent shift from emmer to free threshing wheat. Jasney (1942) used these findings to develop several hypotheses:

1. The western Classical world recognised that bread made from wheat was superior to preparations from alternative grains such as barley.
2. The current preponderance of wheat in European regions represents a cultural bias which is best argued by taking into account the fact that wheat is grown in a number of areas where cereals like barley, oats or rye could be more efficiently produced.
3. The shift from barley to wheat consumption was due to a shift in the types of food consumed, namely a general switch from gruels and coarsely ground products to bread.
4. In general, the type of food consumed in ancient times was little affected by the shift from emmer to free threshing wheat because the shift was almost exclusively associated with subspecies which are qualitatively similar to emmer.

Using textual evidence, Jasney succeeded in distinguishing cereal change at two distinct levels. On the one hand, he recognised an inter-generic shift (from barley to wheat) which he believed was the consequence of a modification in dietary habits. On the other hand, he also identified an infra-generic shift (from emmer – *T. turgidum* L. ssp. *dicoccum* Schübl. to bread wheat – *T. aestivum* ssp.), which he felt was unlikely to have come about as a consequence of direct comparison of the culinary properties of these two taxa.

Moritz (1958), however, took exception to this last point and succeeded in identifying a culinary/dietary distinction between wheat species that he felt had ultimately led to free threshing wheat dominating over glume wheat types. Moritz noted that glume wheats underwent a de-husking operation that free threshing cereals did not. Classical authors reported that this de-husking operation was combined with roasting the grain in its husks. The roasting, Moritz argued, must have largely destroyed the gluten content of the grain. This would have made glume wheats unsuitable for leavened bread (Moritz 1958, p. xxi). A preference for leavened bread was, thus, linked to a preference for free threshing wheat.

1.1.2 Genetic suppositions

Cereal geneticists and breeders, on the other hand, have taken an entirely different approach to explaining dominance, proposing that modification occurred when:

1. existing germplasm was determined to be better adapted;
2. better-performing germplasm became available.

Andrews (1964) for instance, argued that a shift from emmer to spelt represented the adoption of latent potential in existing germplasm pools. Specifically, he proposed that spelt had remained a fractional element in mixed crop assemblages of emmer and einkorn until Celtic speaking tribes recognised its nascent potential. Gepts (2004) argued that the field of choice available to farmers was discontinuous – the relative performance of crop species, like that of livestock species, was continuously modified through time leading to displacements when a better performing cultivar emerged. Salamini *et al.* (2002) proposed that the field of choice was expanded when certain traits became fixed – he proposed that tightly invested glumes only arose in hexaploid wheats after selection pressure for the trait in hexaploid wheat overrode a genetic tendency for hexaploid species to naturally take on the free threshing habit. Amongst those who have also set forth substantially the same types of propositions, but stress different aspects of progressivist 'type' models are: Blatter *et al.* (2004); Dark and Gent 2001; Dvorák and Luo (2001); Nesbitt (2001); Sallares (1991); Lisitsina (1984); Watson (1983); Crawford 1979; L.T. Evans (1981); Zeven (1999, 1980); Dorofeev 1969; Helbaek (1952); Bertsch and Bertsch (1949); McFadden and Sears (1946); Febvre 1940; Stapf (1909).

1.1.3 Regional archaobotanical patterns and propositions

1.1.3.1 Germany

Knörzer (1967) was the first archaeobotanical investigator to call attention to the shift from emmer to spelt in southern Germany and the Alpine foreland and to date its beginning to the Late Bronze Age. By comparing the relative proportions of weed and wheat species in archaeobotanical assemblages to the environmental preferences of each species, Knörzer (1971) and Willerding (1988) were also among the first archaeobotanists to offer an explanation for the shift from emmer to spelt, by demonstrating that samples with high proportions of spelt had a tendency to derive from areas with heavier clay soils. Körber-Grohne (1979;1981;1987) in major series of reviews of Iron Age and Roman cultigens reported similar findings and established that the shift was a feature of the interval between the Late Bronze Age and Roman Periods of southern Germany. Rösch (1998, 115) in a review of 91 assemblages from southern Germany, confirmed that the shift to spelt that had begun in the Bronze Age and observed a chronological correlation between increased proportions of spelt and increased proportions of rye. Kreuz (1999), using an updated dataset, examined contrasts between a whole range of German Iron Age and Roman assemblages and concluded that:

> "When one compares the crop-plant species of the Iron Age with those of the Roman period, there is little difference. Rye (*Secale cereale*) is the only new crop intentionally grown in Roman territory. If we simply look at the presence or absence of species, there seems to be more or less continuity in agriculture. The state of the research is not at all satisfactory and the number of samples from most sites is still too low. It is all the more surprising that despite this poor data we can identify a supra-regional phenomenon, namely a change in the frequency of certain cereals. All the Iron Age sites investigated have produced barley. In many regions it is followed by emmer wheat, whilst spelt is less

frequent. On Roman sites, barley is still important, but its role seems to have diminished. Simultaneously, the positions of emmer and spelt have reversed" (Kreuz 1999, 89).

Similarly, also she notes that specialists in Germany report that spelt is not a regular feature in assemblages from 'Germanic' sites (as opposed to 'Celtic' sites - Kreuz 1999, 90).

1.1.3.2 The Netherlands

Investigators in the Netherlands have tended to report a contrasting pattern to that observed in Germany. Iron Age reports of spelt in the Netherlands are relatively rare despite the presence of archaeobotanical assemblages obtained from excellent preservation conditions. In fact, van Zeist (1968) noted that spelt is almost entirely lacking on most native sites up through late Roman times. However, even in some of the wetter areas, which are generally regarded as unsuitable for wheat cultivation, remains of spelt are found (Bakels 1991, 290). Brinkkemper (1991), in an investigation of a series of sites in the Meuse Delta, entertained the notion that at least some of the wheat and barley found at those sites was imported rather than locally grown. Indeed, a whole series of investigators have concluded that spelt was largely imported to the *horrea* (grain storage structures) of the Roman military camps and towns of the lower Rhine (Roymans 1996; Kooistra 1996; Bakels 1991; Knörzer 1981; Pals *et al.* 1989; *cf.* Gransar 2000). With regard to installations further up the Rhine, Jacomet notes that "already during the first phases of the Roman conquest large quantities of very 'exotic' plant taxa had already reached at least the big legionary camps" (Jacomet *et al.* 2002, 91).

Kooistra (1996), having proposed that rye and oat had been introduced into northern Germany by Romans, drew a contrast between cereal assemblages from low lying parts of *Germania Inferior* (approximately equivalent to the Netherlands), where concentrations of emmer and barley were dominant, and the loess farmlands to the south (Belgic Gaul) where spelt was an important Roman grain. Pals *et al.* (1989) recorded much the same pattern, noting that the Roman influence in the Netherlands differed from that of adjacent regions. In short, the Netherlands never witnessed the same shift from barley to wheat or a shift from emmer to spelt. Furthermore, in the Netherlands it appears that cultivated rye and oat were from an earlier date than many other parts of Europe.

1.1.3.3 Britain

Investigators in Britain and France have reported a similar pattern to that in Germany. Using 55 archaeobotanical records from England, Scotland and Wales, as well as a broad range of environmental, artifactual and settlement structure evidence, Martin Jones (1981) concluded that spelt had begun to replace emmer by the Iron Age. He further posited that the shift resulted from agricultural expansion on to heavier clay soils using the following facts (Jones 1984;1981):

1. the Iron Age in Britain was marked by an increase in the number of crop species – 6-row barley, spelt wheat, bread wheat, Celtic bean and possibly oats because each of these new species is uniquely suited to adverse conditions, this shift therefore reflects individual attempts to expand onto less desirable soils in the face of declining fertility and worsening climatic conditions;
2. the whole of the first millennium BC was clearly a period which witnessed a far greater level of adoption of metal in the techniques of crop production, a technological development which would have enabled farmers to expand onto heavier soils for the first time;
3. the first half of the first millennium BC was a period in which a trend towards increased specialisation and diversification is evident in almost every aspect of agricultural production;
4. the general pattern across northern Europe for the 1st millennium BC argues for expansion; settlement evidence demonstrates an increase in the scale of production, environmental evidence shows increased diversification in the types of crops and soils used for production; archaeological evidence shows signs of technical innovation in agriculture.

Van der Veen (1992), studying plant assemblages from north east England, concluded that spelt wheat had been introduced into both the southern and northern parts of England almost simultaneously during the early first millennium BC, and further discovered that spelt wheat had replaced emmer in the Tees lowlands by no later than c. 300 BC.

Yet she found that the replacement of emmer by spelt did not occur across the whole region. Furthermore, in the assemblages she analyzed, she recognised two distinct groups on the basis of the relative proportion of crop and weed seeds. She found it impossible to explain the nature of such groups solely in terms of intra-regional variation in climate and soil type, and their character appeared to reflect differences in crop husbandry regimes (Van der Veen 1992, 158). Sites characterised by a high proportion of emmer featured weeds favouring high levels of nitrogen and a high degree of soil disturbance while sites characterised by high proportions of spelt were associated with species having lower nitrogen requirements and requiring relatively low levels of soil disturbance. This led to the hypothesis that emmer is the dominant crop under 'intensive' cultivation systems while spelt is more associated with 'extensive' cultivation.

1.1.3.4 France

Agache (1978) called attention to a shift in France from emmer to spelt which appeared to date from the no later than the La Tène period. Audouze and Büchsenschütz (1992), using a broad range of archaeological data, drew attention to the relationship between the timing of the shift and a settlement pattern which indicated increased movement onto hard but fertile *limon* soils. These findings concur with Bakels' (1999, 71) assessment of Aisne Valley assemblages which suggested that the early Iron Age was a major phase of innovation in French agriculture that brought with it further diversification in the types of crops used. Bouby and Marinval (2000, 208), in a comparison of 40 sites within a zone adjacent to the French Mediterranean coastline, found increasing amounts of spelt/bread wheat during Late Bronze Age and Iron Age periods but, here, emmer remained the most important wheat throughout both periods, and records of spelt were exceptionally rare. De Hingh (2000) identified a shift from emmer to spelt at a series of Late Bronze Age sites in northern French in the Meuse-Demer-Scheldt region. Matterne (2001, 79, 109), having reviewed previous evidence as well as new evidence from 78 settlements located in the northern part of the Parisian Basin (Picardie, l'Ile-de-France, nord-Pas-de-Calais, la Haute Normandie, Champagne-Ardenne), observed a similar shift to spelt (most prominent in western sections of the study area), but noted that the cultivation of spelt was highly correlated with edaphic conditions that favoured its production. However, she also noted that the pattern appeared to result equally from: (1) dietary preferences and changing food habits brought about by the Roman conquest; (2) a change from intensive crop cultivation systems to a more specialised type of cereal farming which included the introduction of extensive bread wheat farming along with a shift away from maslin crops; and (3) a desire for superior bread flours.

1.1.3.5 Italy and Greece

In Italy and Greece, archaeobotanical assemblages for the study period are dominated by barley, emmer and free threshing wheat. There are few records of spelt to evaluate but the number of records for each of these countries still remains very small. The continued lack of evidence for spelt confirms the long established pattern especially for Italy. Motta (2002, 73) and Costantini (2002) have both recently emphasised the fact that the sub species is almost entirely absent from peninsular communities in Italy.

1.2 The overview

It is thus evident that a number of changes in the frequency of staple cereal crops in different regions have been noted from the Iron Age to Roman period involving, in particular: (1) a shift from barley (*Hordeum* sp.) to wheat (*Triticum* spp); (2) the acquisition of rye (*Secale cereale*) and oat (*Avena sativa*); and (3) a shift from emmer (*Triticum turgidum* L. ssp. *dicoccum* Schübl.) to spelt (*Triticum aestivum* L. ssp. *spelta* (L.) Thell.); and (4) a shift from emmer/spelt to bread wheat (*Triticum aestivum* L. ssp. *aestivum*) as the primary wheat crop in some areas. These changes have been argued to date to different periods in different parts of Europe, and various motivations and hypotheses have been advanced to explain each phenomenon, of which the following, relating to models of production, consumption and exchange, appear to be recurrent themes (Charles and Halstead 2001).

1. Production: a process of labour (and capital) intensification, associated with extensification of land use, involving an increased use of heavy, fertile but intractable soils, possibly related to increased demand due to the growth of cities and towns or the presence of the Roman Army (Van der Veen and O'Connor 1998; Willerding 1988; Jones 1981; Knörzer 1971).

2. Consumption: a change in dietary preferences, possibly related to the culinary use of different cereal types, e.g. as gruel or bread, a shift in local traditions, a change in the status of particular foods or the effects of colonising populations (*cf.* Schucany 2005, 47; Buxó and Pons 2000; Garnsey 1999; Giacosa 1992; *cf.* Van der Veen 1988, 1991a; 1991b; Goody 1982; André 1981; Moritz 1958; Jasney 1942).

3. Exchange: a shift in the balance resulting from the introduction of new cereal types as a result of demographic movements, diffusion or importation due to trade or obligatory transfers from individuals to state, or specialisation aimed at a particular type of market (e.g. a shift away from domestic production to production aimed at a market economy) (Pals *et al.* 1989; Rickman 1980; 1971; Casson 1954; Marescalchi 1940).

Supporting or contradictory evidence for each model has been found in: (1) the weed species accompanying archaeological crops (Van der Veen 1992); (2) the perceived merits of different cereal types as described by Classical authors (Jasney 1944); and (3) the chronological and geographical distribution of cereal crops in relation to different settlement trends (Matterne 2001; Jones 1981).

1.3 Project aims and objectives

The general aim of this project is to approach the phenomenon of cereal change from a broad spatial and temporal perspective comparing the data on an equivalent basis through a standardised statistical procedure. Hopefully, this will reveal previously unrecognised patterns or strengthen previous notions. Consequently, the objectives are as follows.

1. Descriptive - To map the relative frequency cereal staples in England, Northern France, Germany, Switzerland, The Netherlands, Italy and Greece through the Iron Age and Roman periods.

2. Analytical - To interpret patterns in archaeobotanical data with respect to (a) the general archaeological/historical framework of the study period; (b) descriptions provided by Classical authors, (c) modern agronomic opinion.

Four competing hypotheses are tentatively proposed to account for chronological and spatial variation on the basis of previous findings. Namely, that the frequency changes were due to changes in: (1) production; (2) consumption; (3) exchange; or (4) some combination of the three. Alternatively, the possibility that changing cereal frequencies are best explained by none of these factors but rather by some other effect will be explored.

Evidence for the causes of cereal change will be drawn from associated archaeological, agronomic and textual evidence. Central topics addressed in this study are: (1) whether there are essential differences between Iron Age and Roman cereal patterns; (2) whether there was synchrony between similar patterns or trends at the temporal (diachronic) scale or in relation to some social/economic change; and (3) whether any particular factor could have had an overriding influence on cereal change.

The central aim is to employ the powers of scale and a standardised statistical procedure to gain a broad systematically based overview. The geographic area investigated is larger than any attempted before. Correspondence analysis has been employed to compare the data. In interpreting the patterns in the data, I have sought to bring to bear recent agronomic findings. Operating at the large temporal and spatial scale, the study provides a novel and original account of cereal change phenomena.

The relevant issues and evidence will be evaluated over the next ten chapters. In chapter two, I will set out the criteria used to define the analytical units and to construct a working database from published archaeobotanical assemblages. Next, I will detail the statistical methodology used to reveal patterns in the regional data.

The third chapter presents the results from the statistical analysis of charred archaeobotanical assemblages from the seven designated regions. In chapters four and five, I discuss the sample contexts. This is an attempt to frame the data against its agro-environmental, archaeological, social and economic backdrop. Because the adoption of iron was not contemporaneous across Europe, the fifth chapter requires a brief retrospective into the late European Bronze Age. The range of dates for the beginning of the 'Iron Age' spans from around c. 1100 BC in Greece; from c. 800-700 BC in Germany, France, and The Netherlands and from c. 650 BC over much of England. The 'Roman Period' varies from an early date of c. 750 BC (the traditional date for the founding of Rome and, therefore, the first opportunity for Roman influence) but is generally recognised to begin approximately at the turn of the millennium throughout most of central Europe, Britain, France and The Netherlands (although the Roman army was certainly active in central European areas from earlier dates).

The sixth chapter presents an overview of each of the cereal taxa while the seventh includes a more detailed assessment of agronomic data concerning their production and use. The eighth chapter addresses selection of passages taken from Classical authors portraying the variability between the taxa. It also addresses the classification of ancient cereals because this issue is fundamental to how cereals were compared. The final two chapters summarize the patterns in the archaeobotanical data with respect to archaeological, agronomic and textual evidence.

Chapter 2
Methods

2.1 Introduction

The following is a summary of the methods employed to measure, compare and interpret European cereal frequencies from selected Iron Age and Roman assemblages. It is presented in two sections. The first section addresses the methods utilised to assemble the archaeobotanical dataset and to analyze it for spatial and temporal patterns. The second section outlines the methods used to bring related lines of evidence to bear on those patterns. The standard botanical nomenclature utilised throughout this and subsequent chapters is presented in Table 2.1

2.2 The archaeobotanical data

2.2.1 Constructing the database

2.2.1.1 Sources of data

The study entailed the construction of seven separate regional cereal datasets (Britain, France, The Netherlands, Switzerland, Germany, Italy and Greece). The sites chosen for entry derive from pre-existing databases, regional reviews, or site lists provided by the suite of sources listed on Table 2.2. Some sites were also selected from archaeobotanical reports retrieved from libraries at Sheffield University, Oxford University and Trinity University (San Antonio, Texas). Sample-by-sample data was acquired by accessing original publications/site reports or by request to the original archaeobotanical analyst.

2.2.1.2 Sample eligibility criteria

The goal was to: (1) use the best quality data possible; (2) represent as wide a geographical area; and (3) balance the number of samples between countries. Thus, in countries where published accounts of carbonised remains were judged to be sufficiently abundant, a set of baseline criteria were established for site/sample eligibility (see below). Contrastingly in countries where archaeobotanical records were sparse (e.g. Greece), all available data were integrated into its dataset (i.e. as much published data as possible was incorporated into the regional dataset). Samples were drawn according to the following thresholds:

Britain:

i. Iron Age or Roman samples from available published site reports (from the sources listed above) which were found to report at least 30 samples and at least 100 total cereal items;

ii. Iron Age or Roman samples from available published reports (from the sources listed above) which were found to report greater than 10 samples with at least 1000 cereal items.

After an initial dataset was constructed, using the above criteria, it was further augmented by incorporating additional samples on the grounds that additional samples could bridge perceived gaps in the dataset's geographic and/or chronological coverage. These samples were derived from a collection of sites (from the sources reported above) which reported more than 10 samples and more than 250 cereal remains.

Germany:

i. Iron Age or Roman samples from available published reports (from the sources above) which reported at least 30 samples and at least 100 carbonised cereal items;

ii. Iron Age or Roman samples from published reports (from the sources above) which reported greater than 10 but less than 30 samples and at least 1000 cereal items.

France:

all Iron Age or Roman samples obtained from reports provided in V. Matterne's publication '*Agriculture et alimentation végétale durant l'âge du Fer et l'époque gallo-romaine en France septentrionale*' (Matterne 2001).

The Netherlands:

all Iron Age or Roman samples provided by RADAR (version 2001).

Switzerland:

all Iron Age or Roman samples from a working database at the Institut für Prähistorische und Naturwissenschaftliche Archäologie, Universität Basel-selected and provided by Dr. S. Jacomet and Dr. C. Brombacher.

Italy:

all Iron Age or Roman samples from available published reports (from the sources above) which included cereal remains.

Greece:

all Iron Age or Roman samples from available published reports (from the sources above) which included cereal remains.

A complete list of the sites and reports used in the final database is supplied in regional order in Table 2.3.

2.2.1.3 The variables recorded

The data were archived in an EXCEL spreadsheet in the following manner:

I Records data

- unique code=exclusive identifier for each database entry
- record code=exclusive identifier for the published account
- source report code=informant citing report

II Site data

- country=currently recognised title of geopolitical region
- locale=area or region within a country as specified by analyst
- site name=site name as specified by analyst
- latitude=east/west coordinate
- longitude=north/south coordinate
- site type=settlement, fort, villa, etc.

III Sample data

- sample code=exclusive code for sample
- context=archaeological context of sample as reported by analyst e.g. pit, hearth manure layer
- recovery method=floatation, wet sieve
- sample size=volumetric measures in litres, weights in grams
- sieve size=millimetres
- archaeological period=as identified by analyst
- begin date=beginning of interval as identified by analyst
- end date=end of interval as identified by analyst

IV Taxonomic data

- genus=as identified by analyst
- species=as identified by analyst
- plant part=as identified by analyst

V Quantitative data

- number of items=as identified by analyst. Note, however, that quantitative data for a handful of sites has been reported in a 'summary format' because some analysts haven chosen to publish their results in this manner (i.e. data on each individual sample was not published). Such sites were identified with the prefix 'SUM' in their sample code.

Note that, in some cases, sample records are not supported by a complete account for each variable due to the incomplete nature of the published account.

2.2.1.4 Standardising the data

All non-standard botanical nomenclature from published accounts was either updated or translated into the recognised Latin binomial and all foreign terminology translated to English. The initial data entry process revealed that more than 170 different terms had been used to record the carbonised taxa/plant parts (henceforth regarded as cereal 'items'). In order to standardise this heterogeneous terminology (as well as the level of accuracy claimed) 15 distinctive 'broad categories' of items were established. The cereal items were then allocated across the 'broad categories' according to the following criteria. The specific operation used to allocate an item to a specific 'broad category' is summarised in Table 2.4.

- Items precisely synonymous with the broad category were assigned to that broad category.
- Records of spikelet forks were multiplied by two and recorded as glume bases in the appropriate broad category.
- Records of intermediate type items were assigned proportionately to respective species/plant parts on the basis of the proportions of accurately identified specimens in that sample. Where neither species/plant part had been specified in that sample, the intermediate items in that record were not included in the database. In all cases the numbers involved were small.
- Records of *Avena* lemma bases were assigned proportionately as wild or cultivated *Avena* lemma bases on the basis of the proportions of accurately identified specimens in that sample. Where neither species' plant part had been specified in that sample, *Avena* lemma bases in that record were not included. In all such cases, the numbers involved were small. No distinction is possible between wild and cultivated oat grains.
- Records of *Triticum* sp. spikelet forks, after having been multiplied by two, were distributed between *T. spelta* and *T. diococcum* glume bases on the basis of the proportions of accurately identified specimens in that sample. Where neither species/plant part had been specified in that sample, *Triticum* sp. spikelet forks in that record were not included in the database. Records of indeterminate glume bases or indeterminate spikelet forks were ignored where it was not clear whether they derived exclusively from wheat or from precisely specified wheat taxa. The few occurrences of 'Brittle rachis' were ignored. Items marked or interpreted as fragments (f) were also disregarded.

2.2.2 Data analysis

2.2.2.1 Correspondence analysis

In order to search for chronological patterns in the proportions of different cereal types, the archaeobotanical data were analysed using correspondence analysis. The statistical package used for this was CANOCO and the program used to plot the data was CANODRAW (ter Braak and Šmilauer 2002). Correspondence analysis (CA) is an ordination technique which arranges, in this case, archaeobotanical samples along axes on the basis of, in this case, taxa and plant parts. CA may be employed where the data includes many zeros and the assumption of a normal distribution would be unjustified (a significant feature of archaeobotanical data). A sample's distance from the origin in a correspondence analysis plot reflects its degree of divergence from the 'typical' sample and the distance of a taxon/plant part from the origin reflects the extent to which it is confined to certain samples. Samples and species which diverge from the origin in the same direction are therefore likely to be associated but the distance between particular samples and taxa/plant parts is not a measure of their association. In the correspondence analysis plots presented here, different symbols are used for samples to indicate chronological period (note that mixed period samples are sometimes left blank). Sample symbols are also replaced by pie-charts showing the proportions of different taxa/plant parts in some plots (note that pie chart symbols are always indicated in cases where mixed sample symbols have been left blank- a feature of CANODRAW). In order to investigate the effect of sample size, correspondence analyses were repeated using only samples with greater than 30, 50 or 100 cereal items for all countries.

2.2.2.2 Chronological framework

The scheme adopted to standardise the samples chronologically is intentionally simple in response to two critical issues. The first concerns the lack of agreement between authors, disciplines and regional research traditions for the actual start date of the Iron Age (Harding 2006, 61). Not only was iron introduced into various countries at different dates but its rate and extent of adoption varied widely (Bouzek 1989; Champion 1989; Sørensen 1989; Rowlands 1987; Collis 1984). The second concerns a lack of precise coordination between dates for Roman cultural phases between countries.

In all cases I have attempted to use the most conservative method possible (Table 2.5). In Britain, I have followed a basic chronology set out by Collis (1984) in his review of the European Iron Age (except that I have incorporated his Gallo-Belgic period into the late Iron Age on account of its relatively brief span and a paucity of authors citing such a phase in archaeobotanical records). In France, I have followed the framework used by Matterne (2001) in the analysis of her samples. In the Netherlands, I was fortunate to be supplied with a full set of chronological phases and dates by Brinkkemper (RADAR 2001). For Germany, I adopted a compromise between the scheme used by Kristiansen (1998) and Collis (1984) on account of differences between the respective dates for archaeological phases in the north and the south of that country. In Greece, I followed Collis (1984) once again. For Switzerland, I followed the framework published in Cunliffe (1997). In Italy, I reported sample date by century because of the wide disparity in absolute dates for comparable phases between the north and south (Pallattino 1991; *cf.* van Joolen 2003).

2.3 Interpretation

2.3.1 The socio-economic context

This part of the research set out to link samples with their agro-environmental, cultural and economic surroundings, and to reveal signals, interfaces or factors which could have influenced cereal change. European regions were reviewed from seven approximately equivalent intervals:

1. 1100-800 BC
2. 800-600 BC
3. 600-450 BC
4. 450-250 BC
5. 250-50 BC
6. 50 BC-AD 250
7. AD 250-AD 450

These chronological intervals derive from recognised chronological and spatial divisions used by recognised authors. The data were derived from:

1. general reviews of the European Iron Age and Roman Period;
2. general reviews of Roman economic history;
3. general reviews of European agricultural history;
4. publications addressing the history of agricultural devices;
5. regional histories;
6. regional archaeological reviews.

2.3.2 Agronomic data

The principal goal of this part of the project was to identify: (1) the environmental variables; (2) agronomic variables; and (3) the biological potential of the taxa. This was accomplished across two separate chapters using data derived from a range of modern agronomic texts. Topics engaged include:

1. the manner in which each taxon is currently categorised specifically with reference to how those classifications relate to the analytical categories employed in this study;
2. the evolution and early history of each taxon with reference to the approximate date, route-of-entry into Europe and founder effects;
3. current distribution and agro-ecological preferences of each taxon;
4. priorities and control points associated with different types of production systems;
5. priorities associated with different processing procedures (e.g. milling, baking, fermentation, etc);
6. features or properties specific to individual taxa.

2.3.3 Ancient textual data

2.3.3.1 Constructing the literary database

The process of gathering Classical textual data for comparative purposes entailed a two stage process. Firstly, pertinent Classical passages were collected from selected texts and catalogued in a systematic fashion (for a list of authors and texts see Table 2.6). Secondly, each of the passages was examined in terms of its meaning. This proved especially problematic because the interpretation (meaning) of each of the Classical passages suffers from the inherent difficulties of translating ancient cereal epithets (the words used to name/describe cereals) into modern equivalents. As a result, cereal epithet translation had to be treated as a separate topic and dealt with in the preliminary section of Chapter 8.

Works by four 'principal authors' (Theophrastus, Varro, Columella and Pliny) form the bulk of the database largely because of these authors are recognised for their agronomic competence (Baumann 1993, 14-22; Stearn 1983) but also because they specifically deal with cereals as an independent topic.

2.3.3.1.1 The principal authors

1. Theophrastus of Eresus (4th-3rd century BC) was a highly influential naturalist/botanist from whom authorities, such as Isidore, Nicholaus of Damascus and Dioscorides, would borrow in later works. Although we possess a small fraction of his total output, a compendium of his botanical work survives in two books, *Historia Plantarum* (*HP*) and *De Causis Plantarum* (*CP*). The precision and technical detail contained within both works is extraordinary (Stearn 1983). The first book (*HP*) is an early attempt at botanical description and classification. The second book (*CP*) is an aetiology, a sort of didactic explaining the beliefs and motivations underlying agronomy, horticulture and botany. No other Classical author offers the type of detail or reveals so much about perceptions underlying Classical agriculture.

2. Marcus Terentius Varro was, without doubt, the most prolific author of ancient times with an estimated output of over 600 treatises. We posses accounts of 55 titles but only two survive: *De Lingua Latina* and *Rerum Rusticarum Libri III*. The first title results from an interest cultivated by his early teacher, the first Roman philologist, L. Aelius Stilo. The second, *De Lingua Latina*, is an assemblage of thoughts on grammar and etymology, many considered fanciful but perhaps useful in the analysis of cereal epithets. Of equestrian rank, Varro became a supporter of Pompey during the civil wars. With Pompey's defeat and the subsequent collapse of the Republic, Varro was pardoned by Caesar and employed to procure vast stores of literature for the founding of a great public library at Rome. After Caesar's death he was forced to flee and did not return until after Octavian's victory at

Actium in 31 BC. The *Rerum Rusticum* is a thorough and academic work devoted to agriculture produced some time probably before Cicero's death and the invasion of Britain in 43 BC.

3. The Spaniard Lucius Iunius Moderatus Columella (AD 4 - c. 70) was the principal author cited by White (1970) in his account of Roman agriculture. Drawing on a range of personal experience, and incorporating the works of a suite of authorities, Columella's *Res Rustica* is the most systematic and comprehensive of all the treatises in a long tradition of Roman writers on agricultural affairs. It utilises many sources no longer extant such as Cornelius Celsus, the Carthaginian writer Mago, Tremellius Scrofa and a host of lesser known sources. The work is arranged as a series of instructions, a common genre for the period. The descriptions of cereal varieties within the *Res Rustica* are particularly detailed and deal with botanical and economic topics often ignored by other authors.

4. Pliny the Elder (AD 23 - 79) is the most frequently quoted author in modern archaeobotanical reports, particularly where cereals are addressed as a separate topic. Pliny was a man of amazing energy and focus who apparently drew from at least 400 sources and 2000 manuscripts to produce his prodigious compendium, *Naturalis Historia*. The primary value of his work, published posthumously in 37 books, is that it occurs relatively late, borrows heavily, and thus serves as a vehicle from which to form an overview into Classical agricultural thought.

2.3.3.1.2 The editions utilised

The Greek and Latin passages and their respective English translations were drawn from the editions from the Loeb Classical Library. These editions offer the Classical and English text in parallel which provides the opportunity to observe and evaluate details of the translation. Brackets surround text at points where I have adopted a different translation or conveyed terminology in the original language of the Classical author.

2.3.3.1.3 Recording the data

The database was constructed by extracting Classical passages that reference cereals directly by name (i.e. all passages contain at least one cereal epithet). When a passage utilising a cereal epithet was encountered, the passage was recorded into an EXCEL spreadsheet, and the relevant cereal epithet copied alongside. Each passage was then assigned a 'context' category for review purposes (Table 2.7). For example, passages about sowing were assigned to the context of 'sowing'. Those that described a cereal's appearance were assigned to 'anatomy', and so on. Each passage could be linked to the epithet and up to three different contexts – primary, secondary and tertiary contexts.

2.3.3.2 Interpreting the meaning of the passages

2.3.3.2.1 Establishing equivalence between epithets and the archaeobotanical taxa

Before the Classical passages could be utilised in the interpretation of the archaeobotanical dataset, a formal language establishing semantic equivalency between modern and ancient cereal terminology was required in order to assure that comparisons were correct. Translation of archaic plant names is a problematic and controversial endeavour. Currently there is no universally favoured method and it is only when a term has been analysed from a variety of perspectives that agreements are reached (Fawcett 1997). One elementary approach is to map an assemblage of disclosed characteristics to the epithet. Following such a methodology, I began by listing all the epithets contained within the literary database. Secondly, by reviewing each Classical passage separately, I tabulated all the respective character traits attributed to each epithet. In this way, I was able to gain some understanding of the full range of character traits that were attributed to each epithet during the Classical period. Having accomplished this, I was then in a position to judge which epithets might be analogous to particular cereal species and subspecies.

2.3.3.2.2 Properties and merits

Having successively related some of the Classical cereal epithets to modern taxa, I then attempt to: (1) link the perceived properties and merits of cereal named by the epithets to the cereals in the assemblages; and (2) recognise the general circumstances which might promote or discourage the production, consumption or exchange of particular taxa. This was accomplished by reviewing each passage linked to each cereal epithet for contextualisation cues (i.e. deriving facts via implicit or explicit references to that epithet in the various Classical texts).

Archaeobotanical data and analysis

Chapter 3

3.1 Introduction

The following chapter provides results obtained from an analysis of the seven archaeobotanical datasets. Results for each country are presented in four sections. The first addresses the broad character of the sites and samples used in the analysis. The second section provides an overview of the composition of the samples in terms of their taxa and plant parts. The third section summarises the results of correspondence analyses which were designed to contrast samples of Iron Age and Roman date. The final section contrasts the changes in selected cereal taxa by comparing samples from a series of different chronological phases within the Iron Age and Roman Periods - each illustrated by its own correspondence analysis plot. The discussion of two countries (Britain and Germany) incorporates an additional section which highlights differences between samples derived from the northern or southern areas of those countries.

Two correspondence analyses were attempted for each country. The first analysis incorporated all cereal taxa/items noted in that country's samples. The second correspondence analysis concentrated exclusively on wheat and barley (the most common genera in the dataset a whole). Although this analysis was mainly performed in order to identify changes in wheat taxa, the inclusion of barley made the comparison possible - the mathematical concept underlying correspondence analysis mandates that at least three different categories ('species') be compared and in most cases only two 'species' of wheat were prominent during any particular chronological phase (*cf.* ter Brak C. J. and Šmilauer P. 2002; Greenacre 1984). Indeterminate wheat was always excluded from the second analysis because its overwhelming abundance in certain samples tended to mask crucial patterns in the less frequent but more precisely distinguished wheat remains. Einkorn was excluded because it was always very rare. In addition, where a particular wheat or barley item (usually chaff) distorted the overall pattern for a particular country, because of extreme rarity, that item was also excluded from the second correspondence analysis. A summary of each country's samples is provided in Table 3.1 and the Appendix. Definitions for the abbreviations adopted in the correspondences analysis plots are supplied in Table 3.2.

3.2 The British Dataset

3.2.1 Sites and samples

The British dataset is the second largest in terms of number of samples (759) yet it is quite ordinary with respect to the number of sites (33) (Table 3.1). The median number of samples per site is relatively large (14). The dataset contains a relatively high proportion of cereal rich samples (with greater than 100 cereal items) with half of all samples containing more than 24 items. The number of Iron Age and Roman samples is relatively balanced. There is a relatively high proportion of samples from indefinite dated chronological contexts (164). Iron Age samples tend to originate from rural and/or settlement contexts whereas military encampments and urban contexts dominate the Roman samples. A tendency of British research activity to focus principally on sites in the south skews the site distribution toward the southern third of the British Isles (Fig. 3.1). There are very few sites in Scotland or Wales. In the south, there is a concentrated cluster of sites in the Thames valley.

3.2.2 Species and plant parts

Very few British samples are pure from a taxonomic or anatomical/plant part perspective. Samples containing grain are more common than those with chaff and samples of grain are less taxonomically variable than those with chaff. Approximately three-quarters of the grain is wheat and a high proportion of the other grain items is barley (Fig. 3.2.). Oat and rye grain are relatively rare. Almost half of the wheat grain was unidentifiable beyond the level of genus. Glume wheat grain predominates over free threshing wheat grain by a wide margin, and spelt is by far the most common glume wheat grain. Free threshing and emmer wheat remains, although reported across a fairly great number of samples, tend to be concentrated within a relatively small number of sites. Einkorn is the rarest grain.

The chaff is distributed in much the same pattern. Spelt glume bases are the most abundant by a wide margin. Although emmer glume bases are rare they are more prevalent than the rachis of free threshing wheat. Barley rachis is less common than grain, and oat lemmas are rare.

3.2.3 Changes from the Iron Age to the Roman period

Figure 3.3, a correspondence analysis plot of all samples and all cereal taxa, shows wheat grain clustered at one end of the first axis and barley grain and emmer glume distributed towards the other end (note that one Iron Age sample from Rock Castle was omitted on the basis that it was an outliner in an earlier analysis – the result of an unusually high count of free threshing wheat rachis

Cultivated oat lemma, spelt glume and free threshing wheat rachis are clustered towards the positive (top) end of axis 2, while samples rich in barley grain are located towards the opposite end.

A correspondence analysis of the selected wheat and barley items demonstrates a classic crop processing pattern (Fig. 3.4). Emmer, spelt and free threshing grain appear as a tight cluster in the bottom right quadrant with barley rachis to the top left. Barley grain is located in the lower left quadrant on its own. The grain-rich samples are mostly of Roman date while those rich in emmer glume bases and barley rachis are most frequently from the Iron Age. Samples dominated by spelt glume bases are of both Roman and Iron Age date. Exceptions to this pattern are four large samples from Ilchester and Deansway which were comparatively rich in emmer glumes. There are a number of exceptional Iron Age samples which are rich in wheat grain but poor in barley grain, however, these tend to be relatively small with the exception of two samples from Viables farm (see: Green 1982, 81 for comment on both samples' date). The majority of free threshing wheat remains derive from deposits at two sites (granaries at South Shields) which might be linked to grain imports for the Roman legionaries.

3.2.4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat and barley items discussed in section 3.2.3 (Fig. 3.4) is presented in Fig. 3.5 with each phase (Early, Middle, Late phases for both Iron Age and Roman periods) shown as a separate plot. It is apparent from these plots that the shift from samples rich in emmer glume bases and barley rachis to samples dominated by wheat grain occurs primarily between the Iron Age and Roman periods; otherwise there is no obvious change within each period except possibly in the late Roman phase when samples with high concentrations of free threshing wheat grains appear in comparatively greater numbers (again, these are mostly from the site of South Shields). Samples associated with barley grain and spelt glumes are common throughout (except in the Middle Roman phase plot where the number of samples is very small).

3.2.5 Geographic differences

In order to test the hypothesis that the replacement of emmer by spelt was delayed in the highland zone (M. Jones 1981), highland and lowland sites (as listed Table 3.3) were analysed separately using correspondence analysis. The results provide some support for this hypothesis: while samples containing emmer chaff are fairly common in Mid-Late Iron Age samples from the highland zone (26 samples/6 sites) (Fig. 3.6), in the lowland zone they become relatively rare after the Middle Iron Age (Fig. 3.7). In addition, emmer grains are noted in a greater proportion of (albeit small) samples from highland zone (Fig. 3.6) into the Early Roman period, while in the lowland zone (Fig. 3.7), there is only one example (a small sample from Deansway) where emmer is the dominant grain after the Middle Iron Age. Thus, while it is clear that emmer had begun to give way to spelt as the major wheat component before our study period, there are some indications that it lingered on longer in the highland zone than in the lowland zone.

3.3 The German Dataset

3.3.1 Sites and samples

The German dataset contains records for 21 sites and 439 samples whose locations are shown in Fig. 3.8. The average sample count is relatively high because of relatively large proportion of large samples (27% of samples have more than 100 cereal remains) but half of all samples have less than 16 items. The data is fairly evenly split in terms of the numbers of Iron Age and Roman samples (54% to 46%) but, there are no samples from the La Tène B phase of the Iron Age. Roman samples tend to derive from military encampments or settlements (*vici*) along the Roman frontier. The sites are equally distributed north and south, of a latitudinal line running through Cologne but there are fewer sites in the northernmost latitudes of the country. Almost all sites are situated in river valleys and none of the sites are rural farmsteads.

3.3.2 Species and plant parts

The composition of the German assemblage contrasts with Britain (and, as we shall see, with that of France as well) in that barley grain is very dominant (73% of the assemblage) (Fig. 3.9). Much of the barley grain derives from sites such as the first century Roman military encampments at Neuss (*Novaesium*) and Xanten (*Colonia Ulpia Triana*) where large concentrations have been unearthed. Free threshing wheat is the next most common grain in the samples but spelt grain is also abundant. Emmer is about half as abundant while einkorn is rare. Rye grain is conspicuously abundant (4 %) and oat grain is about half as abundant as emmer grain. There is a great deal of free threshing wheat grain.

Chaff remains of all cereal species are relatively rare in relation to other countries. Spelt and emmer glume bases are more or less equally represented while einkorn glume bases and free threshing wheat rachis is extremely rare or absent from most Iron Age and Roman sites.

3.3.3 Changes from the Iron Age to the Roman period

A correspondence analysis plot of all samples and all taxa (Fig. 4.10) shows three critical features. Firstly, samples rich in rye grains are all Roman and located towards the positive (right) end of the first axis. Secondly, the effects of crop processing are evident along the second axis with samples rich in grain located towards the negative (bottom) end of the axis and glume wheat chaff towards the positive (top) end. This effect is unrelated to chronological period. Finally, samples rich in barley grains from both the Iron Age and Roman periods are clustered relatively close to the origin. Barley grain probably occupies a position near the origin of the axes due to the relative ubiquity of barley in the samples.

Fig. 3.11 shows the results of a correspondence analysis of the selected wheat items. Barley has been excluded here because its relative ubiquity results in plots isolating the few samples in which barley was absent. Free threshing wheat grain is associated with samples from the Roman period in the upper left quadrant of the plot while samples rich in both emmer or spelt grains are common in both periods. Samples rich in spelt glume bases are associated with the Iron Age (bottom right quadrant) while samples rich in emmer glume bases are most associated with the Roman period (upper right quadrant).

3.3.4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat items discussed in section 3.3.3 (Fig.3.11) is presented in Fig. 3.12 with each Iron Age and Roman phase (Hallstatt, La Tène A, La Tène C-D, Early, Middle and Late Roman) illustrated as separate plots. There are too few samples from La Tène A for comment but the figure shows that there is a cluster of samples with high concentrations of free threshing wheat grains in the plot representing the Early Roman phase. It should be noted that although samples with free threshing wheat grain are also present in plots and samples from earlier dates, many derive from a particular Late Iron Age (La Tène C-D) deposit from the site of Steinbühl (Nörten-Hardenberg, Kreis Northeim). Further note that most of these samples and sample counts tend to be small (although there are also a few with over 50 free threshing wheat grains). Finally, note that examples of free threshing grains also appear to diminish in the plot for the Late Roman period.

Emmer grains, on the other hand, are most common in the Hallstatt phase but begin to decline from the La Tène C-D phase, (although emmer can be argued to make a slight resurgence in the Early Roman phase, most of this emmer grain derives from Roman Xanten and Mülheim-Stetten on the lower Rhine where some samples yielded over 2000 grains of emmer). Emmer grain in also present in high numbers in Early Roman samples from Neuss but here it is proportionately less important than free threshing wheat grain. Contrary to the pattern observed in Britain, samples dominated by emmer chaff are common throughout both periods. Samples dominated by spelt grain and chaff are common in both Iron Age phases but less common in all Roman phases.

3.3.5 Geographic differences

The selected wheats were analysed separately for northern and southern sites (as listed in Table 3.4). The results of these analyses are presented in a series of plots in Figs. 3.13 and 3.14. From these plots it seems clear that increases in free threshing wheat grains during the Roman period result from the samples from the northern sites. There is very little difference between the amount of samples rich in spelt glume bases between the Iron Age and Roman periods at both northern and southern sites. Note, however that the analytical divide imposed (between northern and southern Germany based upon a line drawn through Cologne) chiefly reflects latitudinal differences between samples rather than cultural differences (i.e. this is not a comparison based upon cultural differences between Roman or German communities located on either side of the Rhine).

3.4 The French dataset

3.4.1 Sites and samples

The French dataset derives from an amalgam of samples from 52 sites mostly within fertile loess river valleys west of the Rhine (Somme, Aisne, Marne, Seine, Oise Authie) within the regions of Normandie, Picardie, L'Ile-de-France and Champagne-Ardenne (see Fig.3.15 for site locations). The dataset is relatively large with the third greatest number of samples (611) and the second greatest number of sites. The mean number of cereal samples recorded per site is relatively small (12) as is the number of items per sample. Less than half of all samples contain more than 14 cereal items. There are 155 samples with more than 100 items. The samples are chronologically well distributed between Iron Age and Roman contexts, and only 4% (25) of the samples are of mixed period date. The number of samples representing different Roman chronological phases is evenly distributed but Iron Age samples are predominately from the La Tène phase.

3.4.2 Species and plant parts

More than 75% of all samples contain at least one wheat item. A little more than half contain barley. 92% of the items are grain. Wheat is by far the most abundant grain (Fig. 3.16). Barley is the next most abundant grain. Comparatively few wheat grain remains are unidentifiable to the species level. Free threshing wheat is the most abundant grain, followed by emmer then spelt. Einkorn is rare. Rye and oat grain form a relatively insignificant proportion of the total assemblage.

Glume wheat glume bases dominate the chaff but free threshing wheat rachis is also represented. Emmer glume bases are slightly more common than those of spelt. Barley rachis is very rare.

3.4.3 Changes from the Iron Age to the Roman period

A correspondence analysis of all samples and cereal taxa/plant parts (Fig. 3.17) shows einkorn and spelt grains and glume bases towards the positive end of the first axis (right) and all other plant parts and taxa at the other end. Einkorn is likely to occupy this position due to its rarity but this is not the case for spelt. Spelt items are almost exclusively associated with Roman samples. Most of the spelt-rich Roman samples derive from a single site (Amiens/*Samarobriva,* 1st-4th AD) but spelt-rich samples from other Roman sites are illustrated as well. The Iron Age samples with spelt items tend to be small but there are certainly exceptions to this pattern in particular assemblages (e.g. at Thaon, Chambly and Acy-Romance).

The second axis shows Roman samples rich in free threshing wheat items, rye grain and wild oat lemma at the negative (lower) end while Iron Age samples rich in emmer items, barley items, oat grain and lemma bases of the cultivated type are located toward the positive (upper) end. For most species, grain and chaff are grouped together indicating that crop processing has contributed little to the prevailing pattern.

A correspondence analysis of the selected wheat and barley items (Fig. 3.18) replicates the above pattern for both wheat and barley.

3.4 4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat and barley items is presented in Fig. 3.19 with each phase (Hallstatt, Early-Mid La Tène, Late Gallo-Roman, Flavian-Antonine and Middle 3rd century onwards) shown as a separate plots. The Late La Tène phase is represented by very few samples so is not considered further. Emmer grains and/or glumes are common to all phases except the last (Middle 3rd century) but emmer begins to decline from the beginning of the Gallo-Roman-Julio Claudian phase (when samples rich in spelt grain begin to appear in abundance).

Concentrated samples of free threshing wheat grain are represented in all phases except the first (Hallstatt) but free threshing wheat grain becomes most frequent by the last phase (Mid 3rd century onward/Late Roman). Spelt items are most associated with the Gallo-Roman-Julio Claudian and Flavian-Antonine phases having been subordinate to emmer before that (Hallstatt and La Tène). Note, however, that spelt grains are a slightly rarer in the plot representing the Flavian-Antonine phase.

3.5 The Dutch Dataset

3.5.1 Sites and samples

The Dutch dataset is the second largest in terms of number of samples (748) and largest in terms of the number of sites (101). Nevertheless, there is a tendency for the Dutch samples tend to be small as half of all samples contain less than 9 items. The sites are generally well distributed across the country but there is a cluster of sites in the Meuse-Rhine delta region (Fig. 3.20). In terms of date, the samples are slightly skewed towards the Roman Period with 56% derived from Roman contexts, 38% from Iron Age contexts and 6% from a mixture of both chronological periods.

3.5.2 Species and plant parts

Grain is the major component of the assemblage, and barley is the most common of all grain types (Fig. 3.21). Wheat grains are almost equally divided between three wheat taxa, emmer, spelt and bread wheat. Free threshing wheat grain is the most prominent but emmer grain is more evenly distributed throughout all of the samples. Einkorn, oat and rye grain are rare. Spelt glumes dominate the chaff remains while free threshing wheat, barley rachis internode, and oat lemma bases are very rare.

3.5.3 Changes from the Iron Age to the Roman period

A correspondence analysis of all samples and cereal taxa/plant parts (Fig. 3.22) shows wheat (mostly spelt glume bases but also wheat grain of all three taxa) towards the right of the first axis with barley and oat (grain, rachis internodes and lemma bases) towards the left. Rye grain stands alone at the positive (top) end of the second axis. Samples in which rye predominates derive from Roman or mixed period contexts with the exception of two

Iron Age samples which contain a single rye grain each (from Noordbarge-Hooge Loo [Noordbarge, Drenthe] and Enschede-Elferinkse Es [Overijssel]).

A further correspondence analysis of the selected wheat and barley items (Fig. 3.23) shows both spelt grain and spelt glume bases towards the positive (right) of the first axis with all other plant parts/taxa towards the negative (left) end. Samples rich in spelt (grain and glume bases) are predominantly Roman but there are a handful of Iron Age samples rich in spelt glume bases in the lower right quadrant of the plot. Samples rich in free threshing wheat grain (upper left quadrant) are also associated with Roman contexts but there are only a few of these. In the bottom left quadrant there is a slight crop processing trend from barley (and emmer) grain to barley rachis internodes and emmer glume bases.

3.5 4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat and barley items discussed in section 3.5.3 (see Fig. 3.23) is presented in Fig. 3.24 with each phase (Early, Middle, Late phases for both Iron Age and Roman periods) shown as a separate plot. The plot shows that samples rich in spelt grain, while never especially abundant, are almost exclusively associated with Roman samples. They are numerically most abundant in the Late Roman phase. Samples with spelt glume bases, however, are evident from the Middle to Late Iron Age (e.g. Son en Breugel-Hooidonkse Akkers). Free threshing wheat grain, like spelt glume bases, appear first in the Middle Iron Age but are most prevalent in the Roman period. Emmer grain and glume bases, having persisted as cereal components from the Early Iron Age, have largely disappeared by the Late Roman phase.

3.6 The Swiss Dataset

3.6.1 Sites and samples

The Swiss dataset is composed of 435 samples from 12 sites (Fig. 3.25) clustered in the vicinity of Basel and its adjacent cantons. The average number of samples recorded per site (33) is relatively high. The average number of items per sample (3426) is also very high because a relatively high proportion of the samples (11%) contain more than 1000 items. Many of these derive from the Roman granaries at Augst. There are no mixed-period samples. The majority of samples are Roman (see Table 3.1). Iron Age samples tend to be from late chronological phases and condensed into three sub-phases of the La Tène (Lt 1-3).

3.6.2 Species and plant parts

Grain dominates the Swiss assemblage (Fig. 3.26). Much of the cereal grain is barley, free threshing wheat or emmer. Rye grain, as is the case in Germany, is uncharacteristically abundant. Einkorn and spelt grain are present at relatively low frequency while oat grain is very rare. The chaff of all species is particularly rare.

3.6.3 Changes from the Iron Age to the Roman period

A correspondence analysis plot of all samples and cereal taxa (Fig. 3.27) demonstrates the effects of crop processing in the determination of sample composition. Samples with chaff items tend to be located in the upper, right quadrant. Oat lemma bases are the only exception to this. Samples rich in spelt glume bases and free threshing wheat rachis are predominantly Roman. Samples with einkorn glume bases, though rare, tend to be associated with Iron Age contexts. Grains of all taxa are clustered near the origin of the plot.

A correspondence analysis of the selected wheat and barley items (Fig. 3.28) shows no new pattern (rye is abundant in Switzerland but it has been omitted in order to provide better resolution of the pattern of wheat and barley). Samples rich in spelt grain (lower right quadrant) as well as spelt glume bases (upper right) tend to be associated with samples from the Roman period.

A final plot of the selected wheat and barley grain items with chaff excluded (Fig. 3.29) potentially provides a better illustration of patterns in the grain taxa. Samples rich in spelt grains (mainly from the Roman period) are towards the positive end of the first axis while samples rich in emmer, barley and/or free threshing wheat grains are associated with both periods.

3.6 4 Changes within the Iron Age and Roman periods

The correspondence analysis of selected wheat and barley items discussed in section 3.6.3 (Fig. 3.28) is presented in Fig. 3.30 with each phase (La Tène 1, 2, 3; Early, Middle, Late

Roman) shown as a separate plot. These plots show that samples rich in spelt grain and spelt glume bases are principally a feature of the Early and Middle Roman phases. Note, however, that the increase in spelt grains is gradual, more or less replacing emmer by the Middle Roman phase.

Samples rich in spelt glume bases appear to become common from the La Tène 3 phase. Free threshing wheat and/or emmer grains are present to some degree throughout all phases. An examination of sample records indicates, however, that examples of free threshing wheat chaff are mostly restricted to Late Roman samples.

3.7 The Italian Dataset

3.7.1 Sites and samples

The Italian dataset is composed of 111 samples from 22 sites whose locations are shown in Fig. 3.31. The sites are fairly well distributed throughout the peninsula but there are two clusters of sites around the areas of Rome and Pompeii. Most of the Italian samples are Roman and the number of remains contained within the samples is relatively small (Table 3.1). Only 21 samples contain more than 100 cereal items. Because Italian archaeobotanical reports tend to been published in summary format, the number of samples logged per site is usually one.

3.7.2 Species and plant parts

The vast majority of the Italian samples are composed exclusively of grain (see Fig. 3.32). Grain of free threshing wheat is most common, followed by barley, then emmer. There is a trace of spelt and einkorn grain. Rye grain is not abundant but it is slightly more frequent than spelt or einkorn grains. Almost all the chaff is emmer but chaff remains are relatively rare. Italy contrasts with other geographic regions in that here the remains of free threshing wheat predominate over those of glume wheats by a significant margin.

3.7.3 Changes from the Iron Age to the Roman period

A correspondence analysis of all samples and cereal items (Fig. 3.33) shows an isolated/unusual Roman sample (unusual in the sense that it is composed exclusively of rye grain) at the positive (right end) of the first axis with the rest of the samples towards the negative (left) end. In contrast, the second axis shows samples, mostly Roman, rich in free threshing wheat towards its negative (bottom) end. A subsequent correspondence analysis (Fig. 3.34) of the selected wheat and barley items shows several samples rich in free threshing wheat (again mostly Roman) towards the negative (left) end of the first axis. Samples rich in barley grain are chiefly separated from those rich in glume wheats at the positive (top) end of the second axis, but neither group is exclusively associated with a particular chronological period.

3.7.4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat and barley items discussed in section 3.7.3 (Fig. 3.34) is presented in Fig. 3.35 with each phase (9^{th}-10^{th} BC; 7^{th} BC; 6^{th}-5^{th} BC; 4-2^{nd} BC; 1^{st} BC; 1^{st}-4^{th} AD) shown as a separate plot. These plots show some change through over time, however, in many periods (e.g. 7^{th} century BC) there are clearly too few samples to allow for a definitive analysis. There are instances and examples of samples rich in barley and free threshing wheat grain in each of the periods (upper left and bottom left) and in almost every chronological phase. Overall, examples of samples rich in emmer grain (lower right) are less prevalent than those of free threshing wheat and in the final Roman phase free threshing wheat is almost the only wheat grain type.

3.8 The Greek dataset

3.8.1 Sites and samples

The Greek dataset is comprised of 9 sites (Fig. 3.36) and 250 samples. Most of the samples are small with only 15 containing more than 100 cereal items. The chronological distribution of the samples is poor with most sites/samples being from Iron Age contexts. Only one site, Nicopolis ad Istrum, provided samples of Roman date.

3.8.2 Species and plant parts

Almost all of the cereal items are grain (Fig. 3.37) with barley grains composing over half of this. Free threshing wheat and emmer grains are present in almost equal proportions. There is a trace of spelt and einkorn grain and rye grain is very rare. Almost all of the chaff is made up of emmer glume bases.

3.8.3 Changes from the Iron Age to the Roman period

A correspondence analysis plot of all taxa/items coded by period (Fig.3.38) illustrates a strong contrast between Roman samples, composed largely of free threshing grain, towards the positive (right) end of the first axis, and Iron Age samples composed largely of barley and emmer grains (with traces of einkorn and spelt grain and emmer glume bases) toward the negative (left) end. Note that examples of rye grain are also almost exclusively associated with samples of Roman date. Barley rich samples (with a few minor traces of spelt grain) are distinguished from those with emmer glume bases and indeterminate wheat on the second axis (at the positive, top, and negative end respectively). A plot of the selected wheat and barley items (Fig. 3.39) shows the same general pattern.

3.8 4 Changes within the Iron Age and Roman periods

The correspondence analysis of the selected wheat and barley items discussed in section 3.8.3 (Fig. 3.39) with each phase (Protogeometric, Geometric, Archaic, Classical-Hellenistic, and 'Roman 2' phase) illustrated as separate plots (Fig. 3.40) shows samples rich in emmer (grain and the occasional glume base) gradually declining. By no later than the beginning of the 'Roman 2 phase' (0 AD) emmer is largely replaced by free threshing wheat. An examination of the individual contents of each sample additionally reveals that, although free threshing wheat is a component of samples from earlier Iron Age phases, free threshing wheat is not generally dominant in samples containing both wheats until the Archaic phase (top right). There are, however, so few samples with examples of wheat from the Archaic and Classical-Hellenistic phases that it is impossible to argue for any real pattern in wheat frequencies with certainty.

3.9 Summary

3.9.1 General observations with respect to each region

3.9.1.1 Britain

The British samples suggest that Iron Age cereal production in Britain was dominated by barley and spelt along with some emmer. Free threshing wheat, though rare, became more common from the Early Roman phase. Spelt was generally the most dominant wheat type almost completely replacing emmer at many sites during the Roman period. The shift away from emmer was somewhat delayed in the Highland Zone.

3.9.1.2 Germany

The German assemblages examined here indicate that barley was the dominant cereal from both the Iron Age and Roman periods although the proportion of wheat in German samples may slightly increase through time. Emmer and spelt were common ingredients in cereal remains from both periods but emmer was usually the dominant wheat component in samples up until the end of the Middle/Late Roman phase (when emmer began to give way to spelt and free threshing wheat, both of which had begun to increase gradually from the Early Roman phase).

3.9.1.3 France

Barley and emmer were the predominant cereals found in the samples from northern France but remains of spelt and free threshing wheat were nevertheless present in a modest number of samples (even in samples from as early as the Early Iron Age). By the Julio-Claudian phase, however, the relative balance of spelt and free threshing wheat tended to increase gradually compared to previous periods. The proportion of wheat was relatively high in France in comparison to other countries and wheat tended to be a more consistent feature in the French samples.

3.9.1.4 The Netherlands

Dutch samples indicate the same general pattern throughout both the Iron Age and Roman period - one where barley predominated with additions of emmer. Spelt and free threshing wheat, though relatively uncommon in Dutch assemblages, were nevertheless most common from the Middle Roman Period.

3.9.1.5 Switzerland

The Swiss samples indicate that emmer, spelt, free threshing wheat and einkorn were all present in varying amounts during the Iron Age and Roman periods although examples of einkorn in the Roman period were less abundant. Rye was unusually abundant in

Switzerland with respect to samples from other European countries. Free threshing and spelt were characteristically more important cereals during the Middle Roman Period when emmer became proportionally less important.

3.9.1.6 Italy

Although the number of samples and the amount of remains found in them is very low, a couple of features emerge. Barley and free threshing wheat are conspicuous in samples from both periods in Italy. The samples analysed here suggest that free threshing wheat was an important cereal feature from as early as the 6th c. BC when it began to very gradually displace emmer. Spelt was almost nonexistent in Italy and I found little published evidence of it being recorded in samples from areas of central-southern Italy.

3.9.1.7 Greece

Published sample assemblages from Greece are exceptionally rare. The ones analysed in this study tended to be dominated by barley and emmer. There was a substantial increase in the amount of free threshing wheat in samples some time between the Archaic Period and the end of the 'Roman 2' phase. There are, however, too few samples from the Archaic Period through the Classical phase to even begin to account for when this shift might actually have taken place. Spelt wheat was almost completely absent from these Greek samples and was confined to northern sections of the region (Macedonia).

3.9.2 Some general observations with respect to the Iron Age and Roman Periods

1. Emmer decreased through time in all regions. It was most prevalent in the Iron Age but was often a significant, although intermittent, component of Roman samples. Emmer was seldom absent from any phase of the study period.
2. Spelt was apparent in the initial phases of every study region. Its European introduction appears to predate the Iron Age. Spelt wheat generally increased throughout the Iron Age of most regions with intermittent breaks at individual phases and with particular rates. However, in Greece and Italy, records are too few to realistically infer a pattern for spelt. In Britain, where the Iron Age occurs relatively late, spelt was relatively important from an early date.

3. In most regions free threshing wheat can be argued to have slowly increased through the study period but, in Switzerland and Germany, any trend for free threshing wheat is less definitive with substantial amounts being present from an early date. Hexaploid wheats (spelt and free threshing wheat) generally increased through time in all regions. Although free threshing wheat became more important through time, it generally failed to replace glume wheat during the study period. Indeed, free threshing wheat was not a dominant wheat (with respect to glume wheat) in the final phases of any region other than Greece or Italy (where records are sparse). The farther north the region, the more this is the case.
4. Barley was always a very important grain during the study period. In most cases barley maintained an equal status with wheat until the Roman period when it appears to have declined very slowly in importance.
5. Rye was relatively abundant in Germany and Switzerland but there were examples of rye in Greece as well. It is more common than spelt in Italy. In the Netherlands it was rare but almost always Roman. In almost all instances, rye derived from Roman samples.

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Chapter 4
Agro-ecological factors

4.1 Introduction

This chapter explores the ecological and environmental aspects of the study region. It is meant to: (1) identify the primary ecological divisions within the region; (2) explain how the study region's primary ecological divisions relate to cropping choices and; (3) compare each country's agro-potential.

4.2 The agro-ecological context of the study area today

Climate and soil are two main factors which help to determine the spatial configuration of agriculture at large scales (Bryant 1997; Claiborne 1970). Europe's climate is created by three main factors (Cole 1997). The first, and most important, of these is latitude which determines, among other things, the length of the days; the severity of seasonal temperatures and precipitation pattern. The second factor is the position of the landmass with respect to continental and oceanic influences. The final factor is topography, the elevation and alignment of the land with respect to sea level. Figure 4.1 illustrates the major climatic regions of the study area. Three main air pressure zones act in concert to create their weather (Tavernier 1981): (1) a high pressure area over the Azores is responsible for the hot, rainless summers across the Mediterranean region; (2) a high pressure area over Asia fosters periods of severe winter weather in interior regions; (3) a persistent low pressure area over Iceland is responsible for the moist rainy climate along the Atlantic margins.

The distribution of rainfall varies considerably across Europe. In the Mediterranean, precipitation falls almost exclusively in the winter while in other parts of the continent it is more regularly distributed but becoming less predictable as one travels east. Although mean annual temperatures vary locally with latitude and altitude, mean temperatures reach their highest in the Mediterranean where they frequently rise above 17° C. Over much of the remainder of the study area the mean annual temperature averages between 8 -12° C (FAO 1981).

Soils in the study region reflect the nature of the parent rock over which they have formed (FAO 1981). The geology of the area is mainly dominated by thin quaternary sediments (Fig. 4.2). There are, however, areas of relative deep alluvial deposits and glacial outwashes in the west as well as in high altitude localities. The soils of northern Germany, the northern half of The Netherlands, and northern Britain are relatively young and poor having been subjected to the effects of the last glaciation (Fig. 4.3). Along the Atlantic margin, soils tend to have borne the effects of heavy weathering.

Outside glaciated regions, cambisols, luvisols or brown podzolic soils containing greater amounts of organic materials and minerals become more common. In lowland areas, sandy fluviosoils abound while parts of cool humid highland areas (e.g. Scotland) are characterised by acid poorly drained, podzolic soils. Portions of four countries (southern Britain, northern France, central Germany, and the southern Netherlands) fall within an arc of sedimentary deposits that make up some of the most desirable agricultural soils in Europe. Roughly three quarters of this belt is dominated by silt loam soils with silt contents of around 80% and clay contents of 10-20% (Verstraeten and Poesena 2002). The narrower western quarter is much sandier with sand content as high as 40-50%. South of this, complex geology is responsible for the rugged landscapes of the Jura, the Vosges, the Black Forest and the Massif Central. Soils in this area (Switzerland, central and eastern France, southern Germany and northern Italy) are typically coarse lithosols formed over bare rock in a highly dissected topography. Here, the arable fraction is generally less than 25% (Fossati and Ingold 2001). Further south, in Greece and Italy, conditions become more complex owing to the peninsular orientation of both countries and highly varied topography. Some areas contain pockets of very rich volcanic deposits but more generally soils are stony, coarse-textured, deficient in humus (eutrytic and dystric cambiosols and chromic luvisols) and highly weathered as a result of being formed from soft limestone deposits.

All major climate zones differ slightly in terms of the general pattern of arable agriculture. Farms in the northernmost regions (the northern Netherlands and northern Germany) have suffered historically from low relative agricultural profitability due to low mean temperature, moisture accumulation, and the low carrying capacity of local soils. The presiding farming pattern in this region today is one of mixed farming with stock breeding and dairy production making up the most significant component. Predominant crops include potatoes, bread wheat, barley, sugar beet and cabbage.

Further south, on the loess soils (south-western Germany, the southern Netherlands, northern France), there is a much wider degree of variation in the types of crops sown and the types of rotations employed. Where cereals are grown, they are almost always autumn sown and grown in rotation. Spring sown cereals constitute less than 5% of the total (Curtis 2002). Bread wheat is generally planted on the best soils. On lighter soils, rye, barley or *Triticale* is usually preferred (Porsche and Taylor 2001).

In Alpine areas (Switzerland, Southern Germany parts of central and western France), poor fertility, high rainfall at harvest and short seasons typically constrain arable production (Bradshaw 2000). Cereal production predominates in riverine valleys where specific micro-climates favour their growth. In Switzerland, much of the non arable fraction is given over to high value pasture and livestock.

Agricultural production in Italy and Greece is defined by the extremely dry summers which may last for up to five months (Horden and Purcell 2000; Purcell 2000; Braudel 1992; 1979). Most of the arable land is given over to deep rooted, perennial, drought hardy crops such as grapes and olives. Cereals are grown as part of a rotational strategy that exploits the brief, but seasonally predictable, pattern of annual precipitation. Durum wheat production is spread over most of the cereal growing area but bread wheat is sown in the mountainous districts where rainfall is more evenly distributed (Borghi 2001).

Regional contributions to the total European wheat harvest (by far the most important crop) are varied. The major wheat growing countries in order of total production are France, Germany, Britain, Italy, Belgium/Luxembourg, and the Netherlands (Curtis 2002). The Greek contribution to the total is minimal. Wheat is particularly productive in Europe, and western European farmers record some of the highest wheat yields in the world. The Netherlands reaped an average of 8.6 tonnes/ha from 1993 to 1995, with Britain averaging 7.5 tons/ha (USDA 2006). There is a clear contrast in productivity between the northernmost and southernmost farms in every study region (Winchester and Ilbery 1988, 6). Typically, wheat is produced in a rotation schedule with other types of arable crops.

4.3 Implications for cereal frequencies

The entire study area is characterised by south-north/east-west temperature and rainfall gradients which tend to promote the use of short season, drought resistant crops in the southern latitudes. In the middle latitudes, mild conditions, and lengthy growth season, provide farmers with an opportunity to collect increased moisture and light from their agro-environment. In the northern latitudes, the length of the growth season is constrained by harsh winters and short season conditions. In these areas, cold-sensitive crops (crops with a low base temperature rating) are either spring sown or not sown at all.

Although it is difficult to draw conclusions about relationships between soil quality and cereal productivity, agronomists generally accept that the most productive soils for cereal production dominate the middle latitudes – a zone which lies between the lighter, sandier soils of the north European Plain and the coarse, thin soils of the more southerly Alps. Because these soils can provide ample nutrient reserves, water holding capacity, and favourable structures for root growth, they are able to support crop types with high soil nutrient demands. In contrast, soils in the Mediterranean are heavily weathered and not as naturally productive as those further inland. At the infra-regional scale, the European agro-ecological situation can be complex. Nearly every country contains some mountainous land where crop species composition can vary along an elevation gradient or where differences in geology and aspect create environmental niches suitable for individual crop types.

A whole range of cereals are currently grown across the study area and thus hold the potential to have been grown there in the past. The main determinants governing crop selection seem to be: (1) the basic conditions for plant growth – e.g. baseline temperature, soil or moisture availability – climate and soil; (2) yield potential – the capacity to unlock the genetic potential of the plant; and (3) the potential to meet or exceed quality standards demanded by the target market.

Chapter 5

Integrating archaeological evidence

5.1 Introduction

This chapter provides an overview of the political, cultural and economic developments beginning from the earliest phases of the European Iron Age. It summarizes what is currently understood about the production, consumption and exchange systems of each region and highlights socio-economic changes which could have influenced cereal frequency. While the circumstances for most countries are discussed individually, some are dealt with in accordance to the prevailing research tradition. Thus, the review of some countries (during particular chronological phases) entails descriptions of places, events, and patterns which extend beyond present geo-political boundaries. For instance, Roman France and parts of the southern Netherlands are amalgamated in a sub-section which addresses the western province of Gaul. The discussion of the northern Netherlands and southern portions of Roman Germany is likewise conflated with that of Roman Germania.

5.2 Regional overviews

5.2.1 The gradual adoption of iron (c. 1100-800 BC)

Scholars postulate that the Iron Age develops out of eight regional late Bronze Age traditions formed on the basis of common trading practices, burial customs, material culture and religious beliefs (Kristiansen 1998). Fig. 5.1 shows the position of these with respect to the study area. Within these there is substantial variation in the dates for iron introduction (Cunliffe 1997; James and Rigby 1997; Bouzek 1989). Textual sources and fragmentary archaeological evidence suggest that iron working developed as an industry amongst the Hittites, who flourished in Anatolia from about 1450-1200 BC (Gurney 1966). From there, iron smithing spread across the Middle East mostly during the 13th century BC (Dezsö 2001). The new metal was subsequently adopted across Asia and Europe and became common in some parts of Greece by the middle of 11^{th} century BC (Varoufakis 1983). From Greece, it slowly spread westwards becoming more or less common in the various countries of the study region over the next five centuries. Greece and the Aegean islands precede north western Europe in the general use of iron by at least three centuries.

5.2.1.1 Greece

The beginning of widespread iron use in Greece coincides with the Proto Geometric Period (c. 11th -9th BC). The Proto Geometric period is marked by: (1) the final disappearance of Mycenaean culture; (2) the reputed arrival of completely new populations to Greece; (3) persistent regionalism brought about by decentralisation of political control; (4) the dissolution of former Aegean trade networks; (5) the advent of single burial cremation; and (6) the introduction of wheel-made ceramics which are highly stylised in form and precisely crafted with geometric motifs (Morris 1994; Popham *et al.* 1993; Cherry *et al.* 1991; Morgan 1991; Snodgrass 1989).

With a few exceptions, settlements take on the perspective of local cultures and there is little evidence for any type of centralised political control (Snodgrass 1980). The whole of Greece appears cut off from its immediate neighbours (Haggis 1993, 133; Collis 1984, 36). The role of the state in agriculture and the scale of agriculture was also reduced (Killen 1998). Settlements were separated spatially into distinct clusters often isolated by topography or lack of suitable roads (Haggis 1993, 143).

The period is poorly understood in terms of its economic history. Most of the material evidence derives from mortuary contexts, and the range and number of settlements excavated is small (Morris 1994). Finds from a limited number of complete stratigraphic sequences (e.g. Lefankandi, the Argolid, Nichoria, Pylos, Athens, Knossos,) dominate its general discussion (Morris 1994, 2000). Very few archaeobotanical assemblages are published for the period (Hansen 1988). Interpretations of the evidence are framed in a manner which sees palatial economies as complex and proto-geometric economies simple (Thomas and Conant 1999). On the whole, however, few would argue against a model which visualises Greece as a stable agricultural society based upon small and autonomous agricultural communities functioning in relative isolation (Whitely 2001; Foxhall 1995; Wells B. 1992; Burford 1993; Cherry 1988; Jones 1987b; Bintliff 1982; Sakellariou 1980). Holdings must have been small with their owners cultivating exclusively for their own subsistence (Frayne 1979). The arable fraction of agricultural economy was almost certainly based upon three types of crops: cereals (wheat and barley) grapes and olives with pulses a probable addition (Sarpaki 1992).

5.2.1.2 The Urnfields of central Europe

The period from 1100 to 850 BC, although chronologically designated by Reinecke (1930) as Hallstatt A and B, is characterised by a type of culture known as the Urnfield. The Urnfield is usually defined as a pre-Celtic culture but it is also considered by others to mark the origin of the Celts as a unique cultural group. The distinguishing feature which distinguishes it is a burial tradition. An urnfield is a burial ground typically comprising between two and two hundred cremations deposited directly into the ground. Individual cremations may be interred in ceramic cinerary vessels or remains may be interred loose. There is almost never a delimiting boundary to the cemetery as a whole. The dead are often buried with little or no material objects except a ritual fire ignitor or perhaps an incense burner. Analysis of the 'urn fields' suggests few material or social differences (Bouzek 1989). Even the richest Urnfield burials were deposited in wooden or stoned-lined graves with the most modest barrow or cairn above (Haywood 2002).

The settlement pattern indicates that most Urnfield people lived in simple farming communities. Typical Urnfield houses are clustered together, some with a more prominent structure in the centre (Bouzek 1989, 38). Storage pit areas remote from the settlement indicate that there was sometimes the common storage of grain but there is little evidence to indicate the existence of specialised farm structures (Knörzer 1991).

The vast size of urnfields in areas such as the Transalpine region suggests a sharp rise in population over previous periods (Cunliffe 1997, 44; Well 1984, 38). Urnfield period hillforts are often located in inaccessible places and constructed to take strategic advantage of the local terrain. This may suggest the presence of a coercive power which was able to take command of surplus production (Cunliffe 1997). Iron was not common in Urnfield communities and was almost never employed in a domestic sense. The characteristic tool of the period was the bronze socketed/winged axe and many tools remain simple with stone examples persisting in the Urnfield's northern margins. Urnfield livestock included horses, cattle, pigs, sheep and goats (Harding 1989). Sickle hoards and grain storage pits indicate the importance of cereals and pulses (Wells 1984, 50). Burials have occasionally yielded carbonised remains of what appears to be leavened breads (Rösch 1998; Küster 1991). Substantial quantities of nuts and berries were also gathered from neighbouring forests (Audouze and Büchsenschütz 1992). Although horses were present, the state of technology seems to have limited their role as traction animals (Audouze and Büchsenschütz 1992). Wool was spun as is evident from spindle whorls. Salt mining was an important component of some local economies and there was widespread interest in the amber trade and bronze working (Audouze and Büchsenschütz 1992).

5.2.1.3 The Alps

Evidence from the excavation of lake villages dominates the discussion of the late Bronze Age in Alpine regions (Menotti 2001). These lake-margin communities, first discovered in 1850 at Lake Zurich, are especially prevalent in Switzerland where they are known from several especially well preserved examples at Lake Constance and Lake Neuchâtel. Some of these sites were founded in the Neolithic and include sequences which show the continuous cultivation of cereals (Rösch 1993). Most consist of the remains of rows of neatly organised rectilinear houses, resting on piles, slightly raised above the archaic lake shore perhaps as protection against a cycle of seasonal flooding (Menotii 1997). Typically, each village is provided with a ring of outer piles which may have served as some kind of defensive wall. Their inhabitants where efficiently organised, with each family probably participating in the cultivation of cereals, and the management of sheep and goats, as well as gathering plants and hunting of wild animals (Audouze and Büchsenschütz 1992). As in many European regions, bronze axes, knives and sickles are especially common (Audouze and Büchsenschütz 1992). Finds from graves show that bronze working had become highly advanced at the local level and the composition of the copper in metal objects suggests indigenous sources of ore and thus the presence of a local mining industry (Rychner 1995). Jewellery and weapon design was comparatively sophisticated relative to neighbouring countries and, as elsewhere in western Europe, the scale of castings had improved over previous phases but not to a point where iron was used to make utilitarian objects (Collis 1984).

5.2.1.4 Italy

Archaeologists generally approach late Bronze Age Italy from four regional perspectives, treating the Po valley, peninsular Italy, Sicily and Sardinia separately. The Po Valley cultures were heavily influenced by Urnfield Europe as demonstrated by craft and metalwork traditions which took on forms and styles comparable to central European communities. Sheet-metal buckets of Danubian basin, metal greaves with embossed Urnfield motifs, single cast bronze swords and poppy headed pins are amongst the list of items recorded on the region's sites (Pallottino 1991; Collis 1984). Cultures further south in the Apennines, however, communities were more conservative and remained more wedded to earlier traditions (Forsythe 2005; Pallottino 1991).

Sicily was characterised by a rapidly evolving set of cultures (e.g. Elymian, Sicanian and Siculian) some of which came to develop a cosmopolitan lifestyle, adopt an alphabet, and organise themselves into confederations of quasi-autonomous states (Malone 1994).

In Sardinia, the Nuraghic civilisation flowered from the 10th to the 6th century BC (Leurquin 1996; Webster 2001). Here, trade with the eastern Mediterranean is attested by finds of imported metal tools (most of Cypriot origin), ox-hide ingots and ceramics (Webster 1996).

Throughout the period, agriculture probably remained the mainstay of human subsistence, with livestock rearing playing an important role alongside the cultivation of cereals and pulses (Forsythe 2005; Bartoloni 2002; De Grossi Mazzorin 2001; Pacciarelli 1982; Ridgway and Ridgway 1979). The grafted olive is believed to have been introduced from Greece in the previous Mycenaean period and grape cultivation was well established. The first bronze scythes appeared during this period and towards the end of the phase there may have been minor improvements to the ard (van Joolen 2003; Forni 1998). Three types of land utilisation are distinguished: (1) self subsistence with prolonged or sectorial fallowing; (2) permanent cultivation of plots; and (3) rotational farming of medium sized plots (Forni 1998). In some regions there is an increase in the proportions of sheep and goats over previous periods which may be due to the accumulation of animals by a new class of wealthy individuals (De Grossi Mazzorin 2001).

5.2.1.5 The Low Countries

Despite the dearth of late Bronze Age sites in the Low Countries, there is ample research which indicates that this phase was one of agrarian, demographic and economic expansion (Fokkens 1997; Roymans 1991). Most recent publications argue that the origins of the Celtic field systems in this area can be dated to later part of the Bronze Age (Speck *et al.* 2003). Bronze objects from this period are far more numerous and arrive from more diverse regions, and prestige items like horses are more common than in previous phases. New artefact types include technically superior chisels, knives and a new type of axe with a socket intended to fit a handle. Spearheads, swords, pins, axes, and even bowls became larger as casting was attempted on more ambitious scales than ever before. Bronze sickle blades became readily available, with some arriving from distant places like northern Switzerland (Hachmann 1976), and there is evidence for intensively farmed areas in the south (de Hingh 2000). Overall, however, the Low Countries have been traditionally viewed as conservative and materially impoverished relative to neighbouring Urnfield/Hallstatt A and B cultures of southern Germany and north eastern France (Kooi 1979).

5.2.1.6 Britain

Britain held a pivotal place in the Atlantic Bronze Age and because of its metal resources, was internationally important throughout almost all of its phases. Tin was exported from Cornwall and gold and silver were traded from Ireland (Hawkes 1984). Artifactual evidence suggests that late Bronze Age Britons maintained close contact with continental communities and developed similarly in terms of technology (Cunliffe 1997; James 1997). The material culture of the period is principally viewed from a metallurgical perspective. For the first time, there was the alloying of metal with lead. Bronze swords were produced in larger scale castings, where previously it had only been possible to fashion short blades (Hawkes 1984; Thomas 1989). Agricultural tools were mass produced with metal sickles and axes distributed in large quantities. Almost all tools, nevertheless, continued to be fashioned from bronze, stone, bone or wood rather than iron (Fowler 1981).

There is considerable evidence that the density of settlement and the intensity of land use increased during this phase and the mapping of late Bronze Age field systems suggests that the highly friable soils adjacent to river valleys were the preferred locations (Bryant 1997; Rogerson 1995; Harding 1989; Thomas 1989). Cunliffe (2004, 73) characterises land use during the period from 1400 to 850 BC as incorporating large areas of predominantly rectangular shaped coaxial fields. The settlements itself was often situated in an enclosure. Animal corralling may have begun to play a substantial role in the agrarian economy sometime between 1100 and 850 BC (Cunliffe 2004, 73). Small hillforts began to become common and there is increased evidence for horses and warfare over the previous period. Food production was largely based on mixed agriculture with cereal cultivation and stock rearing. Cattle, pigs, sheep and goats continued to be the main meat animals, providing a range of secondary products for clothing and tool manufacture. Fishing and hunting were locally important and a range of wild foods was exploited.

5.2.2 Eastern influences and regionalism (c. 800-600 BC)

5.2.2.1 The Mediterranean

The eighth century BC ushered in a formative period in European prehistory where, once again, change appears to originate predominantly from the east (*cf.* Hammond 1976). In the eastern Mediterranean, Phoenicians began aggressively to expand their trade interests as far as the North Atlantic with the founding of colonies such as Cádiz (Markoe 2000; Aubet 1996). Soon after, the Greek city states of Chalcis and Euboea, Corinth, and Rhodes, having experienced a phase of rapid population growth and urbanisation, began the process of founding colonies: (1) along the coastline of Sicily; (2) at Pithecusa, on the island of Ischia in the Tyrrhenian Sea; and (3) across the toe of Italy and north Africa (Boardman 2006). From the Pontic Steppe, nomadic peoples, known as Cimmerians by later Classical authors, began penetrating into the Great Hungarian Plain via Danubian routes possibly introducing improved breeds of horses and horse trappings (Metzner-Nebelsick 2002). Midway through the period (c. 700- 650 BC), Greek and Italian (Etruscan) art became 'orientalized' - influenced by formative motifs from Mesopotamia, Asia Minor and Egypt. On the western coast of Italy, Etruscan communities reached their cultural apex between 700-600 BC finally assimilating the remaining elements of neighbouring Villanovan, Umbrian, Ligularian, Golaseccan and Venetian stock (Barker and Rasmussen 1998). Almost simultaneously, many of western Europe's seminal cities emerged along the margins of northern Sicily, peninsular Italy, eastern France and southern Spain spurred on by an aristocracy seeking to further consolidated its political power (Bouzek 1997; Starr 1977).

5.2.2.2 Hallstatt C Central Europe

Although the first iron objects north of the Alps appear during the Hallstatt A and B phases, archaeologists recognise the beginning of the Hallstatt C (c. 800-700 BC) as the beginning of iron-dominated metallurgy in the heart of Europe. It is during this phase that communities lost their Urnfield linearity and evolved genuine 'Celtic' traditions in terms of linguistic and material culture (Ellis 1990).

Although the bronze working tradition carries on much as before, bronze was now only utilised in situations where the superior properties of iron are not necessarily required (Collis 1984). Along with the change in metallurgy comes an infusion of artistic ideas and techniques arriving via Transalpine and Danubian trade routes. Iron long swords, fine painted pottery, elaborate bronze vessels and vases with graphite decorations stand out (Briard 1997; Pare 1992). Local artistic traditions were, nevertheless, more conservative than those adopted in Greece and Italy. Ceramics continued to be decorated with geometric motifs, and figurative representations on utilitarian items remained relatively rare (Baitinger 1999). A powerful distinction between social classes is attested by the presence of elaborate burials and costly goods deposited in graves (Briard 1997). Elites were now interred with richly decorated weapons which perhaps suggest that commoners were engaged in agricultural activity under the protection of a dominant warrior elite but their protectorate. Most communities were small ranging in size from ten to fifty people (Wells 1984, 58). Salt, metal ores, amber and possibly slaves were important trade commodities. The salt mines at the prehistoric site of Hallstatt are unique in scale and amongst the oldest industrial complexes in Europe (Kurlansky 2003; Barth 1990 Wells 1984, 88).

The evidence seems to suggest soils were already under pressure and there is evidence for specialised farming practices such as the use of permanent pastures (Stika 1999). Overviews reveal two basic types of field systems (Bradley 1978). The first are the so-called Celtic field systems which are characterised by regular systems of small square or rectangular units defined by low banks or terraces; their actual shape probably having been determined by cross ploughing. The contrasting, and equally prevalent type, features small plots of irregular shape bounded by walls, cairns or stone banks which were probably still largely cultivated with hand tools (Kruta 1999).

5.2.2.3 France and the Low Countries

The archaeology of France provides two contrasting accounts for the Hallstatt C phase. In central-eastern portions of the country, where there are some of the richest Hallstatt burials in Europe, the Hallstatt C culture is well represented by iron and bronze objects deposited in graves (Collis 2003). Tombs in this part of France frequently contain tanged iron swords and elaborately designed iron razors. The richest barrow tombs house some of central Europe's first two wheeled chariots. Western portions (with the exception of coastal areas of Amorica), on the other hand, display a closer connection with the previous phase (Duval and Büchsenschutz 1976). Here, the Carps Tongue cultural complex continued well into the Hallsttat C period and new types of Hallstatt C imports were rare. Freidin (1982) views the western part of the region as in a period of isolation brought on by the efforts of powerful Burgundian chieftains to monopolise access to the east.

A transitional zone is perceived between the eastern and western regions (Freidin 1982). In this zone, burial traditions and grave deposits are of an intermediate variety between the rich Hallstatt deposits of eastern Belgium and the materially impoverished graves southwest of the Rhine. Hence, it may be possible to envision the beginnings of a sphere of interaction between two culturally separate zones (Kristiansen 1998). In north eastern France, tribes appear to have maintained strong links with southern Germany and western Switzerland (Collis 2003).

Throughout the period settlements were small taking the form of scattered farms each occupied by a single family and there is little differentiation in burial wealth (Kooi 1979). Most settlement structures were timber built and have left little impression. Plans of features within settlement sites reveal rectilinearly aligned post holes and remains of storage pits (Marion and Blancquaert 2000; Pauli 1994; Audouze and Büchsenschütz 1992). The limited amount of archaeobotanical data for the phase suggests mixed farming, with cereals providing the bulk of the proceeds from agricultural production (Bakels 1999, 1991; Coles and Harding 1979; Courtin *et al.* 1976). In a review of the region's assemblages, Bakels (1999, 77) reports that "the list of wild plants entering settlement sites and getting carbonised grew considerably - the species noted were mainly weeds from crops and plants from open grassy spaces". There were, of course, local differences in the relative importance of arable farming and animal husbandry and no overarching pattern has been established. Farmers still seem to be relatively conservative and production small-scale (Reille *et al.* 2000; Couteaux 1969). Collis (1984) argues that in many areas bronze remained the main metal used in the production of most agricultural tools.

5.2.2.4 Switzerland

Switzerland absorbed the trappings of Hallstatt culture some time between 750 and 700 BC after it had probably previously crystallized across its border with south western Germany, Austria or eastern France. Its arrival is signalled to archaeologist by increased numbers of iron objects and an abrupt stylistic shift in the design of objects recovered from graves – variations in the types of brooches, fibuli and long swords. It is clear from the archaeological evidence that iron tools now enjoyed a fairly wide distribution. Yet it remains something of a mystery why there is almost no change in the way the tools are used (Audouze and Büchsenschütz 1992). In woodworking, jointing techniques remained the same as before, but the practice of using joinery (e.g. mortising) appears to have gained wider acceptance. Moreover, techniques that were formerly reserved for highly finished items were now employed in commonplace applications such as house construction (Audouze and Büchsenschütz 1992).

House plans remained almost exclusively rectilinear though oval examples are sometimes encountered. Houses are either post-built (aisled) or supported using load bearing walls (e.g. 'Blocbau' technique of superimposed logs or Ständerbau technique of half timbered construction (Speck 1981). Overall, there is considerable variation in settlement organisation but almost all settlements remained, fundamentally, farmsteads. Sometimes these were arranged in hamlets but just as often they occurred as isolated units. As the Hallstatt C progressed into its terminal phase (Hallstatt D), there was an increase in the number of sites on the high limestone plateaux of the Jura, suggesting a movement from wetlands to localities previously considered too dry (Demarez 2001; Eschenlohr 2001). On the whole, this phenomenon may be connected with a newly created desire to protect tribal pastoral grounds but equally, the departure may signify a new desire to control routes into southern Germany and eastern France.

5.2.2.5 Britain

It is difficult to describe this phase in British prehistory. The early Iron Age is said to be one of the least understood phases of British archaeology. Outside of the southeast and the area of Wessex, there is no part of England where the initial transition to an iron using culture is understood in more than outline terms and, in some areas, it has not been investigated at all (Haselgrove 1999; *cf.* Harding 2006; Taylor 1997). This results from the vexing problem of calibrating the radiometric curve for the period (roughly 800 to 400 BC). There is also a dearth of datable artefacts for the interval (Champion 1994, 129). In some sections of the island, the early Iron Age is even aceramic (Harding 2006).

Nevertheless, archaeologists have recorded a number of patterns. Overall, they argue that there was (1) a shift in trans-regional trade patterns from its former north to south axis (along the Atlantic margin) more easterly and more in alignment with the Hallstatt C core; (2) increased regionalism in the economic sphere (Sharples 1990); and (3) innovation in weaponry and metal objects, some which seem to have a stylistic comparisons with northern and central France (York 2002). Overall, however, Britain retained a distinctly insular character, with Britons absorbing few new ideas or technologies from the continent (Collis 2003). This conservatism is most evident in the endurance of the Bronze Age round house. At this time comparative structures on the continent were mainly rectilinear. (Harding 1974). The economy, of course, was almost entirely agrarian. The precise proportion of land relegated to arable cultivation remains quite unknown as does the scale of individual farms. Iron Age settlement sites, for the most part, were loosely constructed and scattered (Haselgrove 2001). The aerial documentation of sites shows a landscape dotted with farmsteads defined by banks and ditches, sometimes with stone boundaries between them (Fowler 1981). The size of individual units was small which suggests they were tended by nuclear families but research indicates that they were generally larger and more curvilinear than their previous analogs (Cunliffe 2004, 70; 1995). In general, their associated field systems were rarely more than two thousand square meters in area though larger sizes are reported (Hill 1995). The fact that they were enclosed suggests that they were mixed use farms (i.e. arable farming combined with livestock production). Smaller scale structures inside the enclosures, as well as bone assemblages, indicate that livestock contributed significantly to the total agricultural output (Hill 1995). Storage pits, presumably for the storage of grain, are a prominent feature on many settlement sites but there is also evidence to suggest above-ground grain storage (Cunliffe 2004, 76; Harding 1974). Some pits show signs of having been used for domestic refuse whilst others indicate the burning of lime or the quarrying of clay. However, bell shaped pits often contain the charred remains of grain (Greig 1991). Though most settlement sites were farmsteads, the variety of sites types began to increase through the earliest phases of the Iron Age (Hill 1999). Some areas had a central place or stronghold site but just as many did not. The variety of sites as well as the objects found within them argues against a homogeneous economy. Instead, what appears are complexes of local economies overlaid upon larger and less interconnected regional economies (Hill 1995). There appears to have been a division between highland and lowland communities and it is clear that the lowland communities were in charge of cross-channel trade. The southern half of the island appears to have led the northern half in terms of the adoption of new innovations and it may have been more heavily involved in trade with the continent (Harding 2006; Haselgrove 2001; Hingley 1989, 133; Haverfield 1912).

5.2.3 The expansion of trade (c. 600-450 BC)

5.2.3.1 The Mediterranean

By the 6th century BC, new spheres of commercial activity began to crystallize in Europe as a result of widespread Phoenician and Greek presence in the western Mediterranean. In 600 BC, the Phocaean colony of Massalia (Marseilles) was founded at the mouth of the Rhône. The establishment of neighbouring trade colonies at Emporion, Agade, Tauroention, Olbia and Nice soon followed. These colonies appear to have been influential in: (1) linking coastal areas of western Europe directly to thriving Etruscan, Greek and Levantine commercial communities; and (2) providing access, albeit limited, into the centre of Europe, usually via a river valley (e.g. the Rhône Valley route) (Archibald *et al.* 2001; Bouzek 1997; Cunliffe 1997; Gills and Frank 1992; Collis 1984).

The shift in the course of trade is described by some as dramatic. Gradually, the inward flow of eastern artefacts into Europe began to emanate from routes along the Rhône corridor which allowed strategically placed centres to develop along the way (Tandy 1997; Starr 1977). The variety of artefacts found at these sites (e.g. elaborate bronze objects, black Attic ware, goods associated with Greek wine drinking customs), and the design of their defensive works suggest that Greeks had begun to exploit new trade relationships, exchanging Mediterranean imports for gold, copper, tin, salt, salted meats, pelts, hides and slaves (Collis 1984). Concurrently, but further east, expanding Etruscan cities had fostered contacts with native cultures of the Po Valley who, by virtue of their geographical location and tribal affiliations, dominated trade routes across the Alps. It was through this new trade bridge that Mediterranean influences probably began to infiltrate into the rapidly developing eastern half of the Hallstatt D world.

One of the most obvious trends throughout the interval is increased sedentism (Isager and Skydsgaard 1992) and we can also see signs of intensification and extensification. Forni (1998) argues that, from 600 BC, land in Italy began to be further subdivided and that an increase in the use of iron ploughshares led to the capacity to cultivate new areas. Spurr (1986) defines three types of farms: (1) small farms growing cereals for subsistence; (2) larger farms growing cereals for subsistence but specializing in other crops; and (3) larger farms producing cereals for sale. Van Joolen (2003, 102) indicates that three ancient land-use schemes were in existence in some places: (1) grazing of natural and improved pastures; (2) slash and burn systems – *ignicoultura*; and (3) short distance transhumance (*cf.* Forni 1998; Sarapaki 1992; Forbes 1976).

5.2.3.2 Central Europe (Hallstatt D)

The beginning of the Hallstatt D phase (Fig. 5.2) is signalled by a shift in the richest graves westward and further north to the upper reaches of the Danube, the upper Rhine and into eastern and central France from their former core areas more to the east. In this new power centre, smaller hillforts were abandoned and replaced by larger and more extravagant examples such as Mont Lassois, Heuneberg, Grafenbühl, Hochdorf, Château-sur-Salins, Britzgyberg, Châtillon-sur-Glâne, the Ipf, Marienberg, Mont Guérin, Camp de Chassey, Montmorot, and Zürich-Üetilberg (Collis 1984; Wells 1984; Freidin 1982). The former division between the eastern and western parts of France was no longer as prominent and there was a final and complete break with any conservative Urnfield legacy (Villes 1992). The earliest wheel-made pottery in central Europe is dated to this phase and, from this point onwards, bronze weapons were an anachronism (Pauli 1994, 71).

In terms of social development, Hallstatt D was a time when the already well established hierarchy of central Europe became even more concentrated. Rich graves contain many more objects but, more importantly, they contain categories of objects, (particularly gold jewellery, four wheeled wagons and bronze vessels) that were of foreign origin (Wells 1984, 120). The *Fürstensitz,* or princely seat, a new type of defensive site concentrated in south western Germany, provides evidence of this newly found power. These sites are distinctive in terms of their Mediterranean-style defensive works and associated grave-mound burials of conspicuous size (Pare 1992). Elsewhere, one can see evidence of underling princes in the *Herrensitze* or 'chieftain' sites (Rieckhoff and Biel 2001). These are generally smaller and of more agricultural character than the hilltop *Fürstensitze* dwellings. In some cases, they are totally undefended. A final category of Hallsttat D defended site is the refuge. These were only occupied on a semi-permanent basis (Härke 1979).

On the whole, undefended settlements became increasingly more complex during Hallstatt D (Wells 1999). Typically, they are of a more village-like character, no longer simple farming communities, and they generally house denser populations than before (Haselgrove 1996). Social distinctions are evident in grander centrally positioned structures and in the variety of objects recovered from graves (Rieckhoff and Biel 2001, 119). There are differences in the work-life of everyday people as well, exemplified by evidence which indicates that some of the population may have worked as full time artisans or traders (Rieckhoff and Biel 2001, 150). Regional archaeological evidence demonstrates that the density of settlement in many places was already very great (e.g. the Neckar Valley in southwest Germany) and that most people lived in well ordered communities, preoccupied with sedentary mixed agriculture and were capable of maintaining wide ranging trade contacts (Menzal 1996; Audouze and Büchsenschütz 1992).

5.2.3.3 Proto-Germanic areas north of the Rhine

Although the Hallstatt culture was the predominant culture in central Europe, communities in the northern portions of Germany and the Netherlands were also powerfully influenced by proto-Germanic speaking groups from southern Scandinavia. These cultures began to expand in a southerly direction by approximately 600 BC bringing with them a culture which may have emphasised the breeding and ritual exchange of livestock. Roymans (1996) prefers to see these Germanic cultures as primarily cattle based (*cf.* Kreuz 1999, 80; Hingley 1989, 146). On the whole, proto-Germanic cultures appear more conservative (in terms of economic sophistication, level of urbanisation and degree of outside influence) than their wealthier warrior neighbours further south (e.g. central Belgium and eastern France to the south) (Wells 1984, 115). So strong is the blending of 'Celtic' (Hallstatt) and 'proto-Germanic' amongst communities along the Rhine that archaeologists have difficulty separating tribal groups on either side of its banks (Gerritsen 1998; Roymans 1990). As a consequence, Iron Age cultures here are sometimes characterised as 'Celto-Germanic' (Collis 2003; Wolfram 1997).

5.2.3.4 The Atlantic margin

Parts of the Netherlands, Britain and north eastern France assumed a similar 'Atlantic' pattern during most of this period. Similarities between these communities include: (1) a simultaneous chronology for the introduction of iron tipped ards; (2) similar arrangement of farm structures on the farm; (3) the widespread use of underground pits and 4- and 6-post structures with raised floors; (4) a general lack of a recognisable burial rites; (5) a lack of formal religious shrines or sanctuaries; and (6) ubiquitous use of prominent earthen-work boundaries either to enclose settlements or to define residential groups in a symbolic sense (Shaffrey 2003; Haselgrove 2001, 47-61).

Overall, the archaeobotanical remains from these areas demonstrate an environment where cultures were probably peaking in terms of agrarian expansion (Roymans 1991; *cf.* Hingley 1989, 129). There is a high degree of cultural continuity which is reflected in the continued use of bronze as a ritual element. Furthermore, in some of the most marginal areas, there is even continued utilisation of the old Urnfield cemeteries. A slight increase in population can be forecast along with the possibility of immigration from outlying regions.

5.2.4 Convergence between Mediterranean and European worlds (450-250 BC)

By the middle of the 5th century BC, the cultural, economic and political landscape of most of Europe began to undergo a series of radical and comparatively rapid changes (Haywood 2002; Kristiansen 1998; Cunliffe 1997; Collis 1984). Firstly, Etruscan influence waned, checked by a series of Mediterranean contenders (Hodge 1998; McEvedy 1967). Secondly, Greece's polis-centred Classical world was overpowered by the Macedonian, Alexander. Thirdly, Rome undertook the conquest of the whole of Italy (Holloway 1996; Smith 1996). Finally, in the heart of Europe, La Tène communities crystallised on the periphery of the Hallstatt core and began raiding into the Balkans and northern Italy (Kristiansen 1998).

5.2.4.1 The Mediterranean

The fifth century BC is especially significant in terms of this study because it marks the point where we may begin to construct a picture of an ancient economy through a combination of written sources and archaeological evidence. On the whole, the evidence seems to indicate that urban life prospered, bringing with it the development of more sophisticated economies and a heavier reliance on trade. Nevertheless, as was the case in all earlier phases, the most important sector of the economy was filled by small farmers (Frayn 1979).

Regional surveys such as that from Brindisino (Burgers 1998), and sites such as Valesio (Boersma and Yntema 1987), suggest there were attempts to industrialize agriculture in some areas of Italy. Nevertheless, most people farmed small plots and inhabited homes made from perishable materials and used simple tools and ephemeral household equipment. People in coastal communities drew their living from the sea. Commerce and industry remained insignificant in proportion to the rest of the economy and there was a general dearth of free capital (Hopkins 1983). Finley's (1973) old model forbids a price-setting, free ranging, and perfect market due to mountainous terrain, lack of riverine routes and the absence of an extensive road network (Temin 2001; Rostovtzeff 1957). Nevertheless, all kinds of traders regularly called in at Mediterranean cities and frontier emporia bringing with them all types of luxuries (Boardman 1980), and maritime trade had clearly become a specialized sector in the economy (Meijer and van Nijf 1992). As the practice of slavery gained hold, it seems to have given rise to early attempts at manufacturing. However, the majority of products continued to be fabricated by hand and with simple tools, in small shops within domestic boundaries (Burke 1992). Mining occupied a niche in the economy but it was centrally controlled and of limited importance in the economic life of most ordinary people.

The incapacity of the countryside to produce an adequate grain supply for the large coastal cities is perhaps reflected in the number of Greek grain merchants who actively called on ports in Egypt, Sicily, Sardinia and the Black Sea in search of grain (Rickman 1980; Casson 1954). Here, we witness the emergence of a new class, the *kapeloi*, who profited as middlemen, owning their own vessels or rent space on a ship owned by another (*naukleros*).

The agriculture of the period holds many features in common with a large region extending from Asia Minor to Spain (Paskevich 2003; Isager and Skydsgaard 1992; B. Wells 1992; Weintraub and Shapira 1975). Standard forms of crop production did not typically utilise irrigation as a means to increase production. Fields were small, and producers worked the land in rotation probably using various means to sustain the soil's fragile potential (Hanson 1999). There were the rare examples of 'extensive type' agriculture but the actual extent of this type of practice at this early period actually remains unknown (Forbes 1995). Farming strategy appears to have remained focused on the goal of achieving productivity while simultaneously avoiding risk (Gallant 1991; Rackham and Moody 1994; Garnsey 1988). Carter (1983; 1990) notes the high density of small holdings in the toe of Italy from 350 BC onward. Relict field systems indicate that the most common cultivation implement remained the traditional wooden ard which by was by now almost universally iron tipped (Isager and Skydsgaard 1992). Cross ploughing was probably still the standard method, and ploughing depths probably rarely exceeded more than 5 cm (Forni 1998; Isager and Skydsgaard 1992). The scarcity of grass and good grazing meant that animal husbandry was generally restricted to small and versatile animals such as pigs, sheep and goats (Leguilloux 2003). Pastoralism and transhumance probably played a role in careful management of resources at the local level. Poultry farming is attested, as is the rearing of pigeons and ducks (West and Zhou 1988). Cheese and milk were important components of domestic production. Cattle, oxen and horses were a probably a luxury. Animal protein derived from hunting was at this point uncommon.

The rise of the Macedonian Kingdom under Alexander (c. 323 BC) brought with it the gradual demise of the Greek city states and the unification of Oriental and Greek civilisations and ideas. From this point onwards, we can see that Greeks developed a penchant for more centrally planned economies (Gabrielsen 2001; Green 1990; Finley 1973). Written records indicate that large quantities of land fell under dynastic control or became 'nationalised' by centrally managed institutions. In some cases (e.g. Ptolemaic Egypt), this meant planting schedules, labour, oxen and tools were maintained under state control (Green 1990). State bureaucracies were created and laws were enacted to ensure fair practices in grain trading, to uphold standards in grain measures, and to a limited extent, control of grain prices (Rickman 1980; Casson 1954). One highly significant development of the Hellenistic period was the wider use of the use of coinage and the instigation of the practice of banking.

5.2.4.2 Europe

By the middle of the 5th century BC, La Tène communities began to develop from within the old Hallstatt chiefdoms between the Marne and the upper Danube (Wells 2001; Kristiansen 1998; Champion 1994; Cunliffe 1997; Rankin 1996; Arnold and Gibson 1995; Green 1995; Moscatti 1991) (Fig. 5.3). To what extent this reflects internal events within the Hallstatt remains a mystery. Collis (1984) argues that, because La Tène communities emerged as centres for craft production, it was trade that made them unique. There is much to be said for this argument. From the La Tène onward Europe provides increasingly more finished goods than raw materials. No longer were coastal emporia the sole source of highly worked luxury goods. Two trade networks funnelling products in both directions can be visualised: (1) the Marne-Moselle group/Rhine-Danube group which held trade links to the Po valley via routes to the St Bernard Pass funnelling in from the Seine, Marne and Rhine; and (2) a Bohemian group which held separate links to cultures along the Adriatic plain via the Eastern Alps (Brun 1994; Cunliffe 1997, 66). These new routes signal a dramatic shift in the pattern of Greek trade (away from the Rhône corridor back towards the Po and the Adriatic) perhaps as a result of strife between Greeks, Etruscans and Carthaginians in the Mediterranean.

Overall, La Tène communities appear as a shifting mosaic of warring autonomous tribes and states, stretching from England (e.g. Arras Culture) to the Balkans (Collis 2003; Haywood 2002; Champion 1994). During the fifth and fourth centuries BC Hallstatt commercial towns comparable to the size of Heuneberg, Stična and Hallstatt had collapsed and, although agriculture still formed the foundation of economic life, tribes seem to have focused new energy on foreign raiding and looting (Wells 184, 125). By the first quarter of the 3rd century BC, Classical authors report that La Tène tribes were on the move in all directions. In 279 BC they sacked the sanctuary of Delphi in Greece. A decade later they arrived at Ankara, in Asia Minor, where they would eventually settle and become known as Galatians.

It is virtually impossible to discuss La Tène agricultural economy in broad terms. Their extreme mobility and warrior-like reputation has gained them a pastoral status. Earlier investigators regarded La Tène tribes as 'pony, pig and cattle breeders who supplemented a mainly carnivorous diet with cereals and pulses' (Fox and Dickins 1950). However, recent evidence suggests that economic circumstances were far more complex and it is probably best to regard separate tribes individually. It is reasonably certain that sedentary agriculture and cereal production was the cornerstone of the subsistence-base of many tribes. Archaeologists inform us that the in the closing centuries of the first millennium BC, tribes expanded onto previously unsettled areas, and turned to agricultural strategies in response to (1) rises in local populations (Hill 1999; Haselgrove 1984; Simmons and Tooley 1981); (2) new kinds of settlement strategies; (3) developing craft specialisation; and (4) innovative agricultural technologies (e.g. iron-tipped plough shares, rotary querns and developments in husbandry practices) (Gerritsen 2003; Van der Veen and O'Connor 1998; Haselgrove 1984, 17-19; Jones 1981; White 1970).

Specific cropping practices linked to intensive type agro-systems are documented in both Greek and Roman sources from the 6^{th} to 5^{th} centuries BC onward (Forni 1998; Sallares 1991; Halstead 1987; White 1970) and Roman writers later provide the impression that Italian and Greek agriculture peaked in terms of technical capacity by the 2^{nd} century BC (for a cogent argument supporting this point see Butzer *et al.* 1987, 480). Nevertheless, to what extent this reflects the situation in central and northern Europe remains a mystery. Coins began to be minted in temperate Europe between the 3rd and the 2nd centuries BC after having first been encountered during a phase of increased contact with the Mediterranean world between the 4th and 3rd centuries BC (Davies 2002; Creighton 2000; Cunliffe and de Jersey 1997; van Arsdell 1989; Harl 1983). This development alone may have influenced agriculture by intensifying the breadth of exchange.

The settlement pattern generally indicates a kaleidoscope of hilltop defended towns and lowland settlements, predominantly on the lighter soils, in some cases extending onto clay soils and uplands, and rarely more than four to five hectares in size (Audouze and Büchsenschutz 1992; Collis 1984, 112; Agache 1978). Farmsteads generally appear to have been undefended but circular ditches and enclosures were a common feature on many. Field systems normally take on a quadrangular shape (Champion 1994, 131). Internal features include the 4-and 6-posted structures that are usually interpreted as grain storage facilities.

5.2.5 The rise of Rome as a world power (250-50 BC)

Having succeeded in becoming the dominant power in Italy and Sicily, the Roman Republic turned its attentions to Carthage and the rapidly fragmenting Hellenistic Kingdoms of the east. The subjugation of the coastal regions of France and Spain was accomplished in quick succession allowing Rome to gain total control over trade in the Mediterranean. The pacification of the newly won provinces, its dominance of trade, and the institution of regular taxes soon made the Republic rich (Starr 1983). Generals, diplomats, officers, soldiers, who in their travels to the East learned valuable lessons from the Hellenistic satraps, returned and began to remodel Italy along Eastern lines in what Rostovtzeff (1957) declared the 'the Hellenization of Italy'. Classical authors report that, following the Punic wars, the number of small family farms in Italy declined and arable acreage coalesced due to: (1) the effects of years of military conflict; (2) the flight of peasants to cities; and (3) the spread of capitalistic farming methods (Forni 1998; Carter 1990; White 1970; Fusell 1967). In response, Italian agriculture re-directed itself to more profitable cash crops which eventually led to the consolidation of small farms and the rise of the large estates of the late Republican and early Imperial periods.

The knowledge-base of Classical agriculture is impressive and, in many instances, rooted in scientific fact (for a comprehensive review see van Joolen 2003; Wells B. 1992; Forni 1998; White 1970; Fussell 1967). By the Classical period:

- traditional sowing dates for cereal cultivars were founded on a systematic and rational basis;
- experimental techniques were in operation to improve landraces/cultivars;
- sowing rates were understood in terms of plant density;
- land use was evaluated in terms of crop value;
- there was a surprisingly modern understanding of the phenomena of plant growth stages and producers were profitably engaged in husbandry regimes timed about these;
- the role of labour inputs and capital were understood;
- tillage routines were highly specific;
- a number of management practices were advocated which provided the means to control certain types of insects and diseases;
- animals were integrated into complex production strategies;
- the significance of soil and plant nutrition was partially understood and soil fertility was being managed on some farms;
- cold hardiness and vernalisation requirements were addressed in a rational manner;
- plant/water relationships were well defined;
- yield was being evaluated in terms of input;
- grain moisture levels were being monitored;
- a variety of storage technologies were available (*cf.* Marion and Blancquaert, 2000; Gransar 2000) and;
- a range of secondary products were being produced.

In short, the agronomic knowledge-base appears to have been broadly on a par with that which we witness in traditional societies today. Such was the advanced state of agriculture that Palladius's fourteen volume work (*De re rustica* - a compendia of Classical sources) remained the principal guidebook to agriculture until the Middle Ages. Cereal husbandry appears not to have advanced beyond this level of erudition until the 17th century (*cf.* Henderson 2004).

To what extent this was the case in the more remote parts of Europe is subject to debate. Throughout the Classical era, the state of affairs between Romans and La Tène tribes remained precarious (Wells 1984, 151). Celtic migrations had succeeded in the tribal colonisation of sections of central Italy by mid 4th century BC. In the last Samnite War of 295 BC, Celtic tribes joined with Samnites and Etruscans in an attempt to block Rome's rise to power. In 283 BC, the Romans conquered northern Picenum, established themselves in the area between Ravenna and Anconna (the *ager Gallicus*), and founded the colony of *Sena Gallica* on the Adriatic coastline taking control of the Po Plain. Between 225 and 222 BC a further series of campaigns were fought which enabled Romans to establish a line of northern colonies buffering central Italy from tribes pressing in from over the Alps. Bologna became a Roman Colony in 189 BC and in 181 BC Aquileia was established as an important port at the head of the Adriatic. By 101 BC Roman forces finally brought an end to Celtic raiding with a victory somewhere near Ferrara.

The *Pax Romana* resulted in an Italian trade revolution for both areas. By the beginning of the second century BC, imported goods on Celtic sites were Roman rather than Greek in origin and the intensity of trade was much greater than ever before (Kruta 1999; Collis 1984, 139). Classical authors attest to markets where captives were exchanged for luxuries like wine (Arnold 1999; Fulford 1985). The vast amount of Roman amphorae found in France attests to the legendary Gaulish obsession with wine, its importance in funerary and political traditions, and the need to encourage trade relationships that insured adequate supplies (Loughton 2003).

In Europe, this was the period of the rise of the oppida (Wells 1993). Although not fully urban, and highly variable in character, oppida seem to represent the development of a type of political organisation which might be compared to a quasi-independent state (Cunliffe 1997, 224; Cunliffe and Poole 1989). Oppida are more sophisticated in plan than their proto-urban predecessors, hillforts, and are constructed to predetermined plans (Haselgrove 1996). They are, however, not really true towns. Some sites such as Aulnat, in central

France, have an almost industrial character. A number seem to have been built and situated solely as fortifications protecting important sources of raw materials or agricultural soils (e.g. Bibracte). Others (e.g. Villeneuve-St-Germain – Gransar 1991) display a regular layout comparable to Classical cities and feature areas especially dedicated for the storage of grain. Their political significance lies in their capacity to provide a meeting place, source of pride and common focus to local tribes. Their economic importance is demonstrated by the increased levels of craft specialisation taking place within their walls (e.g. Manching in Bavaria) (Henon 1992). The high concentration of industrial debris, tools and finished objects found within them suggests that some may have functioned as centres for trading finished objects (Wells 1984, 145). Oppida were nevertheless exceptions to the general settlement pattern and despite the existence of at least a dozen major centres, their role in the economic life of most Europeans was probably minimal (Wells 1984, 143). The vast majority of people continued to live in farmsteads and small agricultural communities.

5.2.5.1 The Roman conquest of the Greek peninsula

Greece was the first country in the study region to fall entirely under complete Roman control. As Hannibal ravaged Italy in the second Punic War Rome moved to block a potential alliance from forming between the Puns and the Macedonians. The conflicts which followed became known as the First Macedonian War. Two decades later, Rome gained a decisive victory over Macedonians in a second war (201-196 BC). In 171 BC, a third Macedonian war broke out as Perseus tried to re-establish his power. The Macedonians were finally defeated forever at the battle of Pydna in 168 BC. The formally recognised date for the beginning of Roman rule in Greece coincides with the sack of the city of Corinth in 146 BC. The Aegean islands were subsequently subjugated in 133 BC.

During the initial years of Roman domination, Greeks probably witnessed few changes to their agricultural economy mainly due to the constraints imposed by Greece's relatively harsh environmental conditions (Bintliff 1977, 104). There is little evidence for the implementation of 'capitalistic farming practices', revolutionary technology, vast estates (Fussell 1967, 36), or the centuriation of Greek land (Engels 1990, 24). However it is generally agreed that the Romans brought new imperatives to provincial rural landscapes in the form of agricultural specialisation, and an increased emphasis on cash crops (Forni 1998; Mattingly and Hitchner 1999, 196-198). According to Kron (2000, 277), Mediterranean farmers were engaged in the practice of alternating fields between several years of continuous cultivation under a succession of grain, root and leguminous crops, followed by several years where land was allowed to rest as pasture. White (1970), however, characterised conditions somewhat differently claiming that the "movement away from fallowing towards the continuous rotation of crops was arrested, so that Roman agriculture remained at a halfway stage between two slightly contrasting systems" (White 1970, 144; *cf.* Kron 2000, 278).

Garnsey *et al.* (1984, 36) argues that the general character of Greek agriculture was always constrained by risk avoidance. "Overall, there had always been a tendency for crops to suffer or prosper together, leading to a situation where there was a condition of famine or glut in the market". The relative productivity of Greek land was highly variable and cereal production entailed considerable risk (Forbes and Foxhall 1995, 76; Gallant 1991; Halstead and O'Shea 1989; van Andel and Runnels 1987; Jones *et al.* 1986, 99-102). For instance, in the 2nd century BC, Thessaly could generate enough surplus wheat to agree to supply several legions of the Roman army with wheat. At the same time, Athens struggled to grow even enough barley for its own inhabitants. Engels (1990, 23) argues for a high rate of settlement continuity during the Classical and Hellenistic and Roman eras. The effort required to walk to fields, and the need to protect the produce in them, required that farmers to remain close to their own *territorium* (Cooper 1978). This may also explain the regular spacing of the agricultural villages of Greece at this time (Thompson 1963).

5.2.5.2 Transalpine Gauls

Throughout most of the La Tène period, Romans probably recognised most of the tribes in the territory bounded by the Alps, the Rhine and the Pyrenees (modern France, Belgium, Holland, Germany and Switzerland) as Gauls (Woolfe 1998; Roymans 1996; Jiménez 1996; Funck-Brentano, 1993; Wightman 1985). Gaulish tribes in a sub-region immediately across the Alps and west of the Italian peninsula first came into conflict with Roman armies in the early 2nd century BC. As was the case in Greece, the initial conflict had its roots in the Second Punic War. In 218 BC, Celtic warriors (whom Classical authors identify as

Gauls) were defeated as they attempted to assist Hannibal in his invasion of Italy via the Rhône. Gaulish tribes fought against Rome under the Celtic Boii again in 202 BC and 191 BC. Subsequently, having established military posts in Cisalpine Gaul (Gaul on the Italian side of the Alps), Roman troops moved on Transalpine Gaul waging war against a suite of tribes along the coasts of France and Spain. In 125 BC Massalia, gained Roman assistance in its war with the Saluvii at Entremont. The ensuing conflict lasted almost three decades and resulted in the annexation of the coastal fringes of France between the Rhône and the Alps. Romans eagerly established a number of new settlements in this newly pacified region (Provincia) and united it to colonies in Spain with the construction of the Via Domitia. Julius Caesar swiftly brought the remainder of Gaul under Roman control during the Gallic Wars (58-51 BC).

In its initial years, Transalpine Gaul consisted of four separate provinces (Fig. 5.4). Parts of all four lay within the borders of modern day France (Drinkwater 1983). The first of these, Aquitania, emerged out of what is today south western France. Its name originally applied to an area bounded by the Garronne, the Pyrenees and the Bay of Biscay. Augustus augmented the province by extending these boundaries to the Loire. Gallia Lugdunensis incorporated the regions of Brittany and Normandy as well as the Paris Basin and encompassed nearly the entire catchement of the Loire including the Rhône Valley and Lyon. Belgica, which included much of my French study area, took in Northern France, Belgium, the southern part of the Netherlands, and Western Germany. Gallia Narbonensis, most of which was originally regarded as the '*Provincia*' took in the modern areas of Languedoc and Provence.

5.2.5.3 Germans

By the late 3rd century BC, German tribes began to exert serious pressure on Celtic tribes crossing the lower Rhine and pushing into the Westerwald and Taunus regions. From there, these invaders entered into an area around the Moselle where they began to harass the Celtic Treveri. A further series of attacks from across the Lower Rhine eventually drove ethnically mixed populations into the area of the Marne-Aisne basin. Caesar (*de Bello Gallico* II.V) indicates that "Belgic tribes" from this area then crossed over to Britain (a fact disputed by many modern archaeologists - James 1997; *cf.* Reece 1987).

5.2.5.4 Alpine communities

A series of tribes with diverse origins and characters were settled within the area of modern day Switzerland during this interval. Around 120 BC, Germanic Cimbri and Teutones forced the Celtic Helvetii into the Alps, where they settled in the region of the Jura, and the Mittelland plain between Lakes Constance and Geneva. Here, they coexisted alongside the Raeti (possibly a tribe of Etruscan origin) who were living as pastoralists in areas adjacent to the Alpine Lakes and the Graubunden Alps. The Celtic Sequani inhabited a large area of the Alpine foreland which took in part of the eastern side of the upper Rhine. The Raurici, who bore a close political alliance with the Helvetii, occupied an area around Basel. The Tigurini, a tribe of dubious origins, are reported to have joined forces with the Germanic Cimbri and Teutones in an invasion of Northern Italy in 109 BC. Tribes in neighbouring 'Noricum' (the upper Alps of Austria) are thought to have maintained excellent trading relations with Rome.

Roman subjugation Switzerland built steadily with a series of minor campaigns. Their first incursion into Swiss territory by way of the St Bernard Pass was ineffective (c. 107 BC). In 52 BC, Rome gained the upper hand when threats from Suebic Germans caused the Helvetti to abandon their homes to try to relocate in southern Gaul. The 'Helvettain' migration route took them through the territory of the Allobrigi who appealed to Rome to counter the advance. At Bibracte, an army under Julius Caesar defeated the Helvetti and forced them back into western Switzerland. Here, they were placed under civilian administration as *foederati* (allies), their pre-Roman oppidum at Mont Vully relocated to a new site at Bois de Châtel on the south shore of Lac de Morat, and their male inhabitants forced to serve in an irregular frontier force (Carroll 2001; King 1990; Schutz 1983). In 15 BC, Roman armies under the control of Tiberius and Drusus pushed into Swiss territory once again to establish the province of *Raetia.*

5.2.5.5 Britons

Roman armies first set foot in Britain under Julius Caesar in 55 BC ostensibly as part of a punitive expedition against tribes who had aided rebellious Armoricans in Gaul (Creighton 2006; Manley 2002; De la Bédoyère 2001; Frere 1987). They left with their mission only partially accomplished. They returned a year later, this time bent on plunder. They were met on the beach by a substantial British force united under Cassivellaunus. After a series of brief battles, the Trinovantes and their allies went over to the Romans and the British cause was lost (Manley 2002). An annual tribute was agreed and Caesar retired to Gaul leaving the island to native control.

5.2.6 High Empire and Romanization (50 BC-AD 250)

Romanization, the process whereby indigenous peoples absorbed Roman artistic tastes, social values, civil institutions and the Latin language, is the principal historical and economic theme of this chronological interval (Mattingly 2006; 2004; James 2001; Carroll 2001; King 1999; Kreutz 1999; Wolfram 1997; Woolf 1998, 1992; Geary 1988; Drinkwater 1985; Wightman 1985; Agache 1978). Although it definitely had a passive or unconscious component, it was also an active process driven by concrete rewards for compliance and emulation and enhanced by cross community rivalries for constitutional privilege. In the main, it proceeded from the elite down and from the more densely occupied areas to the rural countryside. Romanization is traditionally viewed as a one-way process but recent evidence suggests that it incorporated a considerable amount of bilateral negotiation between the conquered and conquering parties (Keay and Terrenato 2001). This may also account for the apparent willingness of the conquered inhabitants to be absorbed into the Roman state (*cf.* Freeman 1993). As James (1997, 117) notes: "Under Roman rule, many Celtic speaking regions maintained much of their identity for a surprisingly long time, and achieved a degree of political stability and material prosperity far beyond that of the Iron Age". The goal seems to be to rule people with a minimum of effort, and not necessarily to acculturate them (Woolf 1992, 351). Despite the fact that Romanization undoubtedly encouraged Italian emigration, there is no reason to believe that Romanization was expressed through immigration. The overall numbers of Italian immigrants into northwestern Europe was probably never great except in the larger cities and military zones.

The conventional model sought to provide focus in the form of a regional *civitas* capital. Three different types of arrangements emerged. The standard type of *civitas* was formulated using the *gens* (tribe) with little change in the political hierarchy that had been previously in place (Millett 1999). A second set of *civitates* accommodated pre-existing similarities between different tribes but superimposed a new elite above. The third form of *civitates* was formed purely on the basis of Roman strategic interest. In this case, tribes were conflated into completely novel political entities and sometimes relocated to new areas but never too far away.

Some *civitas* capitals were erected on important Iron Age sites where local populations may have traditionally gathered to trade, debate, worship or pay tribute; others arose from *vici* (camps) near auxiliary forts; some were built on virgin sites; most came to possess a forum, basilica, religious shrines, amphitheatres, and public baths, paid for by the local elite. Regional economic activity was naturally attracted towards them as they usually housed the local judiciary, market and tax collection point. Houses eventually sprang up around them constructed in a standard Mediterranean rectangular fashion, with internal partitions, often with tiled roofs, and fitted into an orthogonal street grid. The first examples are usually wooden but in many areas the standard form of building progressed to stone.

The acculturation of native peoples was less visibly expressed in the countryside. In the rural interior, the old model of the timber framed rectangular or circular home (in Britain) generally survived, and the rhythm, scale and mode of agriculture probably continued on much as before (Hingley 1989). There is however evidence of: (1) land centuriation in some places (e.g. northern France); (2) land recovery in marginal areas (Ripon 2000); and (3) the construction of highly stylised villas of Mediterranean design.

Villas develop in the landscape almost as soon as Romans arrive into the provinces (Hagendorn 1999; Lewit 1991; Agache 1978; Percival 1976; Rivet 1958). The question of whether villas represent an attempt to impose change on the basic structure of agriculture in the western provinces, however, is still open to debate. In north-western Europe, villas are frequently argued to be prestige symbols or 'holiday' homes for the elite (i.e. most are located within a few miles of major cities). Nevertheless, many do come to display an agro-industrial character particularly by the early-mid 2nd century AD. Most were clearly self sufficient in terms of their most immediate needs. The agricultural buildings and equipment found within their boundaries suggest that they could have served as a focus for a more centralised and extensive form of agriculture. Their primary purpose, however, may have been to project Roman attitudes towards the use of the natural landscape and advertise the wealth and prestige of their owners (Marcello 1997; MacDougall 1987). Archaeobotanical investigations continue to demonstrate that the Romans introduced a large number of new foods, ingredients and ways of preparing food into central and north western Europe. Though these do not appear to have replaced traditional foods entirely, many became integrated into the local diet and food-producing system (Schucany 2005, 42, 44; Bakels and Jacomet 2003, 542; Meadows 1994, 137; Okun 1989).

5.2.6.1 Italy

Archaeological evidence suggests that, throughout much of this period, small scale arable agriculture and livestock rearing continued to be the basis of the Italian economy (Spurr 1986; Frayn 1979; White 1970; Fussell 1967). Historians consistently claim that local agricultural production dropped in the face of rising provincial imports and the consolidation of land, but there are those who argue that there is little real archaeological evidence to support this (Purcell 2000). It is almost unanimously agreed that the wine and ceramic production industries progressively shifted away from the Italian peninsula to places such as Gaul. North Africa clearly exported a great range of agricultural products to Italy (Small and Buck 1994; Rossiter 1981). Rome increasingly came to demand greater amounts of food products from Gaul, Spain, Egypt, Sicily, Sardinia, Cyprus and the Chersonese (Morley 1996).

Cereal production probably remained important in Italy throughout the period but the Classical authors report that its scale was constrained by high land prices near the booming cities and the lack of a sufficient abundance of farm labour caused by a flight to urbanised areas (Rickman 1980). According to King (1999) there were distinct differences in the types of animals raised for livestock in Italy's various geographical districts. Overall, the bulk of livestock production seems to have emphasised smaller animals like pigs. Pork production appears to have fallen off slightly in favour of sheep and goats over time (King 1999).

The area's archaeology informs us that by the Flavian (AD 69-96) period, there was gradual increase in the number of villas in Italy (Kehoe 1997; Smith 1997; Percival 1976). Moreover, we know, from stamps on amphorae that at least some of these functioned in an industrial capacity, exporting products like oil to legions stationed in Germany and of wine to provincials in Gaul (Purcell 2000). Villas like the one at Settefinestre on the western coast of Italy have been interpreted as *latifundiae*, slave-run operations that were undoubtedly engaged in large scale agricultural production (Carandini and Ricci 1988).

By the late second century AD, Italian villas were in a state of decline (Painter 1980; Percival 1976). The reason for this remains a mystery. According to some authorities, their decline signals an end to the old Italian perspective of 'land as wealth' under growing pressure from profits gained through speculation and trade. To others, the decline of the villas is symbolic of empire-wide economic decline (*cf.* Duncan-Jones 1990).

5.2.6.2 Greece

From the reign of Augustus until the middle 2nd century AD, Greece enjoyed an interval of peace, the magnitude of which it had not witnessed since Classical times. Nero granted it tax dispensation in AD 67 but this was reversed by Vespasian two years later. Under Hadrian (AD 177-38) Athens, Sparta, Patrea, Corinth and Ellis were granted vast municipal benefactions as well.

The net effect of Imperial domination, however seems to have served neither the Greek nor the Roman purposes particularly well (Starr 1983). The Graeco-Roman economy remained mildly capitalistic, frail, erratic and restricted by its predominantly small scale agrarian character. Market growth was never sustained and the entire economic system was constantly subject to instability due to famine and disease. Vacillating political structures did little to promote trust in a common currency or ease fears of inflation (Gabrielsen 2001; Finley 1973). Brigandage, corruption and piracy though subdued by the *Pax Romana*, remained persistent problems. Merchants and producers were vulnerable to Roman tax collectors and there was a general lack of capital to promote productivity (Finley 1973).

A population decline is hypothesised to have led to the abandonment of many small farms (Alcock 1993, 83; Boserup 1981; 1965). Plutarch (AD 50-120) reports that Greece no longer had enough inhabitants even to field a sufficient army (*Herodes Atticus* I, 28). In certain places, such as Aetolia and Epirus, there was a sudden upturn in herding and stock breeding (Alcock 1993). King (1999) reports high levels of goat and sheep bones from this period possibly due to an upsurge in pastoral activity fuelled by land abandonment.

5.2.6.3 Gaul

Each of the Gallic provinces were unique but generally assume either a Mediterranean or European character. Provincia had, by this time, been renamed Narbonensis and was organised under senatorial control with a new *civitas* capital established at Narbo. Geographically, its soil and climate mirrored that of Italy, allowing it to maintain a distinctly Mediterranean character (Rivet 1988). It held a reputation for Hellenism, and the Greek triad (cereals, olives and grapes) was firmly in place within its agricultural economy (Garnsey 1999, 13). The region had long been famous for its wine trade. Five Roman *coloniae* (outposts founded by military veterans) were established in the region, and funerary inscriptions attest to an unusually high level of Italian emigration (Hatt 1970). The other three provinces retained more of their indigenous Celtic character. Early on, all three could lay claim to only four colonies: Lugdunum/43 BC (Lyon); Augusta Raurica/44BC (Augst); Noviodunum/45BC (Nyon); and Colonia Claudia Ara Agrippinensium /AD 50 (Cologne). Trier (Augusta Treverorum/Claudian) and Avenches (Aventicum AD 74) are rare examples of later additions.

Gauls appear to have embraced the opportunity for commerce and trade. Gaul's industrial capacity eventually rose to rival that of Italy (OCD, 458). Gaulish *terra sigillata*, *amphorae*, *mortaria* and fine wares supplied markets throughout the western Empire including Britain. Wine production reached its peak in the Bordeaux, Burgundy and the Rhineland by the 2nd century AD (Hatt 1970). Gaul also became a major cereal and stock raising region. Pliny reports that it was especially rich in vast estates (Pliny *NH* XVIII, 261). Aquitania was especially favoured in wealthy Italian circles on account of its favourable soils and ability to produce a wide variety of foodstuffs.

Timber-built villas sprang up in its rural landscape during the first century AD. The first examples were unremarkable rectangular houses but soon afterwards stone-built structures, with Mediterranean style courtyards, took their place. A rapid phase of villa construction took place in the chronological interval from c. AD 200-300, during which approximately half of all Gallia Belgica's villas were erected (Haselgrove 1996). Presumably, the scale of agricultural production advanced to keep pace with the constantly advancing layouts of the villas. Derks (1998) argues that villas commanding vast tracts of land appeared in areas of the best soils by the 2nd century AD but Goudineau (2000, 471), on the other hand, argues that such ideas should be abandoned in face of the lack of compelling archaeological evidence (*cf.* Hingley 1989, 105, 127; Percival 1976, 31; Jones 1964, 416; Applebaum 1963).

Roymans (1996, 97) reports two essentially different agrarian regimes in Belgic Gaul, whose origins, he believes, were ultimately rooted in the pre-Roman Iron Age traditions: the first type focused on arable farming on the fertile loess soils, while the second emphasised pastoral farming in the areas of less productive soils to the north.

The Roman conquest probably supplemented the productive capacity of the Gaulish agricultural economy through the promotion of economic stability and by putting an end to the destructive cycles of raiding amongst tribes (Haselgrove 1996, 167; Hingley 1989, 10). There is evidence of a few advancements in agricultural technology, the most important of which is the regular appearance of iron in the construction of common agricultural tools. It is generally agreed that Roman iron-tipped spades and mattocks replaced Iron Age wooden parallels (Wightman 1985). A larger iron 'Gallic' scythe may have also become common (Pliny *NH* XVIII, 261). Romans probably also introduced new forms of rotary milling technology and new methods to power milling machines (Moritz 1958).

There is, however, little direct evidence for huge leaps in the technical capacity of agriculture of the region (Finley 1973). The most significant developments in agriculture had probably already taken place before the Romans arrived. In the 1st century BC, cross ploughing had been discontinued, giving way to long narrow field systems (Bradley 1978, 267). The wheeled plough, long share and asymmetrical plough may have been known (though they lacked widespread distribution - Rees 1979; Manning 1964). The bow-ard, pulled by the conventional pair of yoked oxen, probably remained the primary cultivation tool as it is the most commonly depicted plough in Gallo-Roman illustrations (Manning 1964). The *vallus* (a semi-mechanised reaping machine) is argued, on the basis of a few depictions in Roman art, to be a Roman introduction, but Pliny's passage treats it as a novelty (*NH* XVIII, 172). Furthermore, it is represented in art primarily in the Moselle region - a region of hills,vineyards and pastures for sheep (textile industry). The flat plains for grain, where the *vallus* would be useful, are located in northern France. It is usually suggested that the rotary quern was introduced between the 3rd- 2nd century BC (Audouze and Büchsenschütz 1992, 121; Heslop 1988), however, Harding (2006, 74) has recently argued for pushing this date back to 5th -4th centuries BC for even remote places such as Scotland (*cf.* Caufield 1978).

5.2.6.4 Germania

With his supply lines stretched to maximum extent, Augustus began to reassess his original intention of incorporating German-speaking people between the Rhine and the Elbe into a single grand province. In 15 BC, he ordered Roman forces back to the Rhine and the Danube. Under Tiberius, the Roman prospect of a *Germania Magna* evaporated entirely. A narrow strip of territory bordering the western bank of the Rhine was annexed and designated a military district under the supervision of the military commanders of armies of *Germania Inferior* and *Germania Superior* (OCD). Around AD 84, Domitian formally declared the military districts as two independent provinces under the same name, designating capitals at Cologne and Mainz. The eastern frontier northwards from Mainz became the Rhine itself. From Mainz southwards, the new border was defined by the *Limes*, a series of forts and palisades which followed the upper Neckar in an arc to the upper Danube. The *Limes*, with its signalling stations and forts, acted as a physical and military barrier and defined the northern and eastern limit into which Mediterranean-style civilisation advanced. In its initial years, it was patrolled by eight legions. Four, however, were withdrawn by Trajan (AD 98-117) following an interval of relative calm (OCD).

Although a substantial number of Roman legionaries were to settle in the area, both Germanies remained inhabited largely by provincials. It has been estimated that the administration and army amounted to less than 5% of the population (Schutz 1985; 1983). Despite their small numbers, Romans made significant inroads into Germanic culture especially in the more urbanised areas. Here, basic house construction evolved from simple mud and wattle structures to more intricate architectural renderings done in stone. Funerary monuments and carved inscriptions suggest the blending of Germanic and Roman tastes.

In other cases, things remained unchanged. With the exception of *coloniae*, the organisation of streets in an orthogonal pattern is not a feature of Roman towns in Germany. Most are oriented with respect to a primary artery, which in many cases is riverine. In the countryside, and particularly in the north, physical remains demonstrate that the traditional hamlet survived. Rural, isolated or clustered native farm houses of the indigenous first and second century German communities are timber-built. They were almost always rectangular and aisled in a manner reminiscent of the previous Iron Age. Their internal space is divided with a living structure at one end and a byre at the other with entrances sometimes visible on the long sides. Some have an additional opening at the end leading to a stable-like structure where animals were probably kept (Carroll 2001).

The many 1st and 2nd century AD villas that dotted the countryside of the German provinces show signs of having sprung from earlier Iron Age farmsteads, sometimes overlaying Germanic *Grubenhäuser* (small sunken-floored post-built structures). Sites excavated thus far indicate that the subsistence base was mixed farming. The rich loess soils of the area were ideal for the production of cereals, and numerous granaries attest to the importance of grains. The floor plan of a villa at Voerendaal (located in *Germania Inferior*) shows a building that has been interpreted as a typical Roman granary complete with a paved threshing floor. Granaries are common on sites east of the Maas (Kooistra 1996).

Very little is known about the region's system of land tenure. In those areas where the population was decimated, there would seem to have been a need to survey land and establish ownership. This fact has led Roymann (1996) to believe that, on the lower Rhine, centuriation was carried out. The farms of the rich loess belt, stretching west of Cologne, where most of the wheat was grown, seem to have been located at regular intervals and in units corresponding to the traditional Roman farm size of 200 *iugera*.

On farms, cattle were the most important domestic animal within and just outside the two provinces. Pig, sheep, goat and dog were also kept as livestock (King 1999). Assemblages from throughout the region display evidence for a new range of domesticated plants (walnuts, beets, apricots, almonds, pears, medlars, plums and cultivated grape) after the arrival of the Romans. These are complemented by a new range of exotics, such as dill, coriander, mint, celery, fennel and rue (Bakels and Jacomet 2003). Several species of farmyard animals also now appeared (donkey, goose duck, cats, guinea fowl, chickens and peacocks). Meadows were maintained by or for the legions as attested by inscriptions referring the *prata legionis* (Rüger 2000, 501). Knörzer (1973) argues that the Romans introduced hay production to central Europe, but this view is not universally accepted and other authorities argue that Germany's grasslands originated at different periods in different districts (Poschold and Wallis-DeVries 2002). On some sites, there is an increase in the height of domestic livestock from the Iron Age to Roman period which may indicate the introduction of new types of livestock breeds (Kreuz 1999, 75-83). "The appearance of larger cattle and horse breeds in the Roman times has often been interpreted as a sign of change for the better. It is claimed that Celts and Germans with their pony-like horses were not capable of breeding bigger animals at all. Yet it seems more likely that small cattle and horses were optimal for the farmers and soldiers of that time" (Kreuz 1999, 82).

5.2.6.5 Britain

In the spring of AD 43, Roman legions, commanded by the future emperor, Vespasian, arrived in Britain for the third time. The logistics of supplying the invading army, and the effects of the army on the island, have been the subject of much scholarly deliberation (Millett 1990; Fulford 1989; Woolf 1992; Branigan 1980; Birley 1981; Collingwood 1969). Some authorities treat the conquest and the subsequent occupation as a turning point. Others have played down its impact (Millett 1999). The history of the conquest seems to indicate that in its initial stages negotiation was typically preferred to military action and that some care was taken to prevent over zealousness. Some have suggested that, in the beginning the military burden on locals was probably no more than their traditional Iron Age tribute (Millett 1999; Goldsworthy and Haynes 1999; Whittaker 1994; Dobson and Mann 1973).

Scholars are divided in terms of their opinions about the sources of grain for the occupying legions (Carrington 2002; 2004). Mann (1985) argued that, before the third century, the Romans failed to levy a grain tax on communities, except in areas where they had inherited the practice from the former ruling class. Grain for the army could be acquired through purchases (*frumentum emptum*) or gathered as tax in kind on the procurator's behalf (Rickman 1971, 271). Various forms of evidence have been used to demonstrate that grain could also arrive from abroad (Miller 2000; Ottaway 1996, 1993; Van der Veen 1992; Middleton 1979; Rickman 1971; Helbaek 1964). The actual process of gathering provisions and keeping soldiers supplied with provisions seems complex and varied. Carrington (2004) suggests, for instance, that:

> "The collection of army supplies, whether purchased or gathered as tax in kind, might be organised directly by soldiers (e.g. Bowman 1994, 40; Breeze 1984, 281) or under contract by *negotiatiores*, who could at the same time trade on their own account, bringing in additional goods and supplies which were available for purchase by individual soldiers and civilians in the *canabae* (Whittaker 1989, 69-72; 1994, 104-13). These supplies could have included grain and other foodstuffs collected as tax but sold on as surplus to government requirements. The actual transport, at least overland, of official supplies and officials within a province could be requisitioned from communities en route (Mitchell 1976, *passim*; Black 1995, 5-6, 8, 11, 22) and was indeed an obligation on communities supplying requisitioned produce (Mann 1985, 22, discussing Tacitus *Agricola* 19). However, it is unclear how far it was practical for these functions to be carried out by a dispersed rural population, and they may again have been carried out by contractors (*cf.* Brunt 1990, 379 and 531 on the gathering and delivery to a central point of rent-grain by *conductores* of imperial domains in north Africa)" (Carrington 2004, 1).

The placement of military forts provides an insight into where demand was the greatest. The largest and most frequent defences were provided on the northern and western borders while in the south east and interior sections of the island, Roman military presence was more diffused.

Caesar reported that the native economy was similar to that which the Romans had encountered elsewhere in north-western Europe. He describes Britain as a densely populated island, dotted with houses and farms which resembled those of the Gauls. He was especially impressed with the number of cattle he saw (*De Bello Gallico* V. 12-14). By the time of the conquest, the population is believed to have been substantial, having grown to two or three times what it would later be at the beginning of the 11th century AD (Hingley 1989, 4; Salway 1981). In the south, many of the previously established hillforts and lowland sites had expanded into *oppida*, which Romans perceived as 'royal towns'. Two forms of political organisation predominated: the less common was a sophisticated and centralised state operating from an established centre. The more common was a confederation comprised of a series of small loosely knit communities. Most authorities agree that there was a substantial amount of cross-channel trade. In order to invade Britain, Caesar was required to defeat the navy of the Gallic Veneti which he described as immense (*De Bello Gallico* III. 8). Strabo (64 BC-AD 21) reports strong kinship ties between tribes on both sides of the channel, and adds that they maintained a lively trade in gold, silver, grain, hides, hunting dogs, wool and cattle.

There can be little doubt that the conquest resulted in the confiscation of land and the redistribution of property in some places. The influx of coinage and rare goods may have also destabilised the former elite. The polyglot nature of the Roman army introduced new ideologies and new forms of administration to most areas. New means of social advancement became possible. Roman authority ended the system of regular tribal warfare and raiding and probably brought a new level of stability to the market. The use of small coinage became almost universal during the early Roman period. In the south, the Roman military was responsible for the creation of dependent urban centres with a regular tax structure which, by their very nature, probably fostered the growth of a market economy. Above all, Romans created roads which enabled goods to flow between distant markets. In the south, the country folk witnessed the construction of villas from the 1st century AD onward (Nevell 1998; Dark and Dark 1997; Wells 1996; Whittaker 1994; Weiland 1993; Hingley 1989; Branigan 1980; Branigan and Fowler 1976).

5.2.7 Crisis and decline (AD 250-AD 450)

By the middle of the 3rd century AD, the Roman Empire had entered a period of crisis as Germanic tribes began to encroach on its borders and the political establishment fell into chaos (Whittaker 1994; C. Wells 1992; Duncan-Jones 1990, 1974; Hopkins 1980; Birley 1976; Finley 1973; Jones 1964; Rostovtzeff 1957). Under Trajan (AD 98-117) the Empire had reached its furthest extent, and after the death of Hadrian (AD 117-138), cities began to stagnate, economic growth slowed, inflation mounted, and central government progressively lost control. Between 180 and 284 AD the Empire was ruled by absolute military dictators who dramatically increased taxation, reduced the economy to ruins, and changed the capacity of the Senate to deal with economic and military crisis. For the following two centuries, barbarians periodically threatened the provinces weakening the empire's economic structure even further while simultaneously putting greater demands on central government. There were frail attempts to manage the economy but most efforts only worsened the problems.

With the central government unable to cope, the fifty year period from Philip II (AD 235-138) to Diocletian (AD 284-305) saw forty Caesars rise to claim office. Most were nominees and then victims of their own soldiers. In AD 257, German Goths overran the eastern province of Dacia, crossed the Danube, sacking a host of Greek cities. In AD 269, the Goths and the Heruli returned to plunder the northern frontier. Two years later the Alamanni advanced as far as Milan. In AD 256 and AD 258, the Franks and allied tribes swept across the Rhine and wreaked havoc as far as Tarragonensis (Spain). A devastating Mediterranean plague began in AD 252 which raged for fifteen years. Alexandria is reported to have lost two-thirds of its population. Diocletian and Constantine stabilised the Empire briefly between AD 284 and 331 but an account of the 4th century AD essentially traces a series of dynastic struggles fuelled by frontier invasions and widespread economic chaos. It is difficult, however, to define a precise terminus for the Empire. Essentially, Rome endured a series of crises in the late third, fourth and fifth centuries AD that enabled a transfer of imperial control to non-Romans and Christian theocrats.

5.2.7.1 Gaul

In Gaul, the 3rd and 4th century AD brought: (1) a change in the imperial system; (2) new social imperatives in the form of the Christian Church; (3) a decline in population; (4) the desertion of some villas; (5) a reduction in overall living standards; and (6) strife with tribes from the north. With the death of Theodosius in AD 395, the eastern and western Empire were permanently parted, providing further opportunity for invasion. In AD 406, Germanic peoples crossed the frozen Rhine and pushed deep into Gaul. By AD 415, much of the former province was occupied by Franks, Goths and Visogoths who erected a fortress inside the amphitheatre at Nimes (Colonia Julia Augusta Nemausus Volcarum Aremecorum) (Darde 1993). After this point, it becomes increasingly difficult to draw social distinction between Gauls, Germans and Romans, as their way of life converged under the influence of the Christian Church.

Much of this is documented in the region's archaeology. From the reign of Postumus (AD 260) onwards, there was an increase in city wall construction and gradual abandonment of settlements on sites in the north and east (Haselgrove 1996). One can see the effects of decentralisation in urban architecture as buildings began to display fewer monumental inscriptions, becoming more functional and less pretentious (Wierschowski 1995). By the mid 4th century AD, decay is visible in the rural landscape as well as the cities. The villas had all but been abandoned (Bayard and Collart 1996) and, for the first time Gaul may have been unable to produce a grain surplus (Goudineau 2000). Zosimus (*Historia Nova*), and Ammianus Marcellinus (*Res Gestae* XVIII 2-3) report that grain was being imported into the Rhineland from Britian between AD 335 and 360 (*cf.* Randall 1930; *cf.* Allen 1995). Bakels and Jacomet (2003) report a drastic drop in the availability of luxury foods in the western provinces and Sandori and Susanna (2005, 392) report a similar regression in Italy.

5.2.7.2 Germania

In the Germanies, the first half of the 3rd century AD was characterised by Frankish invasions in *Germania Inferior* and Alamannic incursions into *Germania Superior*. In some parts of Germany, settlements were being abandoned as early as the late 2nd century AD (Carroll 2001, 138). By the mid 3rd century AD, it is evident that the economy was entering a period of crisis as Roman armies and tribesman pillaged the countryside in an almost endless series of conflicts. The archaeological evidence attests to a countryside particularly hard-hit with much of the arable land abandoned. In AD 260, Postumus, the military commander of the Rhine forces, established himself as emperor of Gaul, with the Germanies, Spain and Britain allied alongside him but, after reorganising the military posts along the Rhine, and repelling a German invasion, he was killed by his own troops. The Rhine provinces were gradually returned to Italian control by Aurelian (AD 273-274). In an attempt to establish order and lessen the power of individual field commanders, Diocletian (AD 284-316) divided the empire into three parts: *Germania Inferior* was renamed *Germania Secunda,* while *Superior* became *Prima* and *Maxima Sequanorum*, all three belonging to the Diocese of the Gauls. Simultaneously, the internal organisation of the army and the state bureaucracy was accomplished along with a reorganisation of the economy with a system of price controls. The controls, however, proved ineffective, and the concept was abandoned.

Throughout most of the 4th century AD, Germany again found itself as part of a weak western Empire with its political and economic fortunes tied to vagaries of migrating tribes from the Rhine's opposite bank. The archaeological evidence from urban areas suggests a succession of destructive phases which are often followed by subsequent phases of rebuilding (Carroll 2001). As in Gaul, the plans of reoccupied towns were smaller and their defensive works were focused into increasingly more concentrated areas. This may reflect a need for a new form of defensive works, a decrease in population, or the relocation of the elite to more secure locations in the south. Equally, it could reflect the fact that a significant portion of the population was left undefended at the expense of protecting government property (Carroll 2001).

By the last half of the 4th century AD, Italian influence in Germany had effectively collapsed. Few efforts were made to refortify the Rhineland. The cities and towns in northern Gaul's belt of rich loess soils were repopulated by German and Frankish tribesman who were allowed to settle wherever they wished, provided they ceased raiding and did not threaten or settle beyond the main economic artery from Boulogne to Cologne.

5.2.7.3 Britain

Although Britain never achieved the prosperity or economic sophistication of Gaul, it held the advantage of being more insulated from tribal invasions and devastation caused by marauding Roman armies. As a result it seems to have suffered less through the second half of the 3rd century AD than either the Germanies or Gaul. It was, however, not completely immune to the unrest that characterises the period. After having joined Postumus' rebellious Gallic Empire (AD 259), Britain was reunited to Roman Imperial control by Aurelian in AD 274. An interval of uneasy peace ensued until mercenary Vandals and Burgundians were dispatched to quell another rebellion in AD 278. A further series of rebellions, incited by the British generals Carausius and Allectus, were crushed by Constantius in AD 293. From this point forward, Britain was divided into four provinces probably in an effort to dilute the authority of Britain's habitually mutinous governing officials (C. Wells 1992). By the late 3rd-4th century AD, Britons were obliged to build a series of forts along the southeast coast to guard against invasions and piracy by Angles, Saxons and Jutes. In AD 396, the general Stilicho reorganized Britain's remaining Roman defences, transferring military authority from the Roman army to local British rulers. In AD 402, one of the two remaining British legions was recalled to defend Rome from siege by the Visigoths. The following year, a combined barbarian force of Burgundians, Alans, Vandals and Suebi swept through central Gaul, severing links between the island and Rome and the remaining Roman forces in Britain mutinied. Honorius abandoned Britain to its own devices in AD 409.

Throughout this crisis, smaller towns appear to have gained at the expense of the once thriving *civitas* capitals (de la Bédoyère 2003; Isserlin 2003). Overall, the archaeology suggests a shift in the economy towards economic decentralisation as priorities shifted away from Rome. In industry, we see a decrease in scale, with craft production refocusing and redirecting itself to smaller and more diversified workshops (Fulford 1977). In urban plans, we find broadly the same type of settlement pattern (increased nucleation of buildings) that we observe in Germany (Dark and Dark 1997; Burnham and Wacher 1990). In the countryside, archaeologists cite a similar phenomenon (a pattern of increased nucleation) (Heather 2005; Dark 2000; Dark and Dark 1997).

The social system is, however, argued to have remained stable. The local aristocracy retained its elite status, communities held to established Roman traditions and abided by Roman law (Heather 2005; Hill 2001; Millett 1999). Newly constructed homes generally increased in size and continued to reflect Roman ideology in terms of floor plans and decor, though their overall numbers (within the urban context) declined throughout the 3rd century AD (Millett 1999). According to de la Bédoyère (1993, 54), Romano-British villas reach their greatest extent in terms "maturity, stability and production" during the mid-late 3rd century AD.

The late Roman to sub-Roman period in Britain is poorly understood because of a lack of historical details. The archaeological record is patchy, contextually fragmented and conflicting. There is continuity, and even progress, in certain places whilst there was total abandonment in others (Esmonde Cleary 2000). The traditional (and up to now consensual) view advocates widespread economic hiatus (Faulkner 2000). Inferior timber buildings were erected amongst the ruins of grander structures inside city walls, the distribution of coinage contracted; and material culture become impoverished (Wilson 2003; Esmonde Cleary 2000). The historical record of the fifth century AD is woefully anecdotal. Sources are limited to accounts of St. Germanus of Auxerre's visit in 429 (Prosper of Aquitaine, *Epitome Chronicon*) and recollections from Constantius of Lyon's (*Life of St. Germanus* 5.25, c. AD 445). Faulkner (2000, 175) argues that although we can draw no conclusions to about the population's state of well being, we should assume that people continued to work the land and that most farming communities remained relatively prosperous in the absence of Roman taxation. The disappearance from the archaeological record of forts, towns, villas, mass production and long distance trade merely testifies to the liquidation of the easily recognisable Romano British superstructure (Faulkner 2000, 176).

5.3 Implications for cereal frequencies

5.3.1 The key developments during the Iron Age period

The overview provided above indicates that, during the Iron Age, a number of events took place which potentially influenced crop production, consumption and exchange. Amongst the most obvious was a change in the general intent and purpose of production. The evidence seems to indicate that at the beginning of the Iron Age, farmers were generally content to cultivate their fields merely as a means to generate food supply. However, as events progressed, economic and political forces began to combine to foster a market for agricultural goods which, in turn, provided consumers with the opportunity to express new kinds of food preference. Such events were almost certainly accompanied by the diffusion of technical knowledge (particularly from the Near East), a development which, in all probability, also provided European farmers with additional production capacity. Evidence also suggests that, as population levels grew, Iron Age communities increasingly focused on methods to expand production as tribes were forced into marginal areas or onto previously intractable soils by a need for more land.

As new priorities and opportunities emerged, consumer demands gradually began to replace the previous preoccupation with food security. This, in turn, probably resulted in an approach to crop production that was more carefully controlled and driven by highly specialised producer and consumer requirements. Furthermore, as new technology spread, it soon became possible: (1) to relax the amount of stress on the crop (2) to complement production by using expanded range of crop choices; (3) to extend production by growing crops over a longer period of time; and (4) to produce a wider range of ingredients from traditional varieties.

As production became further divided into an ever increasing number of specialised and separate fragments, each with its own distinctive requirements and different objectives, agriculture and food processing industries probably generated additional technical expertise. This, in turn, provided producers and consumers with an even greater range of culinary alternatives and opportunities. It seems reasonable to expect that each of these new developments motivated farmers to cultivate cereal plants explicitly suited for industrial purposes and mass markets. As trade expanded and dependencies emerged, an opportunity arose to grow crops preferred by very specific target markets (e.g. specific cities or specific types of bakers). Moreover, the development of a money-based economy facilitated commodity transactions and ultimately made the process of cereal exchange run more smoothly. As a consequence, an incentive arose to grow cereal types which circumvented commodity related problems such as bulk transport.

5.3.2 The key developments during the Roman period

By AD 14 the Roman armies had extended the power of the Empire across almost all of the study area. Although it is difficult to generalize about the effects of Roman influence, the conquest did result in a set of widely similar responses that are embraced under the label of 'Romanization'. In some cases Romanization produced abrupt breaks in the socio-economic fabric of the western provinces and further broadened the range of economic alternatives available to indigenous peoples. Archaeological investigations demonstrate that the Romans introduced new crops, food-ingredients and methods of food preparation into the western provinces. Although most of these do not appear to have replaced traditional foods entirely (e.g. cereal gruels), some became integrated into the local diet, widening the range of available food choices.

The Roman conquest additionally introduced economic stability to regions frequently plagued by inter-tribal rivalry, raiding and theft. Through the network of military installations and border fortifications, the Roman military ensured that: (1) the flow of goods such as grain was regulated; (2) the Empire's grain supply lines were maintained; and (3) economic disturbances like rebellions and invasions were subdued. Ultimately, this may have provided rural producers with the confidence, security and infrastructure necessary to produce grain types which were specifically preferred by an even narrower range of niche consumers. The institution of a regular tax structure brought with it economic incentives to produce specific types of cereal products as payment in kind and provided the opportunity for middlemen to influence production by demanding cereal varieties on the basis of quality standards and price.

One of the most oft cited Roman influences on agriculture is in the scale of farms. Classical authors report that, especially in the period following the Punic wars, the number of small family farms declined and arable acreage began to coalesce in many places because of: (1) the effects of years of military conflict; (2) the flight of peasants to cities; and (3) the spread of capitalistic farming methods. Closely connected to these events was the establishment of large estates and the opulent Classical style Mediterranean villas. Farming at these installations was usually undertaken on an industrial scale and, therefore, almost certainly for profit. Consequently, the grains associated with these types of farms were probably intended for specialised markets with exacting quality requirements and product specifications (e.g. an occupying army; an industrial class of millers). Producers probably also responded by specialising in cereal types which offered transportability and ease of processing in order to increase their margins.

5.3.3 Regional variations in the key changes

The economic imperatives affecting crop choice affected different areas to different degrees varying on different time scales. South eastern Mediterranean communities, which held traditional links to the Near East, seem to have been regularly stimulated by new ideas, techniques, priorities and fashions filtering in from that direction. Patterning in material culture, art, technology, settlement structure, urbanisation and population nucleation suggest that Mediterranean areas like Greece and Italy often followed Near Eastern models. Market development, in turn, followed a broadly similar pattern, with the Mediterranean countries developing urban-style layouts, urban-style markets, and sophisticated urban-style culinary tastes by as early as the 6^{th}-5^{th} century BC. However, the evidence indicates that most of these developments were muted or delayed in central Europe. The development of cities and towns in Europe, for instance, was delayed by at least three further centuries.

Nucleated settlements, as complex as towns, did not emerge amongst outlying areas, such as the northern Netherlands, northern Britain and northern Germany until the final phases of the study period. There was also a division in the rate and degree of penetration of knowledge. Since communications and long distance trade were highly conditioned by maritime links, distant and interior communities appear disadvantaged in terms of the flow of emerging ideas, technologies, and discoveries.

Romans gain influence over the affairs of Greece and Italy between the 4th and 3rd centuries BC. Gaul, Germany and much of Britain were effectively merged into the Roman Empire by the time of Claudius. As a result, much of the study area was probably greatly affected by Roman ideas by the end of the 1st century BC (although the timing between adjacent countries may have varied by a century or more). Roman influences seem to have manifested themselves to different degrees in different places. Firstly, along the Mediterranean fringe, Romanization appears to have been primarily a political event bringing limited social, economic and technical change. Contrastingly, the transition to Roman style civilisation appears to have been readily received amongst the Celtic and Gallic tribes of France and Britain. In northern France and southern Britain, there is evidence of a rapid acceptance of Roman values and material culture, especially in places where the settlement pattern was already nucleated and political power already centralised by the time of the conquest. However, in fringe areas like northern Germany, the northern Netherlands and northern Britain, tribes seem to have remained conservative in their ways and reluctant to adopt Roman traditions. This seems particularly true for the more rural communities.

5.3.4 Crop choices under shifting socio-economic circumstances

5.3.4.1 Subsistence farming

Because one of the the main agro-economic contrasts between the Iron Age and the Roman Period is the shift from subsistence farming to market farming, it is perhaps useful to discuss differences between the structures of both systems. Subsistence farming is normally oriented towards producing only enough food to feed the immediate family or community (with a 'normal' surplus). Subsistence farmers generally favour crops which carry a low level of risk and low production costs and which render sustainability with minimal effort. Moreover, because labour is a critical variable in subsistence farming communities, subsistence farmers traditionally choose crops which integrate well with their livestock and take relatively less time to maintain than other alternatives. There is an emphasis on crop types which offer flexibility in terms of management and which do not have stringent agronomic requirements. Crops are usually grown using simple farming techniques and technologies. Subsistence farmers can also be very conservative and usually adhere to traditional types of crops and cropping strategies irrespective of conditions elsewhere. There is also an emphasis on crops which offer food security rather than short term material gain.

5.3.4.2 Market farming

In contrast, market farmers favour crops which are closely matched with the constantly evolving needs and fashion-driven preferences of consumers. Because profit is the motive envisioned by the owner or operator of the farm, market farmers tend to prefer crops which are responsive to technological inputs and controls. Uniformity, predictability (in terms of qualities such a uniform ripening and uniform grain quality), storability and transportability are high priorities. There is also a tendency to favour crops which offer high returns through low processing costs. There is motivation to use crops which take advantage of strengths in the existing economic infrastructure (e.g. roads) and there is a readiness to redirect the course of production in response to shifts in consumer behaviour. Producers are motivated to seek premiums offered by perceptions of superior quality or value. Profitability, quick turn-around and marketability are prime goals. Consequently, there is a tendency to specialise. Producers respond by growing varieties which offer elevated performance with respect to traits like grain taste, flour colour or baking quality. Likewise, there is also an emphasis on commodity related traits such as transportability.

5.3.4.3 Technologically enabled farming

Cereal frequencies can also be altered by the introduction of new technologies. Iron ploughshares, for instance, are able to penetrate heavy soils. They, thus, provide the opportunity to sow crops which have the capacity to utilise such nutrient rich soils. However, additional opportunities usually entail new and more specialised requirements.

Cereals associated with elevated levels of production technology need to be more uniform and predictable in terms of their growth characteristics than those that are not. This allows them to apply inputs like irrigation and nitrogen simultaneously. They may also need to ripen more uniformly and at the same height so that farmers can use harvesting devices efficiently, or increase the number of ripe grains that are ultimately harvested. Technologically inclined grain processors such as millers likewise prefer types with uniform grain: (1) colour; (2) protein content; (3) hardness; and (4) size.

5.3.4.4 The need to expand production

Farmers expanding production can prefer cereals with accentuated performance of four sorts. Firstly, they can prefer cereals which have an elevated ability to thrive over a wide range of different habits. This allows use in an expanded range of circumstances, situations and instances. Secondly, they can prefer types which display elevated performance with respect to the marginal habitats which need to be brought into production. Cereals of this type tend to have particular traits which allow the plant to cope with particular types of environmental stress effectively. These crop types tend to become most important in situations where there is large degree of maladaptedness between the traditional genotype and the newly introduced habitat. Key factors related to suitability include the capacity to tolerate (1) inundation of land; (2) desiccation; (3) salinity; or (4) periods in which the soils or temperatures are at suboptimal levels. Thirdly, because agricultural expansion can involve extending of the length of the crop growing season, species which extend the agricultural (time) cycle over a greater interval of time than was previously possible prove especially important. Crops which are favoured by this type of expansion tend to be specialists, well equipped for the rigours brought on by early or late season planting. Frost resistance, cold tolerance weed or late season insect tolerance allow these kinds of crops to thrive in months/weeks when other species are either dormant or under stress from competitors or climate. Finally, agricultural expansion lends itself to crops that have a markedly heightened responsiveness to management. The opportunity to extend the spatial or temporal range of a crop species can be made possible by integrating processes, equipment and cultivars so that farming is possible in an increased number of circumstances, over an increased time period or over an increased number of land types.

Innovative management or application of soil nutrients and water, improved weed control and deeper ploughing not only increase yields per unit area greatly but they also extend the range of usefulness of a crop type by relaxing the amount of stress on plant growth.

An overview of the taxa

Chapter 6

6.1 Introduction

The following chapter provides a brief introduction to of each of the taxa. Each genus is described under four section headings. The first outlines the way the genus is classified in terms of botanical concepts. The second section addresses the evolution and early history of each taxon. The third section is a general discussion of some of the commonly held assumptions about the genera. The final section offers a brief discussion of the phytogeography of the genera.

6.2 Oat

6.2.1 Classification

As is the case for most domesticates, the classification of oat is complex. Currently, there is little agreement among researchers regarding the classification of the species in *Avena* L. (Loskutov 1999).

> "Within the hexaploid oats, the four taxa (*Avena byzantina, A. fatua, A. sativa* and *A. sterilis*) represent a complex of wild types, weeds and cultivated derivatives that have been treated as different species in the taxonomic literature. At present, these four taxa are classified as a single biological species (*A. sativa* L.) as they all share the same chromosome number and are mutually interfertile" (Vilars *et al.* 2004, p. 23).

A. byzantina K. Koch is a drought resistant annual grass sometimes cultivated for grain or forage in Mediterranean regions. *A. fatua L* and *A. sterilis* are two of the world's most resilient and destructive weeds in cereal fields (Wilding 1986). *A. sativa* is the most commonly used term in agronomic literature.

6.2.2 Evolution and early history

The genus *Avena* contains about 14 types/species. The types, like wheat, form a polyploidy series ranging from diploid to hexaploid. The commonest cultivated type (*A. sativa*) is a hexaploid formed by two steps: (1) the hybridisation between two diploid species followed by chromosome doubling to form a tetraploid; and (2) the hybridisation of the tetraploid with a third diploid species and subsequent polyploidization to form the hexaploid.

There is currently little consensus about which oat type represents the direct hexaploid progenitor of the most commonly cultivated hexaploid type, although *A. sterilis* is thought to have played a role (Holden 1976; Zhoux *et al.* 1999; Cheng-Dao *et al.* 2000; Jellen and Beard 2000). Two independent paths are currently advocated: one path led to the development of the *A. sativa* type; and the other to the *A. byzantina* type (Vilars *et al.* 2004, 23).

The use of oat as a cereal grain began much later than that of wheat and barley, and oat may have entered cropping regimes as a weed. The earliest claims for cultivated oat in Europe come from excavators of first millennium BC Urnfield sites (Helbaek 1959) but most authorities propose that oat cultivation did not become widespread until the Iron Age. Prehistoric remains are found as far north as Western Scotland and the Hebrides (Dickson 1996). The coastal areas of north western Germany have yielded oat-rich samples from as early as the 1st century AD (Körber-Grohne 1967).

6.2.3 General description

Oat is a tall (c.1-1.5 m.) cereal with types and varieties adapted either to autumn sowing/midsummer harvest or spring sowing/late summer harvest. It is generally regarded to have an aggressive growth habit in comparison to other cereals. Oat is widely grown as a fodder or food grain. When used as a food grain, oat is most commonly used for making porridge. The vegetative plant parts are useful as forage and make fine quality hay (Marshall and Sorrells 1992). "Oat ranks first among winter forage species in intensive production systems, particularly when forage availability is sought in fall or early in the winter" (Vilars *et al* 2004 p. 23). Oat grain is an important livestock feed and is fed widely to ruminants and horses. Crushed oats are excellent for ruminants; they are the standard cereal in horse feeds, but oats generally contain too much fiber to be used as the principal concentrate in pig rations (Abrams 1961). Oats are harvested when grain is in the hard dough stage and straw is still slightly green (when the moisture content of the grain is 14% or less). If the crop is harvested too late, the grain will shatter causing significant yield losses. Under conventional production schemes, the crop is cut and left in the field to dry before being threshed (Fern 1997).

6.2.4 Current distribution and agro-ecological preference

As a group of wild and cultivated taxa, oat is a robust plant with a wider geographical distribution than wheat, barley or rye (Thomas 1995). Oats is an important crop in marginal ecologies and is generally tolerant of acid soils. Oats are most commonly grown in cool moist climates. Most species are sensitive to hot, dry weather between head emergence and maturity. World oat production is generally concentrated between latitudes 35-65 °N and 20-46 °S (Stevens et al. 2004, 52). "The bulk of the world's production comes from spring-sown cultivars, but autumn sowing is practiced in higher-altitude regions, and in regions where summers are hot and dry" (Stevens *et al.* 2004, 52). Common oat grows best as a spring season crop under adequate moisture conditions, and yields best on well-drained neutral loam soils, especially silt and clay loams (Thomas 1995). Although it is considered more aggressive (in the sense that spreads matures and reproduces relatively rapidly) than barley and wheat, oat is not nearly as aggressive as rye (Thomas 1995, 135).

6.3 Rye

6.3.1 Classification

Taxonomists currently recognise five species of *Secale*. Within these two distinct groups of species are readily distinguished (on the basis of cytological analysis) one group which includes cultivated or ruderal annuals or biennials, and another which includes perennials, the *cereale* and *montanum* groups (Evans 1995). All cultivated forms of *Secale* grown within Europe are recognised under the term *Secale cereale* (Evans 1995). All the natural *Secale* species are diploids as are most rye cultivars (Evans 1995, 166). Bushnik (2001), however, reports that a handful of potentially valuable synthetic pentaploid varieties currently available as production alternatives.

6.3.2 Evolution and early history

The precise progenitor of rye remains unknown although many authorities contend that *S. montanum* Guss. was probably involved (Evans 1995). Hillman (1978b) has argued for domestic use of *S. cereale* in Anatolia from at least 6000 BC. There is little agreement about when or where the intentional cultivation of rye began in Europe (Evans 1995). Several routes for the European introduction of rye have been proposed, among which, those through the Caucasus or the Balkans currently seem to be the most favoured (Salamini *et al.* 2002; Evans 1995). Some authorities argue that intentional rye cropping spread from regions where arable farming was restricted to poor sandy soils (e.g. northern Germany) (Behre 1992). Because rye is genetically and morphologically very similar to wheat, and since both crops interbreed freely and coexist within cultivated fields, the precise date for the beginning of intentional rye production is difficult to determine (Bushuk 2001; Hillman 1978b). In areas where rye occurs as a weed, it will out-crop wheat over time if seed-corn is not well cleaned (Bushuk 2001). According to Behre (1992) rye remains are traceable as admixtures to wheat crops as early as the *Linearbandkeramik*. Concentrated finds of cultivated rye (in central Europe) are very rare for any period earlier than the Iron Age (Behre 1992, 143).

6.3.3 General description

Rye is a tall (c.1–1.5 m.) hardy, tufted annual or biennial cereal grown for food, feed, pasture or soil cover (erosion prevention). Rye is a cross pollinated crop with a strong self-sterile habit (Bushuk 2001). It is particularly valued in cool climates being the most cold tolerant cereal species and the only grain other than wheat with the capacity to produce flours with natural leavening properties. Of all the small grains, rye has the lowest seed germination temperature requirement, a trait which conveys a late autumn sowing advantage (Bushuk 2001). Rye is an aggressive crop producing more biomass than wheat, barley or oat, and it yields generously in areas with poor soils. Where it grows today, wheat is usually the consumer-preferred grain (Stoskopt 1985). Rye is an excellent maslin crop and is commonly sown in mixtures with wheat or barley (De Rouen *et al.* 1991). As a food grain, rye is most commonly used for the manufacture of bread but it also distilled into whiskey. Rye is the most widely used small grain in situations which promote winter grazing because of its tolerance to cold weather and waterlogged soil. Rye grain tends to mature earlier than other grains but forage quality drops off more rapidly (Bushuk 2001). It is usually harvested at the milk stage (45% moisture content), since shattering becomes a problem at lower moisture levels. Rye threshes very easily but care is required to prevent kernel cracking (Bushuk 2001).

6.3.4 Current distribution and agro-ecological preference

Commercial rye production is today almost exclusively restricted to the north-western part of the Eastern hemisphere. It is particularly concentrated into cold agro-climatic zones (like the steppes of Russia) on account of its extreme cold tolerance and ability to adapt to poor soils (Evans 1995). Nearly 95% of current global production takes place between the Ural Mountains and the North Sea. The most intensive production takes place in Germany, Poland, western Russia, Belarus and Ukraine (Bushuk 2001).

6.4 Barley

6.4.1 Classification

The botanical classification of barley is as confused as that of oat. Cultivated barley is most commonly classified as *Hordeum vulgare*. Wild or weedy races of barley are most commonly distinguished as *H. spontaneum* but, from a biological perspective (in terms of a capacity to interbreed), weedy types belong to the same species as the cultivated types. "Hybrids between wild and cultivated forms are easily made and occur naturally wherever the two species are found" (Harlan 1995, 141). A taxonomic division is usually maintained between 6-rowed types (*Hordeum vulgare* L.) and 2-rowed forms (*H. distichon* L.) (NewCROP 1999). All wild forms are 2-rowed. An agronomic division is maintained between 'hulled' and 'naked' grained forms (NewCROP 1999). A further agronomic division is normally acknowledged between autumn/winter sown and spring sown types. All cultivated barleys are descended from diploid wild species. The main differences between wild and domesticated barley are the acquisition of a non-brittle rachis and increased seed weight. Naked seed types are unknown in non-domesticated forms.

Feed barleys are usually of the hulled type. In naked grained types, the lemma and palea do not adhere to the grain when it is threshed. Naked grain types are preferred where barley is grown for human diets (Harlan 1995, 141). Malting types are divided into 2 and 6-rowed types. Two-rowed types are most popular in Europe while 6-rowed forms are preferred in the United States because of their proportionally higher enzyme and protein levels (NewCROP 1999).

6.4.2 Evolution and early history

Barley is one of the earliest domesticated crops, with remains having been recovered from the Pre-pottery Neolithic at many sites in the Middle East (Zohary 1996; Zohary and Hopf 1993). Current consensus holds that domesticated forms of barley first arose in the Israel–Jordan area (Salamini *et al.* 2002). Genetic studies have shown that wild barley populations from this region are more similar to domesticated forms than are accessions from other regions, but the topic remains controversial and numerous points of origin are constantly being proposed (Molina-Cano *et al.* 2002; Badr *et al.* 2000). Barley's route of entry into Europe is also still unknown. Barley reached Spain by the 5th millennium BC and is reported to have reached the lower Rhine not much later (Zohary 1996; Zohary and Hopf 1993).

6.4.3 General description

Barley is typically a short cereal seldom reaching more than 1 m in height. Today it is primarily grown for animal feed, malts or food and, even in the most recent past, it has been a basic component in human diets. In terms of total international production, barley is currently about one-third as important as wheat (Fischbeck 2002; Magness *et al.* 1971). At least half of the world-wide crop is currently employed as livestock feed (Fischbeck 2002; Magness *et al.* 1971). Around one-quarter of barley is used for malting and the majority of that portion is used in the manufacture of beer (Fischbeck 2002; Magness *et al.* 1971).

A small fraction is also used in the production of certain types of cake mixes and breads. Barley for human food is 'pearled' by grinding operations which remove the hulls (lemma, palea) and the embryo. Whole pearl barley is incorporated into salads, puddings, soups, stews and casseroles. The vegetative portion of barley is commonly used as hay and straw and sometimes as a grazing crop. Winter barley can be used for grazing purposes without serious grain yield reductions provided animals are removed before culms begin to elongate (Harlan 1995). Forage producers generally sow early to maximize their growing season and provide feed as early as possible but sowing too early can lead to risks which offset any potential gain.

Barley is physiologically mature at between 30-50% moisture. When ripe, barley is fairly easy to thresh, and harvesting can begin when moisture level in the grain is as high as 20% (MAFRI 2005-barley). Mature barley is more easily damaged by adverse weather than wheat, oat or rye. Consequently, it is critical that harvest is not be delayed.

6.4.4 Current distribution and agro-ecological preference

Barley is produced over a wide geographic range prompting some authors to argue that it is the most adaptable of all cereals in terms of ecological requirements. Because it is an early maturing grain with a short growth season, it may be grown on the fringes of agriculture where few crops are able to flourish. Barley is currently cultivated over a wide range of habitats ranging from areas where rainfall is restricted to moist boreal forests where precipitation can occur every day (Fischbeck 2002). Barley generally does best on light or sandy loam soils and may be grown on soils which are too light or otherwise unsuitable for wheat cultivation. Barley is only exceeded by wheat, rice and maize in terms of total land area under production (Fischbeck 2002). Barley production, because of its importance in traditional malt beverages, can be a cultural, rather than an economic, phenomenon.

In countries such as Syria and Iraq, barley amounts to over 40% of total national cereal production probably because it fits well into traditional production systems that favour large flocks of sheep and goats (Fischbeck 2002). Europe currently leads the world in terms of total production. North America and Central America are only fractionally important in terms of total international production (Fischbeck 2002). In Europe barley production extends into the Nordic Countries (Norway, Finland, Estonia) where the cultivation of wheat is constrained by the length of the crop growing season.

6.5 Wheat

6.5.1 Classification

No fewer than seven classification schemes have been proposed for the genus *Triticum* within the last 25 years (van Slageren 1994; Mac Key 1988; Kimber and Sears 1987; Tan 1985; Löve 1984; Gandilyan 1980; Dorofeev *et al.* 1979). Current schemes are largely based upon Sakumara's (1918) determination of chromosome numbers (which allowed taxa to be constructed on the basis of homology - shared characteristics inherited from a common ancestor). Divergences between modern schemes result from conflicts between: (1) botanical concepts and genetic studies; and (2) theoretical approaches and practical requirements (Szabó *et al.* 1994).

Overall, cultivated wheats comprise a polyploid series of diploid, tetraploid and hexaploid species that have evolved through seriated hybridisation between members of the genus *Triticum* and species of the related genus, *Aegilops* (Feldman *et al.* 1995).

Einkorn is a member of the diploid group, which is characterised by species and subspecies that carry two complementary sets of the A genome. Emmer and durum are in the tetraploid group which contains taxa that combine both A and B genomes in duplicate. The final group, the hexaploids combines the A, B and D genomes. Spelt and bread wheat fall into the hexaploid category. Both wild and cultivated 2n wheats are internationally recognised as einkorn wheats (Mac Key 2005, 9) and cultivated einkorn (AA/2n) races are grouped into one wheat species, *T. monococcum* ssp. *monococcum* (Szabó *et al.* 1994). Further divisions within this group are variously recognised based upon a combination of morphological, ethnographic and eco-geographic criteria. The cultivated tetraploid races with a genomic constitution of AABB are currently aggregated together in the *T. turgidum* group with glume wheat types recognised as emmers. Durum is the only free threshing member considered in this study. Note, however, that Watson (1983) has argued that 'genuine' durum (the specific and unique free threshing tetraploid wheat used specifically in the manufacture of high quality Italian pastas) was a late Arab invention and, as such, 'durum' cultivars represent substantially advanced lines of free threshing tetraploid wheat (in contrast to earlier types of free threshing tetraploid wheat). At present archaeobotanists are unable to distinguish the grains of *T. durum* and *T. aestivum* and it is only by means of their chaff that a specimen can be (positively) identified to species (Zohary 1996; Zohary and Hopf 1993; Hillman *et al.* 1992; Jacomet *et al.* 1989).

The term 'spelt' is inclusive of a broad group of hexaploid glume wheat races with the AABBDD genotype (de Rougemont 1989). A classification of spelt types on the basis eco-geographical differences was first proposed by Zhukovskii (1971) and subsequently adopted by Dorofeev *et al.* (1979). The scheme recognises two groups: a European group (subsp. *spelta*) and an Asian group (subsp. *kuckuckianum*) (Konarev *et al.* 2005). The first group comprises two further eco-geographical groups: *bavaricum* (accessions from Germany and Switzerland) and *ibericum* (accessions from Spain).

Bread wheat is the term used to recognise free threshing wheat races with the AABBDD genetic constitution. The label, 'bread wheat', is somewhat misleading since bread can be made from almost any cereal grain. Leavened bread, however, is almost exclusively made from bread wheat flours (see section 6.3.2.4). A variety of market based classification systems are currently used to classify bread wheats. The U.S. grain market, recognises five principal classes of bread wheat: (1) hard red winter; (2) hard red spring; (3) soft red; (4) hard white; (5) soft white. In Britain, wheat is divided into four groups. Groups 1 and 2 are wheat varieties which produce bread and blending flour (flours produced by mixing wheat types). Group 3 varieties are used for biscuit making, distilling and for animal feed. Group 4 wheats are composed of high yielding varieties that are usually used in animal feeds.

Authorities urge care when comparing different categories of wheat across wide areas and over long expanses of time (Miller 1992). Viewed over time, the flow of germplasm across taxonomic lines has undoubtedly been continuous, large and multidirectional (Mac Key 2005; Feldman 2001; Miller 1992; Evans 1981). Data directly comparing species and subspecies (even across reasonably similar environments), can be conflicting (Stehno and Trcková 2005; Saleem 20003; Olivera 2004; St. Burgos *et al.* 2001; Pena-Chocarro 1999; van der Veen and Palmer 1997; Parviz 1999; Hucl *et al.* 1995; Ruegger and Winzeler 1993; Reynolds 1992; Rüegger *et al.* 1990; Guzy *et al.* 1989; Davies and Hillman 1988; Percival 1974) and research indicates that 'genotype X environment' interactions can play a strong role (*cf.* Annicchiarico 2002; Rüegger *et al.* 1993).

6.5.2 Einkorn

6.5.2.1 Evolution and early history

Archaeobotanical and genetic evidence demonstrate that domesticated einkorn originated via the domestication of a wild progenitor (*T. monococcum* subsp. *aegilopoides* (Link) Thell.) sometime in the early 8th millennium BC (Nesbitt 2001). Wild and domesticated forms of einkorn are present at early agricultural sites in the northern Fertile Crescent of south-east Turkey and northern Syria dating from 7700 to 7500 B C (Nesbitt 2001; Feldman *et al.*1995). Einkorn (along with emmer and barley) was amongst the first cereal to be cultivated for food in the Neolithic Near East. From there, einkorn became widely distributed throughout Transcaucasia, the Mediterranean region, south-western Europe, and the Balkans at an early Neolithic date (Harlan 1981). Einkorn continued to be a popular crop throughout the Neolithic and Bronze Age (Kreuz *et al.* 2005; Renfrew 1973).

6.5.2.2 General description

Within recent memory, einkorn was grown in the Levant, Asia and Europe but it is largely a relic wheat species today. It is typically a small plant rarely growing to more than 70 cm. though it can reach 1.5 m. in height (Empilla *et al.* 2004). The ear of einkorn is very brittle and disarticulates easily at threshing breaking into spikelets which are typically awned. Each spikelet generally contains a single kernel which has developed from a single floret but sometimes two florets will produce multiple seeds in one spikelet (Hammer and Sprecht 1998). Einkorn kernels do not thresh free of their glumes, lemma or palea (i.e. einkorn is not free threshing). Einkorn grain is long and narrow and when ground produces distinctive yellow flour (Waines *et al.* 1987). Einkorn can be used in much the same way as emmer. In the few places where it is still grown today, it is employed in a variety of baked products, soups, gruels and especially animal feeds (Vallega 1996). Recommended cultural practices are generally similar to those used for the production of modern bread wheat though einkorn has a tendency to mature later than most spring varieties (Stallknecht *et al.* 1996). Kreuz *et al.* (2005, 244) suggest that einkorn is especially resistant to lodging.

6.5.2.3 Current distribution and agro-ecological preference

Modern production is confined to small isolated regions within France, Spain, Italy, Turkey, Yugoslavia, Northern Switzerland, Swabia, Baden, Castelfranco, and the higher Apennine and India (Perrino and Hammer 1982). In Spain, it is common in traditional mixed farming systems that incorporate pigs (Pena-Chacarro 1999). Einkorn is typically restricted to cool dry environments on marginal agricultural soils (Harlan 1981; Perrino and Hammer 1982). Vallega (1996, 212) argues that modern einkorn production is restricted by high processing costs, quality and yield concerns, varietal prejudice, breeding gaps and marketing problems. According to Empilli *et al.* (2004) tightly adhering glumes, excessive height, late heading and small seeds currently limit einkorn cultivation in the Mediterranean. Though einkorn kernels contain comparable amounts of crude protein to modern bread wheat cultivars, they lack the specific proteins (glutens) that are associated with baking quality (Borghi *et al.* 1996; Acquistucci *et al.* 1995).

6.5.3 Emmer

6.5.3.1 Evolution and early history

Domesticated emmer is thought to have been descended from a wild progenitor, *T. dicoccoides* (Koern. ex Ascb. & Graebn.) Aaronsohn. Emmer is generally recognised to have been an important crop in the Fertile Crescent (along with einkorn and barley) from the early Bronze Age (Zohary 1996), and domesticated forms are present at many early Neolithic archaeological sites (Kreuz *et al.* 2005; Hillman 2000). Emmer is argued to have been a principal crop of Danubian Neolithic farmers from the 5th century BC where it is frequently found side by side or in admixture with einkorn (Kreuz *et al.* 2005; Zohary and Hopf 1993, 44). It was also a common component of the crop assemblage that initiated agriculture in the Aegean region and, together with barley, contributed to the origins of agriculture on the Indian subcontinent (Zohary and Hopf 1993, 44).

6.5.3.2 General description

Plants of emmer are similar in many respects to those of einkorn but generally the ear is larger and more compact. Spikelets are 2-3 flowered, producing one or two grains per spikelet, though two grains is the usual configuration. Most existing emmer varieties are awned (Percival 1974). Emmer kernels do not thresh free of the glumes or the lemma and palea. The grains tend to be slender, reddish and relatively hard (Zohary and Hopf 1993). Emmer flours are reported to be especially white (Percival 1974). In places where emmer is still grown today it is used in a wide variety of products. In Ethiopia, for example "where emmer is locally known as *aja,* it is utilised in various ways. Some is ground into flour and baked into a special type of bread (*kita*). Some is crushed and cooked with milk or water to make porridge (*genfo*). Occasionally, emmer is mixed with boiling water and butter to produce gruel" (BSTID 1996, 239). Emmer grain is generally used as an animal feed where it is still grown today (Oliveira 2004; Karagöz 1996). The nutritional profile of emmer is said to be better than modern bread wheat particularly with regard to its high protein content (Stehno and Trcková 2005). Stallknecht *et al.* (1996) report that emmer's baking characteristics, although better than those of einkorn, are still poor with respect to bread wheat.

6.5.3.3 Current distribution and agro-ecological preference

The current distribution of emmer is in many ways similar to that of einkorn but wider (Mac Key 2005, 20). Emmer is still produced in Anatolia, Iran, Caucasia and India (Zohary and Hopf 1993). It is maintained as a traditional crop in some regions of Central Italy (Toscana) and Spain as well as the Czech Republic and Slovakia where it is employed in the production of porridge, groats and flat bread (Oliveira 2004; Harlan 1981). Emmers continued to be popular in America and south-central Russia into the early 1900s until they were supplanted by more profitable cultivars of bread wheat (Martin and Leighty 1924). It is widely believed that the addition of the B genome to emmer provided the mechanism which allows it to be grown across a broader range of environments than einkorn (i.e. in regions having higher average growing season temperatures (Mac Key 2005, 20; Stallknecht *et al.* 1996; Feldman *et al.* 1995; Harlan 1995). Authors continually argue that emmers perform well over a wide range of soil types and temperature condition. Emmer holds a reputation for high performance on nutritionally poor soils (Percival 1974; Stallknecht *et al.* 1996). Korber-Grohne (1987, 322) reported that emmer holds the potential to yield far more than einkorn in Germany.

6.5.4 Durum

6.5.4.1 Evolution and early history

The time and place of the origin of free threshing tetraploids awaits explanation. Zohary and Hopf (1993, 46) report that "free threshing tetraploid wheats, identifiable by occasional rachis fragments scattered among the grain, made their appearance in the Near East soon after the firm establishment of cultivated emmer". According to Jacomet *et al.* (1989), free threshing tetraploids were cultivated on Swiss lake sites during the Late Neolithic (4300-3500 BC). Maier (1996) reports the presence of free threshing tetraploids in Germany from approximately the same period. Durum is generally not considered to have been especially prevalent in warmer climes during the Neolithic, but it is believed to have become more abundant during the Bronze Age, gradually replacing glume wheats at many sites in Mediterranean regions and the Levant (Zohary and Hopf 1993). Egypt is a Mediterranean exception, with emmer remaining the predominant wheat type through the Neolithic, Bronze Age and Iron Age periods (Zohary and Hopf 1993).

6.5.4.2 General description

Modern durum wheat is of short height (c. 0.5-1 m.) and compact growth habit with respect to other cereals in the *T. turgidum* group (Mac Key 2005). Its ears are square or compressed laterally, and oblong in cross section. The rachis is usually tough but, in some varieties, spikelets disarticulate easily, especially near the base of the ear (Percival 1974, 209). The ear is of average density when compared with modern bread wheat. Lemmas are usually awned. Spikelets are 5-7 flowered with three to four fertile florets. Those of the more compressed ear types will only ripen two grains (Percival 1974, 211).

Durum wheat is the only tetraploid sub-species of wheat still widely cultivated today. The endosperm produces a bright yellow flour when ground. Its coarse-grade flour, semolina, is employed to make gnocchi, pasta, couscous, puddings and a variety of confections because it produces a firm product when cooked. A finer by-product from the production of semolina (durum flour) is used for noodles, some types of pasta and flat breads. Durum flour is also added to leavened bread flours to fortify their protein content (Fabriani and Lintas 1983). *Frikeh*, a distinctive product made by charring green durum wheat harvested at the milk-ripe stage is widely manufactured throughout the Middle East (Palmer 1998, 152).

In Mediterranean countries, durum flour is generally the preferred ingredient for flat breads (Palmer 1998). Durum wheat kernels are typically large with respect to most wheat classes, and contain little pigment in their pericarp. The kernels are distinguished by their highly translucent appearance and hardness.

6.5.4.3 Current distribution and agro-ecological preference

Durum's Mediterranean predisposition is probably a reflection of its eco-geographic preferences (Damania *et al.* 1996; *cf.* Börner *et al.* 2002; *cf.* Moffett 1991; *cf.* Hubbard 1980). Durum holds a reputation for drought resistance. Mac Key (2005, 18), for instance, argues that "durum wheat, with its large seeds, short habit and many seminal roots is likely to have evolved from ecotypes which preferred a dry habit". He especially notes the morphological contrast between the modest root structure and comparatively tall growth habit of western European races of the free threshing tetraploid *T. turgidum*.

Durum wheat is cold sensitive compared to modern bread wheat, and requires a relatively prolonged warm and dry season for the grain to mature (Percival 1974). Excess moisture, particularly late in the growing season, results in premature sprouting and low vitreous kernel counts (Brajcich *et al.* 1986). Traditionally, durum production (and consumption) has been concentrated across the Mediterranean - North Africa, Ethiopia, Spain, Italy, Greece and Turkey (Brajcich *et al.* 1986).

6.5.5 Spelt

6.5.5.1 Evolution and early history

According to Nesbitt (2001, 51) "Spelt appears in the Swiss lake district in the Early Bronze Age (2200-1500 BC) and during the same period elsewhere in Europe, at sites ranging from Germany to Greece" (*cf.* Akeret 2005). Its precise mode and place of origin is undetermined. From the Bronze Age to Roman period, spelt is thought to be, first and foremost, a central-north-western European phenomenon. In terms of its northern limit, spelt occurred regularly in prehistoric Denmark, Germany and Poland (Jørgensen 1979) but seldom occurs beyond any of the latter countries' northern borders. Macedonia was spelt's southern boundary in the eastern part of the study area. There are publishe reports of Bronze Age spelt in Greek Macedonia (e.g. at Kastanas and Assiros but not further south - Jones 1983; Jones *et al.* 1986; Kroll 1983). In the western edge of the study region, archaeological remains of spelt have been unearthed as far south as southern France (Boulby *et al.* 2005). Spelt does not appear to have played a role in the agriculture of prehistoric Spain (Pena-Chocarro 1999, 36; *cf.* Buxó and Pons 2000; Buxó 1989). Moreover, the currently cultivated Spanish spelts are considered by geneticists to be distinct from the central European glumed hexaploid wheats - Elía *et al.* 2004). I was also unable to find any achaeobotanical account to suggest that spelt was ever produced in central and southern Italy, Sicily or Sardinia. Spelt is also conspicuously absent from the archaeobotanical records of north African countries (including Egypt). Spelt's southern boundary thus generally follows the northern limit of olive production, a boundary set by minimum winter temperatures (Horden and Purcell 2000, 14). Spelt's eastern (European) boundary appears to follow the eastern borders of Poland, Bulgaria and the Ukraine. Some observers have characterised spelt's easterly European distribution as patently Danubian (Andrews 1964). It should also be noted that speltiform varietal groups of *T. aestivum* in southwestern Asia are argued to have different origins than those of Europe - for a review see: Salamini *et al.* 2002).

Whether spelt represents the ancestor or a derivative of bread wheat is still debated. Campbell (1997) reported that storage proteins in all *T. aestivum* subspecies have a similar profile, and repetitive DNA sequences are also highly conserved among the *T. aestivum* group (Talbert *et al.* 1992). McFadden and Sears (1946) first interpreted the tightly invested glumes of spelt as primitive in comparison to free threshing hexaploid wheat. "Archaeological evidence for the presence of free threshing hexaploid wheat and emmer in Neolithic Europe, however, suggests that spelt could have originated from a hybridisation event of a free threshing hexaploid and a hulled tetraploid wheat in this region" (Nesbitt 2001, 51). A Caspian origin and Danubian route into Europe is also proposed (Lisitsina 1984; *cf.* Nesbitt 2001; Mac Key 1966). Wheats within one ploidy level are more closely related to one another than wheats with different ploidy levels and, despite some self-sterility barriers, all hexaploid wheats are generally interfertile (Mandy 1970; Sharma and Gill 1983)

6.5.5.2 General description

Spelt is a relatively tall (c. 1.1.5 m.) relic type of hexaploid wheat. The spikes of modern accessions of spelt are typically long and narrow, shatter easily and typically display the lax eared trait (Lupton 1987). The spikelets are usually 2-grained and upright. They are closely pressed to the rachis and very tightly held. Spikelets do not thresh free of the glumes, or the lemma and palea, when threshed. Grains of modern accessions are dark, long, usually reddish and flattened. Spelt grain yields a glutinous flour which Percival (1974) claimed was more renowned for its effects in pastry than in bread. Spelt is currently used in flour and baked goods as a substitute for soft red winter wheat. Harvested green, spelt is sometimes used to make a German soup known as 'grüenkern'. Spelt flour is generally held in high regard and, in places where spelt is traditionally cultivated, it is frequently treated as a delicacy (Pena-Chocarro 1999). In Umbria and Tuscany, special forms of pasta are derived from spelt flour (Ruegger and Winzeler 1993). The whole grain is also fed to animals (Pena-Chocarro 1991).

Spelt displays considerable polymorphism and performance variance (Hucl *et al.* 1995). In a series of field trials, Van der Veen and Palmer (1997) found spelt to yield significantly higher than emmer. Olivera (2004) and Reynolds (1992) reported little difference in yield between the same two grains. Parviz (1999) reports that spring spelt grown in central Saskatchewan produced an equivalent grain yield with respect to common wheat. Rüegger *et al.* (1990) compared two spelt cultivars and two bread wheat cultivars under three different temperature regimes. At favourable temperatures for growth, yields of the spelt cultivars were 12% lower than those of bread wheat cultivars. Percival (1974) reported that spelt yields less than bread wheat in an average year. Agronomists generally agree that spelt produces grains of slightly greater protein content compared to bread wheat (Hucl *et al.* 1995; Ruegger and Winzeler 1993). Reiter *et al.* (2000) report that spelt generally displays favourable baking characteristics but also a significant degree of variability in the dough making properties across accessions.

6.5.5.3 Current distribution and agro-ecological preference

Spelt is produced as a specialty crop in isolated clusters throughout south-eastern Europe, primarily in Germany, Switzerland and northern France. It is still maintained as a traditional crop in northern Spain and the Alpine areas of Italy and Austria (Olivera 2004; Caro-Baroja 1972). Percival (1974) argued that spelt would grow anywhere that bread wheat will grow. Spelt has gained a reputation for cold hardiness and is also argued to thrive on soils either too dry or too light for bread wheat (Campbell 1997; Hucl *et al.* 1995; Percival 1974). Frost resistance has been studied in *Triticum* and *Aegilops* by Barashkova (1981) and Limin and Fowler (1981), who evaluated a great number of species, accessions and populations. They concluded that species carrying the D genome (especially *Aegilops tauschii,* the donor of the D genome in spelt and bread wheat) are the most frost resistant wheat species. Percival (1974) claimed that the absence of de-husking apparatus (rather than soil or climate) limited spelt's distribution in Germany.

6.5.6 Bread wheat

6.5.6.1 Evolution and early history

Although the precise origin of free-threshing wheats remains unknown, free-threshing hexaploids dating from 9,700 BC are reported from sites such as at Çan Hasan, Çafer Höyük and Abu Hureyra (Hillman 2000, 399; Salamini *et al.* 2002). Cytogenic and molecular evidence combine to suggest that free threshing hexaploid wheat (i.e. bread wheat) originated from the hybridisation of a tetraploid wheat (probably emmer) with the diploid goat grass, *Aegilops tauschii* ssp. *strangulata* (the D genome donor) – the hybridization event presumably having taken place inside the present ecological range of goat grass. However, recent authors have also stressed the possibility that *Agilops tauschii* provided more than one allele at several loci which, in turn, suggests a series of hybridisation/domestication events (Dvorák and Luo 2001; Dvorák *et al.* 1998).

Although wheat is a self pollinated crop, it is known to outcross. Crossability experiments have shown that:

> "Crosses such as (diploid x hexaploid, tetraploid x hexaploid) reduce the fertility of the F_1 generation substantially. Hybridisation is more successful if the parent with higher chromosome number is used as mother plant, although it should be noted that hybridisation between wheat x barley is efficient when barley (14 chromosomes) is used as the female parent. Most F_1 hybrids from hexaploid x diploid crosses are sterile.

Only manual crossing of *T.aestivum* x *T.monococcum* produced F_1 hybrids with grains that germinated. Grains of the reciprocal hybrid did not germinate. When tetraploids were manually crossed with hexaploids, only the crossing of *T. aestivum* with *T.turgidum, T.durum, T.timopheevi* or *T.carthlicum* was successful (Mandy 1970, Sharma and Gill 1983). Hybrids from *T aestivum* and *T.turgidum* are fertile." (OECD 1999, staff publication, section 5, cross-fertilisation in wheat).

6.5.6.2 General description

Although the morphology of bread wheat cultivars are highly variable, modern bread wheats are typically relatively short plants (but may grow up to 1.2 m. tall) with long broad, slender, dorsally compressed spikes, which are flattened. The spike of modern cultivars is long with respect to einkorn, emmer and spelt (Stehno and Trcková 2005). Spikelets are 2–5-flowered, slightly overlapping, nearly erect, and pressed close to rachis. Glumes are reduced with respect to the lemmas. Lemmas can be awned or awnless.

Bread wheat is one of the most widely grown and diverse crops in terms of end use and genetic diversity (Slaffer and Sattore 1999). It is unique amongst grains in several ways: Bread wheat production occupies more area than any other crop, and world trade is greater than for all other wheat crops combined. It provides more nourishment for humans than any other food source (*cf.* Brenchley 1940). Bread wheat is a major dietary component because of its agronomic adaptability, ease of grain storage and ease of converting grain into flour. It is preferred as a food grain because of its potential for making edible, palatable, interesting and satisfying foods (Curtis 2002, 2). Its main food-use is for leavened breads but it is also employed as an ingredient in a range of baked products and alcoholic beverages. Its starch component is used as a thickening agent. Various compounds within the grain are employed in industrial processes. Its bran may be used to provide bulk or fiber to feed concentrates. The embryo is a source of high energy carbohydrates. Vegetative portions can be cut for straw or used as high quality pasturage. Bread wheat straw is woven into mats, carpets, and baskets, employed as a structural material, and used as animal bedding (Magness *et al.* 1971).

6.5.6.3 Current distribution and agro-ecological preference

Although bread wheat is one of the most widely distributed crops in the world, its production is concentrated into areas of similar growing conditions between the latitudes of 30- 60 °N and 27- 40°S (Nuttonson 1955). All major production zones are prairies, pampas or steppes with deep, fertile soils and above-average levels of soil nitrogen (Bonjean and Angus 2001). Bread wheat is most productive where summers tend to be relatively cloudless and rainfall low but evenly distributed (Bonjean and Angus 2001).

A review of current trends shows that since 1997 the level of bread wheat production has been declining on an international basis relative to other primary grain crops. (FAOstat 2005). In 2001, maize (*Zea mays* L. ssp. *mays*) overtook both rice and bread wheat to become the number one crop with respect to total international production (FAOstat 2005). This decline is mostly attributable to declining market prices and recent genetic advances which have allowed maize to compete more effectively with bread wheat (FAOstat 2005). Bread wheat production losses across the Great Plains of the U.S., for instance, result from disproportionate genetic improvements in competing crops. Breeders, for instance, have recently succeeded in producing new cultivars, enabling maize and soybeans producers to expand into areas formerly dominated by bread wheat (FAO 1996; USDA-NASS 2005).

Some authorities have suggested that crops such as bread wheat and maize have a natural capacity to adapt to new environments (evolvability - Kirschner and Gerhart 1998). Evolvability has, in turn, been linked to polyploidy (*cf.* Feldman and Levy 2005; Allard 1999). Mounting evidence suggests that ploidy provides a range of advantages to advantage to domesticated crops (Sugiyama 1998; *cf.* Zeven 1980). Polyploidisation, and particularly allopolyploidisation, leads to increased crop utility: (1) by increasing the ecological range of polyploid species compared to diploid relatives; and (2) by creating diversity which can, in turn, enhance the number of potentially useful variants.

Polyploidy is widely recognized to confer a host of adaptive advantages (Comai 2005). Polyploidy (specifically alloploypoidy – alloploids are polyploids of hybrid origins) is likely to have influenced wheat on three levels. Firstly, it may have directly contributed by enhancing agronomic characteristics which are obviously beneficial. For example, higher levels of ploidy have been linked to larger cell size, more robust growth habit, higher levels of nutrient uptake (Comai 2005; Smith *et al.*2001; Allard 1999; Hart and Collier 1992;

Halloran and Pennel 1982). Secondly, polyploidy could have led to increased levels of heterozygosity in the crop (i.e. allopolyploidy bears novel genes to the taxon - Gepts 2004). Thirdly, polyploidy may have conveyed the opportunity for novel epistatic interactions between genomes (*epistasis* exists when the effect of two or more non-allelic genes in combination is greater than the sum of their separate effects) (Gepts 2004). For example, the proteins which give bread wheat its superior baking qualities are unknown in the two parents of the hexaploid, suggesting that this property arises from an interaction between genes of the two progenitors (Smith 1995).

Proponents of polyploidy hypotheses suggest that:

1. Multiple genomes in polyploids represent gene duplication;
2. Duplication leads to the relaxation of selection on one gene copy;
3. Relaxation allows divergence between duplicated genes and the acquisition of new/novel function (Zhang and Kishimo 2004; Adams and Wendel 2003, 575; *cf.* Comai 2005; Knight *et. al.* 2005; Wendel 2000; Rosenzweig 1995).

Ranny (2000, 1) provides a poignant example of how polyploidy may have contributed towards late dominance of hexaploid species:

> "since alloploids represent a fusion of [at least] two distinctly different genomes, these can potentially produce all the enzymes produced by each parent as well as new hybrid enzymes. This enzyme multiplicity may provide polyploids with greater biochemical flexibility possibly extending the range into which the plant can grow".

6.6 Implications for cereal frequencies

6.6.1 Possible implications for genera frequencies

Each cereal genus offers potential. The main advantage offered by oat seems to be its aggressive nature with respect to competitors, such as weeds, and its adaptability with respect to hostile agricultural habitats. Oat is an ideal low input crop, which, once included in rotation, can provide crop diversity and extend the growing season beyond that of other staples like barley or wheat alone. In addition to the direct value of the grain, the vegetative plant parts of oat are also useful as forage. Because, oat performs well on marginal soils, oat production is especially appropriate for wet, cool and moist conditions and climates where wheat and barley production is not necessarily profitable. The main advantage of sowing rye is its extreme productivity, cold tolerance and robust growth habit. Rye plants have an especially rapid rate of growth. Rye is commonly regarded as a dependable crop, hardier and more frost and drought resistant than wheat, so it can be grown in environments where wheat will not normally thrive. Rye can also be inter-seeded with wheat to improve the yield stability of the combined crop. Barley is favored on the basis of its short season character, low production costs, and dependable performance. Barley is commonly used as a livestock feed because of its relatively low production costs. The yield stability of barley is almost always higher than that of wheat and its grain is almost universally preferred to wheat in the malting and brewing industries. Barley also requires a shorter cropping period than wheat. Consequently, it is held to be a less intensive crop in terms of management and labor requirements. Of the grains used for the production of flour, wheat is especially unique in terms of its versatility. The relatively large number of wheat 'sub-types' currently recognized by plant taxonomists demonstrates its wide range of variability compared to other cereal competitors. This property may result from the relative large size and complexity of the wheat genome.

6.6.2 Possible implications for wheat species frequencies

The main advantage of einkorn seems to be its capacity for dependability under adverse conditions and applicability in subsistence farming regimes that incorporate animals. We can infer from emmer's broad geographical distribution that it held the potential to be sown across a comparatively wide range of habitats in the past. It has relatively good grain and forage productivity potential today. It currently maintains a reputation for performance on poorer soils but under intensive production systems it is generally less profitable to grow than free threshing alternatives. Emmer (like einkorn) suffers from high production costs associated with removing the tightly held glumes. Durum is the only tetraploid wheat which is profitable to produce under modern management practices probably because it offers a unique quality advantage in terms of its yield stability under hot and dry conditions. Spelt is closely related to bread wheat in terms of its genetic background and performance. Its main advantage over emmer seems to be in its gluten content, but its tightly held glumes make its grain relatively costly to process compared to modern bread wheat. Bread wheat offers the combined advantages of productivity, baking quality and the free threshing habit. Bread wheat also holds the potential to respond more positively to intensive management practices, such as the application of fertilizers, than its diploid and tetraploid competitors. Although its current distribution is closely correlated to the plant's climatic and edaphic preferences, its status as a leading international crop reportedly results from its usefulness in the baking industry. The hexaploid nature of bread wheat is reported to contribute to its high yield potential. Alloploidy, has widened the range of potential variants within the bread wheat population which, in turn, has probably extended the agronomic utility of bread wheat beyond that of its diploid and tetraploid relatives. This may suggest that higher level polyploid/alloploid variants such as bread wheat carry an elevated capacity to generate heritable variation compared to their lower ploidy relatives.

Integrating modern agronomic evidence

Chapter 7

7.1 Introduction

This chapter explores: (1) methods that are used in cereal production; (2) cereal consumption practices; and (3) cereal characteristics associated with production and consumption. The discussion is presented in two parts. The first part (section 7.2) sets out to illustrate the structure of production processes and to illustrate how it can affect which types of cereals are used. The second part (section 7.3) is a discussion of relevant cereal traits.

7.2 The production process

The outcome of the process of cereal production depends upon the architecture of the production system operating in conjunction with cereal plant traits. Control points include: (1) farming system; (2) cropping system; (3) seed production system; (4) agronomic method; and (5) crop monitoring system (Cox 1979).

7.2.1 Farming system

The term 'farming system' refers to the manner in which production is organised in relation to the land. Two broad categories of farming systems are recognised by agronomists: settled agriculture and shifting cultivation (Haines 1982; Grigg 1974). Settled agriculture may be characterised as either 'intensive' or 'extensive' according to various definitions. In archaeological literature, intensive husbandry generally refers to agricultural regimes which involve high units of inputs of labour/capital per unit of area resulting in high per-area yields. On the other hand, extensive systems, involve comparatively lower amounts of input per unit area, resulting in smaller per-area yields (Grigg 1984, 49, 174). Because extensive agricultural systems produce lower yields per unit of land, they typically require large quantities of land in order to achieve profitability. This requirement for land generally means that (at least in modern terms) extensive cereal production is practised where land values are low with respect to labour and capital costs, which in turn means that extensive cereal production is *typically* practised where population densities are low and at some distance from major markets (Cohen and Kennedy 2000).

7.2.2 Cropping system

The cropping system refers to the way the production of the crop is arranged in the field. Two contrasting schemes are recognised: monoculture and polyculture (Piper 1998). Monoculture is the system of producing a single crop exclusively in a particular field. In its most extreme form, monoculture is practised even in absence of crop rotation (i.e. the same type of crop is produced on the same land year after year) (Piper 1998).

Polyculture is a cropping system whereby multiple crops (genera, species, subspecies or genotypes) are cultivated on the same given space at the same time (Jaradat *et al.* 2004; Wolfe 2001; Juskiw *et al.* 2000; Sarandon 1999, 239; Zeven 1999; Stoskopf 1981).

> 'The terminology used to describe polyculture is confusing and includes such terms as mixed cropping, multiple cropping, intercropping, polycropping, interculture, relay planting, mixed farming, and simultaneous polycropping. These multiple cropping systems have been defined as systems in which two or more crops are simultaneously planted within sufficient spatial proximity to result in interspecific competition and complementation (Bajwa and Schaefers 1998, 1). In most instances the relative value of either cropping system is determined by problems and yields offered by monoculture" (Bajwa and Schaefers 1998).

Within modern and modern ethnographically derived contexts, monoculture systems are: (1) normally oriented towards obtaining maximum yield in high-input systems under near-optimal environmental conditions; and (2) mostly applied in risk-averse, profit-oriented agriculture where sustainability tends not to be a basic priority (Wolfe 2001; Jiggins 1990). Contrastingly, polyculture systems tend to be appied in farming areas which are under sub-optimal conditions for maximum yield production and as such are a feature of traditional agro-systems (Bajwa and Schaefers 1998). This is mainly because polyculture tends to foster yield and quality stability (food security), and helps to maximise available resources efficiently (by exploiting the plasticity of the crop) (Jiggins 1990). Polyculture can also be used to extend production into marginal, high risk, production environments in localities where profitability is not a critical factor.

7.2.3 Seed production system

The future competitiveness and character of any crop is partly determined during the process of seed production. Research has shown that traditional, so called 'farmer seed systems' typically function through informal seed exchange networks where farmers engage in the maintenance, transfer and development of new varieties within localised spheres (Jusu 2000). Methods vary regionally according to specific requirements, level of agricultural skill, local traditions, consciousness and degree of isolation (Jusu 2000; Almekinders and Louwaars 1999; Peña Chocarro -1999, 44; Zeven 1999; *cf.* Gari 2003).

Variations in the genetic makeup of grains within a single ear, across a field and between different fields mean that farmer-producers are, in effect, constantly injecting various levels of heterogeneity into their seed cultures (Finckh *et al.* 2000; Newton *et al.* 1998). In this respect, agriculturists define farmer seed stocks as landraces. A 'landrace' is thus a farmer-developed variety of crop plant that is often heterogeneous (but not necessarily so), and specifically adapted to local environmental conditions.

Seed stocks of cereals such as wheat have been continually transformed by selection in different environments (Dark and Gent 2001; Zeven 1999). Viewed over time, the flow of germplasm has undoubtedly been continuous, large and multidirectional (Mac Key 2005; Feldman 2001; Miller 1992; Evans 1981). As a long term process, continuous selection has tended to emphasize certain types of traits (*cf.* Mac Key 2005; Evans 1981). Amongst the most obvious are: (1) selection towards erect type, synchronous tillering and uniform ripening; (2) increases in grain production by the addition of fertile florets and increase in the size of the inflorescence, or the number of ears produced per plant; and (3) reduction of grain investment mainly through the reduction of awns, the reduction of glumes, and the reduction of the degree of tightness by which grains are invested (Zohary and Hopf 1993, 18).

7.2.4 Agronomic method

Agronomic method refers to the manner in which the growing crop is managed and to the type of agricultural technology exercised over the crop. Agronomic method is important to the discussion of cereal change because, in conditions where water, temperature and light conditions are adequate, the choice of agronomic method determines whether the genetic potential of any particular type of crop can be realised (Peterson *et al.* 2000). The agronomic methods utilised for the production of cereals vary with respect to the agro-climatic, social and economic conditions of the production environment (Martin 2004). Prevailing methods are influenced by a number of factors (e.g. traditions, the level of available technology, the biological properties of the crop, the production goals; Cook 1994) and can be highly dependent on scale (e.g. farm size, size of the target market, size of the available labour force) (Cook 1994; Grigg 1974).

The principal elements of agronomic method include: sowing method, cultivation method, irrigation management, growth regulation (e.g. by physical methods such as grazing or topping), nutrient management, pest and disease control, harvesting method, processing method and storage method (for a more detailed review of cereal production methods see: Martin 2004; Hayes 1983; Fisons Limited 1977; Logsdon 1977; Arnon 1972; Bland 1971).

Cereals are produced using a whole range of agronomic methods which are, in actual application, combinations of specific elements or operations. For example, seeding method can be broken down into: (1) operation of placing the seed at a specified depth; (2) arranging seed spacing in a particular manner; and (3) performing the operation either on a spring or autumn date.

The theoretical range of potential methodologies for cereal production is vast but some are almost universally applied (Altieri 1991). Typically, cereal seed is sown by the broadcast method or, less frequently, sown in shallow furrows no more than 22 cm apart over a vast range of soil types. The depth of sowing is usually quite shallow (1–5 cm). Most commonly, cereals are autumn planted (this is why the taxa in this study are regarded as winter cereals) but spring sowing is also practised to some extent. Seeding rates vary widely as the respective yield performance of genera, species, varieties and individual plants are highly sensitive to planting density and plant spacing (Egli 1998). Modern cereals require very little inter-culture or weeding, but this is not necessarily true for conditions in the past. Today, most cereal crops are produced under non-irrigated conditions but in dry areas two to three irrigation cycles can improve yields dramatically. The application of fertilizers/manures containing nitrogen, phosphorus or potassium, in various proportions, can significantly influence yield and quality (of both the grain and the vegetative plant parts) in a positive fashion. Cereals are generally harvested when the grain is dry. Consequently, harvest time for cereals is determined largely by monitoring the moisture content of the grain. There are, however, special cases where grains are harvested before they mature.

Of all the methods/operations which have an impact on production, those surrounding seed sowing are probably the most critical. The two most important factors in the sowing operation are sowing date and sowing density. Sowing date is important because it can influence the agricultural calendar, crop type and conditions under which the crop will develop (but it is more likely that crop type determined sowing time in the past - G. Jones, personal communication). Sowing density is also important because it is a significant factor influencing the crop-stand's ability to achieve maximum yield (i.e. achieve yield potential) (Egli 1998).

7.2.5 Crop monitoring system

Crop monitoring is the periodic or continuous operation of observing, testing or measuring the status or condition of the crop. Crop monitoring systems are important because they are a factor in determining the productive potential of the crop (Binns *et al.* 2000). Effective crop monitoring systems are a vital to: (1) insuring food security; (2) achieving maximum levels of productivity; and (3) achieving quality goals. Monitoring allows the producer the opportunity to intercede with the appropriate operation before injurious factors reach economically damaging levels (e.g. bread wheat farmers benefit from monitoring when the flag leaf (last leaf) emerges as this leaf contibutes about 75% of the total grain assimiltes. As such it should be especially protected from disease or insect attack during the grain filling phase. There can be differences in the production outcomes of two otherwise identical crops which are monitored in different ways. Farmers who monitor their fields once a day, for instance, should theoretically achieve higher crop qualities and yields than farmers who visit their fields less frequently. Planting decisions (i.e. the type of taxon a farmer chooses to plant) can also hinge on a farmer's capacity and/or willingness to meet the crop's monitoring requirements, with some farmers preferring to grow crops which require less intensive monitoring.

Most monitoring systems attempt to evaluate three production variables: (1) meteorological conditions; (2) crop condition; and (3) market demand (Binns *et al.* 2000). The means employed for the measurement of these variables range from casual to precise observation (Supit 2000). The effective application of any monitoring system is dependent upon: (1) the availability of analytical tools (e.g. concepts about when is the best time to apply irrigation or when is the best harvest date); (2) the level of crop knowledge; (3) the amount of variability in the production environment; and (4) the structure of the market for the crop (*cf.* Supit 2000).

7.2.6 Methods of preparation for consumption

The choice of which cereals are sown is also dependent upon the circumstances under which they will be consumed and the means by which they will be prepared. As raw ingredients, cereals are pressed into service for the manufacture of a whole range of products which are different in terms of type and quality. Crucially, processing technology governs whether characters can be accessed from a particular cereal taxon. Innovations in processing technology can unlock latent potentials in taxa. Moritz (1958) argued, for instance, that Roman advancements in the field of milling technology enabled the manufacture new types of bread.

7.2.6.1 Milling

Cereals normally need to be crushed, cut or ground into flour before they can be used as ingredients in processed foods and, in certain cases, incorporated into animal feeds. Consequently, milling is a major processing operation applied to cereals. Two main divisions in the process are recognised: breaking and reduction. In wheat, the milling stage normally begins by conditioning the cleaned grain with water. This softens the grain preparing it for the mill. The moist grain is then broken, cut, crushed or sheared in the mill revealing the internal constituents. This amalgam is then passed through a series of sieves in order to reduce it into distinctive components (or the grinding process repeated).

Milling potentially results in several products – bran, germ and flour. Separate products can be produced from separate parts of the grain or whole grain flour can be extracted (100% extraction rate) but flour made from whole kernel will become rancid if stored because of the oil in the embryo. Plain white flour (approx. extraction rate: 50-60%) results from the last stage of the separation process - the finest portion of the ground kernel. Bran or 'ash' is normally the coarsest. 'Straight' flour results when various flour elements and additives are intermixed. Different types of milling operations and technologies can produce a range of distinct granulations which result in unique outcomes under identical baking conditions. The series of individual break and reduction operations in the modern milling process can potentially result in as many as 150 unique flour granulations with distinctive performance parameters. The performance of a 'semolina', for instance, is highly distinctive from that of a standard durum wheat flour but essentially the difference between the two products is in the degree of milling - semolinas are distinctly granular. In the same vein, groats are whole or semi-crushed grains (usually de-hulled and heat treated) which can be used for, among other things, gruel.

Once the ground product has been obtained, it can be then blended or fortified (either with other cereals or non-cereal compounds) to promote performance. Normally, the central quality parameters in flour manufacture are: content/purity, colour, and moisture level.

Barley, wheat and rye are all milled in much the same way. However, in their malted form, barleys (and less frequently wheats) are milled after germination and kilning, into order to create malt flour. Oat flour is a graded product manufactured from groats of either the de-hulled or whole oat grain. Cleaned oats are first heat treated to inactivate their lipase enzyme (which promotes rancidity), then dried, hulled, exposed to live steam and finally ground into flour (Sosland 2005). Oat and barley flours are commonly used as fortifying agents for increasing dietary fibre content (Sosland 2005). Rye flour increases the density, colour tone and rising time of wheaten breads and provides a richer-flavoured alternative to wheat flour. Spelt flour contributes a nutty flavour to standard bread wheat flours (LeClerc *et al.* 1918).

7.2.6.2 Baking

Baking is the process of cooking cereal substrates using dry heat (for a complete review of the baking process see Pyler 1988). Normally this involves the use of a dough or batter - a dough is a mixture of flour, liquid and /or leavening agent (such as eggs or yeast), which is pliable. By contrast, a cereal batter is semi-liquid.

During the baking process, the cook normally strives to apply heat evenly through the use of an oven but similar effects can be obtained by a range of options including roasting over an open flame or pan frying (for a full discussion of reasons for cereal roasting see Peña Chocarro 1999, 44). Heat treatment results in an interaction between various raw ingredients altering the odour, taste and texture of the substrate mainly through the chemical process of oxidation. All cereals possess unique baking properties but additives and conditioners can be used to alter the baking properties of any flour or dough (e.g. ascorbic acid/vitamin C). The use of conditioners can, for example, make dough stiffer, rise faster, alter final crumb structure, convey flavours or improve the shelf life of the baked product.

7.2.6.3 Fermentation

Fermentation is a process which incorporates the actions of microrganisms/enzymes to modify the characteristics of cereals. According to Steinkraus (1995), fermentation serves several functions:

1. Dietary or 'valued added' enrichment through the creation of a specific product flavours, aromas or textures (e.g. leavened bread).

2. Preservation through the manufacture of specific compounds which deter microbiological activity or degradation (e.g. alcohol).

3. Structural modification adjusting processing parameters of the substrate (e.g. decrease cooking time).

Fermentation generally increases the relative nutritive value of cereals (especially available lysine - Hamad and Fields 1979) while decreasing their fibre content (El-Tinay *et al.* 1979). Fermentation may also improve the availability of certain minerals.
Fermentation can vary according to the type of: (1) fermentation process; (2) fermentation agent; and (3) ingredients used in the fermentation. Traditional fermentation practices

typically incorporate local ingredients, are labour-intensive and highly ritualised (Wood 1994). The common ingredient to all is ethanol, a form of alcohol that can be highly concentrated by a simple distillation process (Heath 1987).

Beer can be made from either wheat or barley. Because the raw grain of neither species is particularly well suited for brewing, they are usually malted before being subjected to the brewing process. To do this, the cleaned and sorted grain is soaked in water and allowed to germinate (malt). The malted grain is then mixed with water to obtain a mash. Finally, a 'wort' is produced by heating the mash. The insoluble grains collect in the bottom of the vat creating a filter through which the wort flows. During the mixing process, the insoluble starch of the grain is extracted and eventually converted into fermentable sugar enzymes (barley malts are especially adept at providing enzymes to convert grain starch to sugar). Hulled barley is presently preferred for brewing purposes on account of: (1) consumer product preferences; (2) a high maltose content which contributes to fermentation; and (3) the presence of a husk which provides protection for the embryo during malting and a filter for the wort (Rabin 1998).

7.2.6.4 Par-boiling

Par-boiling is the process of partially cooking a cereal by boiling or steaming in water. It is ancient process still used in parts of Asia, the Middle East and the Mediterranean. The process can be used to improve extraction rates, salvage quality in a spoiled crop or promote specific characteristic in the grain (e.g. tastes). Par-boiled cereal products are commonly termed 'bulgurs'. Bulgur is not a particular type of grain, but rather a cereal prepared in a specific way (usually durum wheat). Because bulgur is partially cooked, while simple cracked cereals are not, bulgur cooks faster and has a greater shelf-life. Additionally, since par-boiling 'case-hardens' cereal grain, it can sanitise raw cereal ingredients prior to storage.

7.3 Cereal characteristics relevant to production and consumption

Cereal characters can be divided into three categories for the purpose of analysis: (1) character traits related to production - the agronomic, physiological and morphological characters which impact on the plant in the field (most commonly at the level of yield);

(2) grain traits - the physical and chemical traits/properties of taxa that affect the utilisation of the grain; (3) biomass quality traits - the physical and chemical traits that affect the utilisation of the vegetative plant parts in products like straw. The following is a discussion of these categories of characters in the same order.

7.3.1 Production characters

Crops differ in terms of their environmental preferences and capacity ability to capture resources (Monteith 1994). No single character is mutually beneficial in every production circumstance. Furthermore, production success ultimately depends on a combination of characteristics working in concert (sometimes in synergistic rather than additive fashion).

7.3.1.1 Spring or autumn sown growth habit

Spring sown cereals are defined as those which are planted in the spring and harvested in the late summer or autumn. Spring planting usually predominates in areas where winters are particularly cold (e.g. the Alps, northern European Plain and the high northern plains of America). In contrast, autumn sown cereals are most frequently planted where the winters are not severe. The starting date for spring planting is generally dictated by onset of the threshold soil temperature. In autumn planting, the seed germinates in the autumn and the plant (after forming a crown) remains dormant through the winter (usually in prostrate growth habit). Plants then resume growth in the late winter or early spring (at this stage, the plant becomes strongly erect) and are ready for harvesting in late spring or early summer. Autumn sown cereals normally carry a vernalization requirement (a requirement for a period of low winter temperature to initiate the flowering process) while spring cereals are usually either insensitive or weakly responsive to winter temperatures (Lupton 1987). Winter wheat can be sown from late August to late December. Sowing usually occurs between mid-September and late October. Winter wheat cultivars normally require 40 to 70 days vernalization with a temperature between -1° C and 8° C (Geisler 1970). Seeds of spring wheat, on the other hand, need only 3 to 14 days (Reiner *et al.* 1992). The sowing season for spring wheat in Europe can range from January to May (Kübler 1994).

Selecting a cultivar on the basis of spring or autumn sown growth habit is important because combining the appropriate growth habit with local resource availability increases the opportunity to achieve maximum yield from any particular cultivar. All of the cereal taxa encountered in this study incorporate cultivars of either spring or autumn sowing habit (Stallknecht *et al.* 1996). Predominant sowing type is typically dictated by social factors and the character of the agro-environment. Strong regional patterns are apparent today. For example, in the Mediterranean basin, durum wheat is almost always of the autumn type, while on the high northern plains of North America, durums are predominantly of the spring type (Percival 1974). In Germany, the majority of emmers tend to be spring sown (Percival 1974) while the majority of Spanish spelts are autumn sown (Pena-Chocarro 1999). In the whole of Europe, however, less than 10% of all bread wheat production is currently of the spring type.

The purpose of the autumn sowing is: (1) to establish a resilient stand; (2) to initiate critical physiological growth stages (e.g. tillering in wheat) before winter dormancy begins; (3) to ensure early maturity, a key element in ensuring maximum grain yield (Cox *et al.* 1988); (4) to provide the means for drought avoidance; (5) to assure that young plants are physiologically equipped to take advantage of favourable temperature conditions and dependable spring rains; (6) to provide the means to avoid some of the most aggressive weed pests; and (7) to promote food security by allowing an opportunity for a spring re-sowing should winter sown crops fail (Arnon 1972).

In locations where winters are too warm for vernalization requirements to be met, farmers are constrained to the use of cultivars which lack the requirement. Equally, where winters are too harsh for autumn planting, farmers are constrained to spring cultivars. In cases where winter cultivars are spring planted, they will fail to achieve a reproductive growth phase (i.e. to produce grain) but winter cultivars are useful for pasturage or hay. In places where the production of both types is possible, autumn cultivars typically out-yield spring cultivars (Calderini and Dreccer 2002). Because cereal stand establishment is the foundation for realising maximum yield potential, advancing sowing date is one of the most practical means for improving crop yield and, in cases where germination rates are equivalent, a penalty is almost always incurred for late sowing (Peltonen-Sianio 1996). This fact alone can result in the predominance of autumn sown over spring types where both sowing dates are equally possible. Amongst rye cultivars, for instance, there is a modern preference for autumn sown types in Canada that is based primarily on relative yields of the two types (Bushuk 2001).

Yield is not the only factor considered by farmers in determining sowing date. Sowing date can also be a function of labour availability, task sequencing or simply a matter of random choice. Sowing date affects a number of different aspects of production (Vincente-Carbahosa and Carbonero 2005). Varying sowing time has an effect on the specific end qualities sought in the grain. For instance, early planting can have a substantial negative effect on the protein content of grain (Shoyer *et al.* 2001). In general, it is necessary to understand how far sowing date may be advanced or delayed before abiotic or biotic stress factors offset gains won by modifying planting date. For instance, although advancing sowing date may decrease moisture stress, it may also result in bringing young plants into contact with virulent pathogens which thrive at low temperatures (Calderini and Dreccer 2002; Smiley and Uddin 1993).

7.3.1.2 Photoperiod

After vernalization requirements are met, cereals must meet photoperiod requirements (exposure to a specific day length interval) in order to bring the plant to flower. Photoperiodism is an extremely important element in determining the adaptability of cereal plants because differences of even a few days in flowering can have a large effect on yield and quality of cereal crops (Fowler 2002). Generally speaking, plants may be classified into three groups. Short-day cultivars require a dark period exceeding a genetically dictated length while long-day cultivars are inhibited from flowering until the light period exceeds a genetically determined critical length. Day-length insensitive cultivars have the capacity to initiate flowers under any night length. Within all of these three groups, however, there are also varieties that need particular combinations of day lengths to initiate particular stages of growth (e.g. tillering) (Fowler 2002).

Although most cereal cultivars tend to be long day plants, flowering faster as day length increases, some cultivars within each of the taxa are recognised to be day length insensitive (Mahfoozi *et al.* 2001). Consequently, these cultivars may posses the capacity for increased yield in northern areas where yield may be increased by delaying flowering and thereby gaining the advantage of a longer growing season. In southern regions, the situation for maximum yield is the reverse, mainly because extending growing season into hot summer conditions usually results in plant desiccation. In southern regions, shortening the season may lead to increased yield by lessening the crop's exposure to risks (Worland and Law 1986).

Barley is typically a long day plant but barley cultivars can vary with respect to the critical length of the photoperiod (Hanumappa *et al.* 1999). Wheat's flowering season depends on geographic location. In wheat, sensitivity to photoperiod also varies between individual genotypes both within and across species lines. The commencement of growth of shoots in spring wheat is decisively influenced by the photoperiod (Kübler 1994). Early spring sown bread wheat cultivars, for instance, typically shift from the vegetative growth phase to reproductive phase after seven to eight leaves have been initiated on the main shoot (Fowler 2002). Nevertheless, some long day wheat cultivars have a photoperiod requirement that can extend the vegetative period allowing for the production of more main shoot leaves and larger numbers of tillers (Fowler 2002). Rye is a long-day plant with flowering typically induced by 14 hours of daylight accompanied by temperatures of 5 to 10 °C (Stoskopf 1985). Holland *et al.* (2002) have demonstrated that oat genotypes have a variable photoperiod response. Longer photoperiods promote earlier flowering but the response to longer photoperiods in oats tends to be greater in cultivars produced at higher latitudes (Holland *et al.* 2002).

7.3.1.3 Winter Hardiness

Cereal cultivars do not all possess the same ability to withstand the extremes of winter. In some cases, minimum growing season temperatures prohibit the use of particular cultivars (i.e. in field trials certain cultivars fail to survive winter conditions whilst others are able to endure winter undamaged). According to Fowler (2002), winter-hardiness can vary by as much as 100% between wheat cultivars.

Winter hardiness is not solely a function of the capacity to survive exposure to a particular mean low temperature. Exposure to light frosts late in the growing season, for instance, can damage plants more severely than exposure to extremely cold mid-winter temperatures.

Moreover, winter hardiness can be conditioned by temporary environmental circumstances (e.g. snow cover may have a major effect on a plant's physiological response to cold) (Mahfoozi *et al.* 2002). Management practices may play a role in conditioning plants to cold (e.g. extending the 'hardening' or cold acclimatization period increases winter hardiness) (Fowler 2002). Abiotic factors such as soil nitrogen levels and biotic influences such as resistance to winter diseases (e.g. snow mould *Fusarium nivale*) can additionally influence the effect of cold temperatures by altering the plant's physiology in negative way (Worland *et al.* 1987).

In general, rye and barley are recognised as the most winter hardy taxa of these studied here, with rye generally regarded as the hardier of the two. The minimum temperature for germination of barley occurs between 3 and 4 °C, with the optimal temperature being about 20 °C (Briggs 1978). The extreme cold hardiness of rye provides it with one of the widest distributions of any cereal. It is capable of growth within the boundaries of the Arctic Circle and can be found at high elevations near the equator (Bushnik 2001). Oat shows moderate resistance to cold and is generally less hardy than autumn sown cultivars of wheat (Martin 2004). Oat is considered a cold-tolerant species during germination because its minimal germination temperature is between 3 °C and 5 °C (Martin 2004).

The optimum growing temperature for wheat is about 25 °C with minimum growth temperatures of approximately 3-4 °C but this varies over the growth cycle of the plant and the prevailing climatic conditions (Oplinger *et al.* 2002). Frost resistance, for instance, is lost gradually towards heading and flowering but cold hardiness is increased by exposure to dry late season conditions (Oplinger *et al.* 2002). In general terms, Körber-Grohne (1987, 322) reported that einkorn is more cold hardy than emmer. Percival (1974) considered emmer one of the least cold resistant wheats (an erroneous assertation, G. Jones, personal communication). Spelt is generally regarded as more winter hardy than soft red winter bread wheats (Oplinger *et al.* 2002). Sutka and Veisz (1988) report that particular lines of spelt carry a particular gene for frost resistance. Several studies have also noted the yield stability of spelt at cool temperatures and on wet soils (Kuckuck 1964; Riesen *et al.* 1986; Ruegger *et al.* 1990).

7.3.1.4 Immunity to pests and diseases

Genetic resistance or tolerance to pests is a major factor determining the productive value of cereals. Some authors are even prepared to argue that pest and disease immunity is the principal factor constraining the spatial distribution of cereal taxa (Rausher 2001; Logan *et al.* 1990; Vavilov 1951). Cereals are currently subject to attack by a wide range of organisms. Wheat grain yield is currently decreased by some 50 major diseases (OECD 1999). It is probably impossible, however, to characterise particular cereals in terms of overall pest resistance/tolerance, in part because of the rapid evolution of new plant resistance and counter-resistance in the cereal plant's enemies (Rausher 2001; Andow 1983). Additionally, the timing of the damage caused by pests varies widely between regions and is significantly affected by specific circumstances (Altieri 1991). Finally, the set of traits that convey resistance and tolerance are highly variable and even potentially conflicting in terms of their outcomes (Andow 1983). Traits that contribute to disease resistance for instance are based on the ability of a host plant to reduce or to prevent the development of a pathogen while traits which contribute to tolerance are based on the ability to recover without a reduction in productivity. Crucially, pest resistance/tolerance is highly influenced by management practice. The prevalence of pests in cereal fields is also influenced by: (1) the arrangement of crops in time and space; (2) surrounding environment; and (3) the intensity, diversity and skill exercised in management practices (Altieri 1991).

The intensification of farming, including changes of cultivars, crops and cultivation patterns, creates conditions more favourable to pests and the breakdown of natural modes of pest resistance. Kilpatrick (1975) estimated that, as an overall average, monogenic resistance to leaf and stripe rust, for instance, lasts only five to six years under current types of cereal management regimes. According to Heisey and Brennan (1991), higher cultivar turnover rates are associated with more favourable production environments because the conditions conducive to high productivity are also conducive to disease development.

In general, observers report that genotypic variation for disease and pest resistance in winter cereals is small (within species) with 'high genotype x environment' interaction effects and thus moderate to low heritabilities (Oettler and Schmid 2000). The glumes of hulled wheat cultivars are, nevertheless, commonly argued to convey higher levels of resistance to both pests and disease but empirical data is rare and results from past studies mixed. In a study of disease resistance in winter bread wheat, hulled spelt and a 'free threshing cultivar of spelt', Riesen *et al.* (1986) noted that infection by a number of fungal diseases was significantly less for hulled spelt than for free threshing bread wheat and, although protection against infection was probably conveyed by the glumes, the 'free threshing cultivar of spelt' was also more resistant than bread wheat.

7.3.1.5 Soil moisture requirement

Moisture is a principal environmental factor affecting crop performance in terms of yield and quality and, in most production environments, moisture stress is the principal factor responsible for crop failure (Musick *et al.* 1994; Baker 1989). The capacity to endure particular levels of moisture stress varies between cereal species, cultivar and season (Anderson 1985; Boyer 1982). Moreover, species and cultivars show differences in the amount of time they can undergo particular levels of moisture stress at different growth stages (Bidinger 1985). Although a precise definition of soil moisture requirement remains elusive, general consensus holds that a ratio of yield under sub-optimal dry conditions to yield under optimal conditions is a useful concept in modelling the approximate soil moisture requirement for any given crop (Arnon 1972). Note, however, that the capacity for grain yield under drought conditions depends as much upon the character of the cultivar's phenology (the timing of growth cycle events) as on its physiological capacity to draw moisture from the soil (Acevedao 1991). Drought also occurs in different patterns (i.e. it can come early or late in the cropping cycle) and soils have varying capacities for storing moisture (e.g. sandy soil may promote moisture stress in a normally stress free environment).

Two factors are crucial to plant moisture uptake: (1) water absorption capacity, which is ultimately controlled by root characteristics interacting with the physical properties of the soil; and (2) evapotransporation rate which is controlled by crop characteristics such as extent of ground cover, osmotic adjustment and stomatal conductance interacting with atmospheric conditions (Guoxiong *et al.* 2002).

It is difficult to characterise productivity under low moisture conditions. For example, Arnon (1972) points out that because rainfall is highly variable from year to year in arid areas, farmers are actually better off growing varieties that have the potential to return good yields in good years even if yields are relatively disappointing over a number of other years.

Soil moisture stress may be managed using a number of methods. Planting date may be used to synchronise key plant growth stages to local weather patterns (e.g. autumn or spring planting) (Fischer 1989). Plant density may be adjusted to compensate for inadequate levels of soil moisture (e.g. yield of older wheat varieties is similar to modern varieties when inter-plant competition is reduced) (Reynolds *et al.* 1994). Irrigation may be employed to reduce or obviate the negative effects of climate on grain yield or harvest index (biomass produced per unit input of plant nutrient) (Fischer 1989). Breeders can attempt to intervene by improving yield stability (Baker 1989).

In Europe, cereals are predominantly a dryland crop with irrigation employed only on high value crops such as durum (Byerlee and Moya 1993). Barley normally plays a central role in arable agriculture where crops are routinely grown under conditions of moisture stress (Arnon 1972). It almost always replaces wheat in areas where rainfall is either low or erratic. Yield losses in barley occur when moisture stress occurs at crucial growth stages (e.g. a drought during heading will result in sterility of 20-90 % of the spikelets) (Briggs 1978). Barley can also be negatively affected by high levels of moisture from overly generous spring rains (e.g. excess water at the beginning of development. Barley is especially sensitive to high soil moisture levels during tillering (Briggs 1978).

Rye, because its root system branches extensively in the first 300 mm of soil, tends to be more drought resistant on poorer soils than wheat, and uses 20-30% less water per unit dry matter formation than wheat (Bushik 2001). Tetraploid varieties are generally more sensitive to low soil moisture than diploid varieties, though drought in the period from tillering to heading has little effect on yield in either type (Bushik 2001). Water deficits in the period from shoot formation until flowering and from heading to milk stage are the most injurious to grain yield (Bushik 2001).

Oat and wheat show a wide degree of variance for drought resistance dependant upon sowing time, cultivar and sowing density (Miller 1984). The amount of rain normally required for oats is moderate, 300-400 mm/cycle (Miller 1984). Common oat is reported to tolerate annual precipitations of 200-1800 mm (Miller 1984). However, better yields are obtained when annual precipitation rises above 500 mm (Miller 1984).

Moisture stress influences both yield and end-use quality of wheat. About three-quarters of the land area where wheat is grown receives an average of between 375 and 875 mm of annual precipitation although wheat can be grown on most soils where precipitation ranges from 250 to 1750 mm (Hanson *et al.* 1982). According to Guttieri *et al.* (2001) the overall moisture-deficit-induced reduction in yield of spring wheat is due primarily to reduction in kernel weight and kernel number per spike.

Durum wheat is argued to be especially adapted to dry climates, with hot days and cool nights, and does well under dry conditions. Durum is also reported to show less reduction of plant biomass production and grain yield under conditions of low moisture stress than typical hexaploid bread wheat cultivars (Saleem 2003). St. Burgos *et al.* (2001) report that a comparison between the grain yields of winter bread wheat and spelt showed that, in marginal agro-climatic zones, spelt is more sensitive to flooding (on the point of soil flooding see Davies and Hillman 1988).

7.3.1.6 Nitrogen requirement

Nitrogen is the soil nutrient most frequently in short supply in the soil. Where cereal plants grow without serious temperature and moisture constraints, nitrogen availability is usually the chief variable affecting wheat yields. Furthermore, nitrogen plays a central role in determining the quality of grain and vegetative plant parts (Arnon 1972). Bread making quality, for instance, is positively influenced by nitrogen levels in wheat (Fageria *et al.* 1991). The dynamics of nitrogen use is extremely complex. Species, subspecies and varieties can vary markedly in their response to nitrogen. There is variation in: (1) the amount of nitrogen required for optimal productivity; (2) the timing of nitrogen acquisition; (3) the efficiency of fertilizer nitrogen recovery; and (4) the utilization of absorbed nitrogen to make grain.

Nitrogen use efficiency (NEU) can be calculated by many methods but most methods estimate NUE for cereal production at approximately 30- 35%. Top-dress applications (applying nitrogen to the surface of the soil) in the middle of the season can result in NUE's as high as 50%, but there is usually an offsetting reduction in grain yield because of early application (Olson and Swallow 1984; Moll *et al.* 1982).

It is difficult to characterise cereal taxa on the basis of their actual nitrogen requirements. They vary across a range of production environments as well as production goals (e.g. malsters prefer low nitrogen content in barley). Crops further differ in their capacity to return nitrogen to the soil via plant residues. Below is a ranking of the typical nitrogen requirements for winter cereals in Ontario ranked in order of least to most in terms of typical nitrogen requirement (OMAF 2002):

1. Spring oat
2. Spring rye
3. Spring barley
4. Spring wheat
5. Winter oat
6. Winter wheat
7. Winter barley
8. Winter rye

Amongst wheat species, and cultivars within wheat species, nitrogen requirements are equally variable according to environment and production goals (e.g. grain or hay) (for a review of NUE under pre-industrial management systems see Chorley 1981). However, in one study, Guzy *et al.* (1989) report that, because of generally higher rates of biomass accumulation, wheats in the diploid group display characteristically higher nitrogen demands than the hexaploid wheat group (in terms of total nitrogen required for equivalent grain yields). Ruegger *et al.* (1993) compared nitrogen uptake and dry matter production of modern winter bread wheat and spelt cultivars under two levels of nitrogen and two seeding rates at two locations in Switzerland. While the combined yield of spelt grain and glumes was 10% higher than that of bread wheat at high elevations, grain yields of spelt were 25% lower than those of bread wheat. Rüegger *et al.* (1993) also reported that the photosynthetic rate and nitrogen uptake were not significantly different between the two wheats and the study failed to find spelt to be more efficient at dry matter production than bread wheat – a finding further supported by Feil and Geisler (1988).

In her evaluation of British assemblages from northern Britain, van der Veen (1992) indicated that spelt was primarily associated with extensive type husbandry practices (poor soil fertility as indicated by a comparatively greater proportion of weed species associated with low levels of nitrogen) (for a full review of this approach see Bogaard 2004). Alternatively, Pena-Chocarro (1999, 38) reports that "neither emmer or spelt are directly manured in [modern day] Asturias because of a tendency of these species to grow too tall over a short period of time and therefore lodge" (however, fields are manured in the previous year). Nevertheless, authorities contend that lodging caused be high nitrogen levels can be obviated by allowing animals to graze young plants in order to encourage tillering. Halstead (in press), having considered all the ethnographic evidence, suggests that 'in Greece, manuring rates vary according to individual plots of land, and are passed on between generations and adjusted on the basis of personal experience'.

7.3.1.7 Tillering

During the vegetative growth stage, side shoots called tillers are produced by cereal plants. Tillering (the process whereby tillers are produced) is an important factor in determining crop yield because each tiller represents the potential for an additional stem complete with its own leaves, roots, and ear. All cereals possess the ability to produce tillers although the number of tillers produced varies widely. Some species and varieties are more freely tillering than others. Tillering rate is generally determined by cultivar, sowing date and latitude (Stoskopf 1981). Certain conditions may foster more tillering. The long vegetative phase in autumn sown cereals, for instance, promotes tillering. Stresses resulting from inclement weather, too little or too much moisture in the soil, soil compaction or nutrient imbalance may reduce tillering. Very high seeding rates can also reduce the number of tillers due to competition between plants (Stoskopf 1981).

Agronomists continually debate whether it is better (in a given environment) for plants to produce: (1) few tillers, each bearing high numbers of grains; or (2) many tillers with few grains. Excessive tillering leads to a compensatory reduction of yield for the primary ear (Egli 1998). Tillering in wheat is reported to be highest in diploid wheat groups as is plasticity for spike number and seeds per spike (Guzy *et al.* 1989). Although spike number per plant is less in both hexaploid and tetraploid groups compared to diploids, earliness (early growth habit) and stable harvest index (grain weight as a function of total dry weight) provide hexaploid and tetraploids with yield superiority over diploids (Guzy *et al.* 1989). Barley is generally more freely tillering than wheat. Rye tillers freely and is the fastest tillering cereal type (Kucera and Giampiero 2004). In oats, tillering is highly variable (Kucera and Giampiero 2004).

7.3.1.8 Lodging resistance

Lodging is the term used to describe a condition whereby the shoots of cereals become displaced from their vertical orientation (Berry *et al.* 2004). Lodging can be one of the most important factors influencing yield. Two forms of lodging are recognised: stem lodging (Thomas 1982) and root lodging (Ennos 1991). Stem lodging results from a structural failure at one of the lower internodes. Root lodging, on the other hand, is brought on by poorly developed roots or weak soil structure.

Lodging is capable of reducing yield by up to 80% (Berry *et al.* 2004). In British fields, lodging is frequent, occurring in one out of every four years (Allan 1989). High winds, rains and/or hail usually bring on the condition but it can also result from a combination of heavy ears and weak stems. Lodging is most likely to occur during the two or three months preceding harvest, usually after ear or panicle emergence (Martin 2004).

Lodging can be discouraged by appropriate management practices and careful cultivar selection. All factors which contribute to excessive vegetative growth increase the possibility for lodging (e.g. high nitrogen, high sowing densities, mild temperatures and high moisture conditions) (Arnon 1972). Early sown crops are typically at greatest risk for lodging for three reasons: (1) early sowing typically leads to a longer period between ear emergence and ear production and thus exposes the plant to greater risks; (2) early sowing increases both the number of leaves and the number of internodes, making plants heavier and taller; and (3) early sowing may also encourage tillering which leads to a condition where light is less able to penetrate the dense canopy, causing plants reach higher for light (Martin 2004).

Plant genotype plays a role in lodging by influencing: (1) plant height; (2) root type; and (3) the circumstances under which the plant anchoring system is formed; and (4) strength of the stem base. Plant height contributes most to vulnerability but, while shorter cultivars are less vulnerable, they are never assured against vulnerability, and attempts to reduce susceptibility to lodging, through selection of shorter individuals, usually results in a compensatory penalty in grain yield (Borojevic and Borojevic 2005).

It is difficult to typify susceptibility to lodging with respect to the taxa in this study since local weather patterns, management practices and individual plant characteristics all play a significant role in influencing the outcome of a lodging event. There is also a range of variation within each of these three variables. Plant height, for instance, may vary as much within a taxon as it does across taxa. According to Empilli *et al.* (2004), plant height varied widely across 1039 einkorn accessions. Kreuz *et al.* (2005) proposes that einkorn is more resistant to lodging than emmer. Stallknecht *et al.* (1996) reports a similar degree of lodging susceptibility across both emmer and spelt. According to Campbell (1997, 194) spelt is more susceptible to lodging than bread wheat. Wide variations in the plant height of bread wheats are widely accepted (Wiersma 2000). Letts (1999) has drawn attention to archaeobotanical examples of smoke blackened Medieval thatch (generally from tetraploid free threshing cultivars) which sometimes exceed 5 feet.

7.3.1.9 Grain maturation

Grain yield is determined by the grain formation period which begins with the genesis of the embryo and proceeds through a series of phases characterized by nutrient assimilation. Physiological maturity in cereals is typically complete with the cessation of all nutrient movement into the grain (Vincente-Carbahosa and Carbonero 2005; Farnworth 1997; Crane *et al.* 1959). Amongst wheats, differences between the length of this interval are considerable ranging from 30 to 70 days. Grain filling periods tend to be short in high-stress environments and long in high-yield, low-stress environments (Nasyrov 1978; *cf.* Farnworth 1997).

Barley is characterised by the shortest crop cycle because ripening can be initiated under cool temperatures. It will normally ripen within 80-100 days after sowing, with winter forms ripening at least two to three weeks earlier than those of wheat (Farnworth 1997). Oats typically require at least seven to ten more days to ripen than barley, but grain maturation is less of an issue in oat cultivation because oats can be harvested green (Welch 1993). Wheats vary widely in their ripening requirements but they generally require more days (alternatively degree days) than either barley or oats. Hard red spring wheat, for instance, typically requires 10-15 more days to mature and ripen than barley (Farnworth 1997). In general, all winter wheat varieties typically require more thermal units (growing degree days) than spring forms. The onset of the growing season for spring wheat is determined by the onset of the threshold growth temperatures. Durum wheat varieties require a longer growing season than most other wheat types, but durum is typically grown as a short season grain in relatively warm areas. According to Stehno and Trcková (2005), the number of days from sowing to wax ripeness is nearly the same for bread wheat and durum but significantly longer for emmer and einkorn. Although rye comes into ear earlier than most cereals, the grain typically takes much longer to mature (generally, 7-10 days more than wheat - Farnworth 1997).

7.3.1.10 Pre-harvest sprouting resistance

Pre-harvest sprouting (PHS) is a condition in which germination prematurely occurs in the ear before harvest (Zanettia *et al.* 2000). PHS results from high levels of atmospheric humidity or rainfall during harvest time. It is a significant production problem in wheat and barley but less so in oat and rye (Walker-Simmons and Ried 1992). The main effects of pre-harvest sprouting are a reduction of grain quality but it can also cause a substantial decrease in yield. Sprouted cereals generally make poor quality bread flour and are normally only fed to livestock. Important physiological characters that contribute to prevention are: (1) reduced enzymatic activity (note that increased enzymatic activity is beneficial to malsters); (2) the presence of chemical germination inhibitors; and (3) reduced water absorption (Walker-Simmons and Ried 1992).

Though the condition results largely from environmental factors, resistance varies according to variety and genotype. Awned varieties are reported to have greater tendency for PHS because awns tend to channel rainwater onto the ripe grains, increasing the risk of them sprouting. In wheat, PHS resistance is a quantitatively inherited trait closely correlated with bran colour. White bran types are more susceptible to PHS than red types (Walker-Simmons and Ried 1992). This predisposition is probably due to pleiotropic effects (a condition where one gene affects more than one character) of genes controlling grain colour. Genes offering high levels of PHS resistance have been recognized in both bread wheat and spelt (Xiu-Jin *et al.* 1997).

7.3.2 Grain characters

7.3.2.1 Ear characteristics

In cereal crops, the inflorescence, the cluster of the florets on the rachis, is recognised as an ear. Because grain yield is primarily a function of: (1) the number of grains per unit area; and (2) the processes that take place during the grain filling interval, ear character is a particularly influential factor in determining grain yield (Egli 1998). Ear architecture has two effects on yield. Firstly, it influences the number of kernels per head (prolificacy). Secondly, it plays a role in determining the way the grains are filled (Vollbrecht *et al.* 2005; Gutieri *et al.* 2001; Fredrick and Bauer 1999; Egli 1998). For example, the arrangement of the vascular tissue within the inflorescence influences the rate of assimilate flow into grain.

The general structural architecture of the inflorescence of barley, rye and wheat are similar (i.e. the flowers are borne on congested lateral branches of a false spike). The oat inflorescence, on the other hand, differs as it is typically an open panicle. The density of spikelets on the rachis (or the panicle) in barley, wheat, oat and rye varies between and within the taxa. Usually the spikelets are arranged regularly along the rachis but this is not always the case (e.g. club wheat spikelets are arranged more tightly toward the tip of the rachis). In wheats, dense-earred types are most common amongst hexaploid bread wheats (Percival 1974). Depending on the proportion of well-developed ears, the average grain count per ear in modern bread wheat varies between 20 and 40 though the average is 30-35 (Kübler 1994; average data in Germany). In the past, dense-eared forms of bread wheat were amalgamated into a separate category where they were regarded as compact types (USDA wheat classification regulations subpart M). In barley, 2 and 6-rowed ear types are recognised. The 2-rowed forms of spring barley carry ears with 15-30 grains/ear compared with 25-60 grains per ear for 6-rowed barley (Kucera and Giampiero 2004). Rye bears its grain on an elongated, pointed spike (c.7-15 cm) with spikelets densely held.

The panicle of oat varies widely in form, shape and density between types (upright, bush-like, one-sided, spreading and drooping) (Kucera and Giampiero 2004). According to Campbell (1997, 163), the ear of spelt is longer than that of bread wheat but spikelet number is similar.

Grain number per spikelet varies between species. Einkorn spikelets typically carry one grain but certain cultivars bear two. Emmer bears two kernels per spikelet. Durum and bread wheat vary widely and, according to Blumler (1998), increase in grain number per spikelet becomes more possible with the loosening of the glumes.

7.3.2.2 Grain weight and size

Species and cultivars naturally vary with respect to typical grain weights, but across wheat cultivars, some researchers note a tendency for tetraploid grains to be heavier than those of diploids (Hammer and Sprecht 1998). Durum wheat typically demonstrates highest grain weight. Stehno and Trcková (2005) report average 1000 kernel weights of 22, 23, 38 and 47 g. respectively for einkorn, emmer, bread wheat and durum wheat.

Grain size is governed by genetic and environmental components. The genetic basis of grain size is derived from a capacity to produce more endosperm cells (which is itself a function of the rate of endosperm cell division) (Lupton 1987). However, the capacity to achieve maximum size depends on the duration of the grain filling period, the rate of supply of assimilates to grain and the rate of incorporation of these into grain structure from anthesis onwards (Sharma and Sain 2003). Ries and Everson (1973) report that for wheat seed size is positively correlated with seed vigour: larger seeds tend to produce more vigorous seedlings. Singh and Kailasanathan (1976) demonstrated that larger seeds of spring wheat produced higher yields than smaller seeds under late-sown conditions but not under optimum management conditions.

Stallknecht *et al.* (1996) proposes that wheat species can be characterized by relative grain sizes: einkorn - medium grained; emmer - large grained; bread wheat - extra large grained. Campbell (1997) reports that grains of spelt are larger than those of bread wheat. According to Halloran and Pennell (1982), differences in grain size within the three ploidy levels of wheat are related to total photosynthetic area and dry weight accretion in the seedling. Hexaploids were recognised to display the largest seed size and tetraploids were superior to diploids.

Kernel size relative to weight (i.e. grain density) is a prime quality parameter in small grains. The test weight concept was developed many years ago by the grain trade as a means of accounting for the varying densities of grain caused by differences in genotype, moisture content, weather and/or production practices. When grain density is lower than the accepted standard (low test weight), more volume is needed to store and transport a given weight of grain, thus increasing storage and transport costs (Beuerlein 2005, 1). The current USDA assigned one-bushel test weights for winter grains are: 60 pounds for wheat; 56 pounds for rye; 48 pounds for barley, and 32 pounds for oat (Beuerlein 2005).

The shape of grains can also be a parameter for judging quality. Plump grains normally have a lower percentage of hull or bran and thus a lower crude fibre content which results in a higher feed value for livestock. Plumpness is also used for determining the quality of malting barleys (Marquez-Cedillo *et al.* 2000).

7.3.2.3 Grain and endosperm hardness

Endosperm texture (relative hardness) is defined as the resistance to deformation in terms of the milling process (i.e. hard endosperm types require significantly more energy to reduce the grain to flour). It is a complex trait correlated with the degree of adhesion between starch and protein molecules in the endosperm of the grain.

Grain endosperm hardness is used as an important parameter for quality prediction in wheat. The relative hardness of the endosperm affects flour particle size, ease of sifting, flour density, starch availability, absorption properties and, crucially, the milling yield of the grain (extraction rate) (Blackman and Payne 1987). In wheat, endosperm texture is a major factor used to determine baking quality, and premiums are generally paid for harder types. Endosperm texture may also be used as a means for making general distinctions between wheat variants. Hard wheat yields coarse, gritty flour while soft wheat yield very fine flour. In relative terms, grains of einkorn, emmer and durum wheat are hard compared to those of bread wheat but bread wheat can vary widely for the trait (Thurnbull and Rahman 2002).

In wheat, 'hardness' is a simply inherited character and, though the locus is termed 'hardness', 'softness' is the dominant trait (Thurnbull and Rahman 2002). The trait is thought to act by regulating levels of lipid binding proteins (puroindolines) (Morris 2002). Temperature, nitrogen and moisture levels can also influence the level of endosperm hardness (Thurnbull and Rahman 2002). In most places in Europe (e.g. Britain), warmer and dryer conditions produce the harder grains (Percival 1974) but agro-envorionmental conditions rarely modify grain hardness enough to result in grain reclassification (e.g. from soft to hard type, or visa versa) (Hoseney 1987). In relative terms, the grains of einkorn, emmer and durum wheat are almost always classified as hard. The softest grains tend to be produced in varieties and species which bear high relative numbers of grains (e.g. bread wheat) (Percival 1974 p. 20). Rapidly growing, lower yielding and heat loving varieties generally tend to produce the hardest grains (e.g. einkorn, emmer and durum) (Percival 1974). In barley, endosperm hardness is involved in malting quality and harder types are generally perceived as more valuable (Beecher *et al.* 2002). In rye, hardness does not appear to be recognised as an economic variable as it is not discussed in the literature. In oats, endosperm texture is an insignificant factor because oat products tend to be cut or rolled rather than ground.

7.3.2.4 Dough strength, bread and baked products

Wheat and flour quality is expressed by a variety of chemical and physical properties none of which are entirely independent or necessarily positively correlated. According to Tipples *et al.* (1987), the ideal bread flour produces bread over a wide range of processing conditions and yield doughs with well balanced handling and short mixing requirements. Dough strength (visoelasticity - elasticity without breakage, a physical characteristic highly correlated with protein content and quality) is a key parameter used to evaluate the suitability of dough for baking. Strong doughs have a greater capacity for trapping carbon dioxide during the leavening process and thus are superior for the manufacture of high volume, low density breads. In wheats, the degree of visoelasticity is thought to be determined by: (1) the relative hardness of the endosperm (i.e. the microstructure of milled grains influences the absorption capacity of flour granules - Blackman and Payne 1987);

and (2) the quality and quantity of high molecular weight proteins present in the flour (Blackman and Payne 1987) – the gluten fraction is responsible for dough development (Pyler 1988) and the gliaden fraction defines loaf volume (Hrušková and Faměra 2003; Gianibelli *et al.* 2001).

Hard flours display a greater proportion of damaged starch particles after milling than soft types. Because damaged starch granules are more water absorbent than undamaged granules, hard flours produce more absorbent doughs (Blackman and Payne 1987). This added absorbency promotes the creation of gas when fermentation agents are added to the dough. When these gases are retained, the dough begins to rise, with retention being most efficient in flours which contain high levels of the visioelastic protein, gluten. The most optimal wheat types (in terms of dough strength) are those which theoretically combine high shearing requirement (i.e. hard grains) with high gluten content (Ohm *et al.* 1998). (Note here that the suitability of any wheat for bread making is principally determined by the quantity and quality of its proteins. Protein quantity, as previously mentioned, is largely determined by environment and/or sowing date whilst protein quality is genetically determined).

Different foods prepared from wheat require different dough strengths. Soft wheat flours are used for the manufacture of unleavened products because: (1) fermentation is not a factor in their production; (2) soft kernels require less energy to mill; (3) soft dough requires less energy to mix; and (4) the price of soft wheat is typically lower than hard types. Durum is the basis of nearly all noodles and pastas since it has the highest dough strength, and therefore protein content, of any flour.

Premium leavened bread is made from hexaploid bread wheat cultivars (e.g. hard, red, spring sown types of bread wheat or spelt) but there is great variation in the gene pool of the bread wheat species (Gianibelli *et al.* 2001; Campbell 1997). It is a commonly held belief that high gluten, spring sown bread wheat is the best choice for oven baked, leavened breads but some authorities question this, pointing out that, although spring wheat does have a high quantity of gluten, it does not have the necessary quality of gluten needed for long fermentation (Pyler 1988). Le Clerc *et al.* (1918) compared the bread baking properties of several relic wheats with that of hard red spring bread wheat and concluded that bread baked from spelt flour was indistinguishable from that baked from spring bread wheat. According to Stallknecht *et al.* (1996), the dough characteristics of the einkorn are significantly inferior to bread wheats. He concluded that the gluten strength of einkorn is similar to that of soft bread wheat, but the dough remains sticky and has a low water retention capacity. Barley has practically no gluten-forming proteins and thus varies little in terms of dough strength. Although rye contains gluten, it does not contain enough to produce the same results as bread wheat. Modern rye bread is typically fortified with about 70% strong bread wheat flour to dampen the effects of rye on the dough (Bushik 2001). The more wheat flour is used, the lighter and milder the bread (Bushik 2001). Oat contains no gluten but may be blended into flours to provide a variety of texture and taste to baked products.

7.3.2.5 Grain and endosperm colour

In wheat, grain colour may be either white or red depending on the colouring of the bran (testa). In white wheats, the bran is actually colourless while in reds colour develops as a result of a resinous material that is produced during grain ripening (Percival 1974). Bran colour is genetically controlled and is one of the most easily manipulated of wheat's characters (Lupton 1987). White or red colour is controlled by three genes with an additive effect. Each of the wheat taxa examined in this study has the genetic capacity to achieve the full range of bran colours. Red is the most common colour in preserved accessions of einkorn (Empilli 2004 *et al.*). Durum wheat is lustrous, lacks pigment in its bran altogether, and is generally classified as translucent or lustrous. Emmer and spelt cultivars are typically red (Percival 1974).

The most important gene controlling red bran colouration also regulates seed dormancy, and thus governs both traits (Himi *et al.* 2002). In general, this means that red wheats will not sprout as readily as whites (Himi *et al.* 2002). Also, hard red varieties will sprout less readily than soft red types (Himi *et al.* 2002). In those areas where there is a possibility of rainfall at harvest, red wheats are generally preferred because whites have a tendency to sprout in the ear (Himi *et al.* 2002).

The colour of grain endosperm affects the colour of manufactured flour. In most cultivars of wheat the endosperm is white. Durum and einkorn are exceptions, with yellow/amber endosperm. White bran types are preferred by producers who are engaged in the manufacture of products which require non-pigmented flour because bits of bran inadvertently escape into flour during a typical milling process discolouring the flour.

Barleys do not show great variation in grain colour so colour is generally not an important concern for barley producers. Flours made from barley are, nevertheless, typically much darker than those made from wheat. Rye is predominantly a tan colour but grain colour may vary from yellowish brown to greyish green. Yellowish light coloured grains occur more or less spontaneously in heterogeneous rye populations (Bushik 2001). Yellow tinted grains are perceived by some consumers to be more easily digestible and to produce a milder taste in rye breads (Bushik 2001). Rye flour types are classified according to the degree of bran removal during milling. Whole grain rye flour (pumpernickel flour) gives the most typical rye flavour. Other grades are termed 'dark rye', 'medium rye' and 'white rye', in order of the extent of bran removal (Bushik 2001). Oats are available in a broad range of genetically governed colours. Grey and red oats are frequently perceived by modern farmers to be inferior animal feeds (Karow and Hilliker 1993). Oats of these colours tend to be less plump, but there is little evidence of nutritional inferiority in grey or white types (Karow and Hilliker 1993).

7.3.2.6 Nutritional quality

Cereals provide several classes of compounds in a nutritive package that is high in carbohydrates but disproportionately low in protein. Generally, grains of winter cereals consist of 65-75% carbohydrates, 12-14% water, 7-12% protein and 2-6% lipids (for a complete review of this subject see Haard *et al.* 1999). The nutrients are not uniformly distributed throughout the grain. The aleurone layer is primarily starch but wheat aleurone contains 25 times more minerals than other parts of the grain. Half of the lipids (fats) are distributed throughout the aleurone and the embryo. The remaining lipid portion is mainly incorporated in pigments and solubility agents. The endosperm is predominantly starch. The germ is composed largely of protein but contains starches and lipids as well. Glumes, lemmas and paleas are typically high in cellulose and contain traces of fat and ash (minerals).

The principal carbohydrate in cereals is starch, reaching a maximum proportion of 56% in oats. The types of starch are similar in all of the taxa (74-79% amylopectin, 25-30 %

amylose) but flours prepared from oat, barley and rye contain a relatively high percentage (5-25%) of non-starch polysaccharides in comparison with wheat. Rye flour contains a relatively high proportion of water soluble pentosans which are compounds that are capable of absorbing large amounts of water to form gels (Eliasson and Larsson 1993). Barley contains a high relative proportion of beta-glucans which aid in the malting process.

The nutritive value and net protein content of cereal proteins is relatively low due to insolubility problems and low levels of essential amino acids (Chaven and Kadam 1989). Proteins in cereals are divided into four classes on the basis of solubility: (1) water soluble albumins; (2) salt soluble globulins; (3) alcohol soluble gliadins; and (4) insoluble glutenins. The proportions of each vary widely across the taxa and to some extent across species and variety. Proteins in barley, rye and oat generally have a lower rate of digestibility (77-88%) than modern bread wheat (95-100%).

Although lipids are typically low in cereals, certain oat cultivars may contain up to 10% fat (as compared to about 2-3 % for other cereals). The glycolipids in bread wheat play an important role in enhancing dough properties (Pomeranz and Chung 1978). The mineral component of cereals is generally low. All cereal grains are low in calcium but moderate to high in potassium. Potassium tends to occur in the form of a phytate, rendering it insoluble. Cereal grains are generally a poor source of trace minerals but vegetative portions of the plant have relatively higher mineral contents. Oat and barley are the only winter cereals with a high dietary fibre content (Chick 1957).

7.3.2.5 Feed quality

Oats, barley, wheat, and rye are amongst the most common feed grains used in livestock production. They are principally used as an energy source but grain is also used to supplement protein levels. Availability, palatability, relative price, nutrient balance and presence of inhibitory or toxic substances combine to determine the relative value. No one type of grain can be characterised as the ideal feed for every livestock species and, in actual practice, cereal grain is often blended to achieve optimal effects (Kellems and Church 2002).

In the more recent past, barley was held to be the premium feed grain probably based upon relative availability and low price. Barley grain is high in crude protein and essential amino acids but, on the other hand, it is also high in dietary fibre. Digestibility data indicates that feed conversion is negatively affected by the high fibre content of the hulls (Zinn *et al.* 1996).

Wheat is low in fibre and high in metabolizable energy, and compares favourably with other grains in energy content (Pond and Maner 1984). Expressed on a dry matter basis, wheat contains on average a high percentage of digestible nutrients for swine, poultry and cattle production. According to Pond and Maner (1984), the relative feeding value of wheat is 109–114% that of barley but high prices usually limit its widespread use (Kellems and Church 2002). The feed value of spelt is reported by some to be similar to oats (Arscott and Harper 1962).

Oats are particularly high in fats but have a lower feed value than barley, wheat or rye but, because approximately one-third of the grain is hull, oats have low starch and high fibre proportions (Pond and Maner 1984). Nevertheless, in actual practice, this high fibre component can be of benefit in certain mixes where oat is used to 'bulk down' high energy feeds (e.g. where oats are used in combination with wheat in equine feeds) (Kellems and Church 2002).

Rye is not commonly used as a grain for swine and poultry production and only to a slightly greater extent for sheep and cattle. It is generally unpalatable to most livestock species and contains two anti-nutritional factors: an appetite-depressing factor (in the bran) and a growth-depressing factor in the grain (Kellems and Church 2002). Research has demonstrated that pigs, poultry and cattle perform poorly when fed rye.

7.3.3 Biomass characteristics

7.3.3.1 Forage Quality

The vegetative plant parts of cereals are often used as a substitute for annual or winter grasses in livestock production because cereals are typically higher in protein and lower in fibre than most annual grasses (Horn 1985) and because autumn and winter grazing has little effect on grain yield (but rigorous spring grazing reduces yield significantly) (Horn 1985). Moreover, when cereals are subjected to multiple early season grazings, tillering and leaf-to-stem ratios are actually increased (Poland *et al.* 1998). Various methods can be used to produce cereal forages. When cereals are sown as a dual purpose crop (for forage and grain) they are usually autumn sown to: (1) achieve greater forage quality; (2) achieve higher forage and grain yields; and (3) avoid the build-up of anti-nutritional compounds in vegetative plant parts (Patel and Nishimuta 1978; Horn 1985). Higher forage yields can be achieved by increasing plant density by 50%-100% over rates employed to obtain the best grain yields (Horn 1985). The forage quality of leaves decreases as plants grow older because, as plants mature, a greater proportion of the plant nutrients in them are converted into non-digestible substances such as lignin. Cereal forage quality peaks just before flowering (Stoskopf 1981). Research has shown that intercropping winter and spring sown cereals enhances forage availability and quality. However, total forage production can be reduced when spring and winter cereals are sown together compared with sowing spring cereals alone (Carr *et al.* 1998).

Rye, because it is hardier and grows at cooler temperatures than wheat, barley or oats, provides later autumn and earlier spring grazing than other winter grains. As forage, rye exceeds its competitors in terms of biomass produced. Rye's vegetative growth, however, is usually restricted by short season requirements (Bushuk 2001). Barley generally displays higher-quality forage than oat or wheat (Cherney and Martin 1982). Wheat makes suitable forage where autumn and spring conditions are favourable for its growth. In combination with rye and/or barley and oat, wheat can provide excellent forage especially in regions where existing natural forages are limited in quality and quantity.

7.3.4.2 Straw

Straw, the stem or culm of a cereal plant, after the leaves and grain have been removed, makes up about half of the total dry matter yield in wheat, oats, rye or barley (Ahlgren 1956). In livestock producing areas, straw may contribute significantly to the total value of a cereal crop and can influence which types of crops are grown (Engle *et al.* 2003). In some horse rearing parts of North America, for instance, high returns for barley straw result in a predominance of barley over wheat (Macmillan 1991). In livestock production systems, straw can be used as feed and/or bedding.

Straws used for feed vary greatly in energy content ranging from almost worthless to exceptional (Macmillan 1991). Straw production needs to be carefully managed in order to achieve improvements in animal performance. Feeding poor quality straw can lead to metabolic dysfunction (Barnes *et al.* 1995; Vough 2000). The composition of such feeds also requires careful consideration. Nutritional deficiencies and low reproductive potential is a common feature in animals fed on high percentages of straw (Barnes *et al.* 1995, Vough 2000). The best straws maximise palatability, protein content and absorbency (Barnes *et al.* 1995; Vough 2000). Awned varieties are usually not used for feeding purposes as they have reduced palatability. Premium straws are produced from cereals harvested between the heading and soft dough stages of grain development, with palatability and protein content penalties incurred following flowering - after flowering, plant assimilates are transferred rapidly from vegetative plant parts to grain (Lardy and Anderson 1999). Depending on the cost of production costs, straw can be an economical energy source for livestock, but poor straw generally has more value for bedding than for feed because of its bulk (Slack 1960). Many factors influence the quality of cereal straws. Absorbency is a major factor for straws used for bedding. Digestibility and caloric value are important for straws used for feed (Slack 1960). The condition of the straw at harvest is usually key to its ultimate value. Depending on species and variety, straw may contain 60-80% stem and 20-40% leaf, but weathered straw may contain 100% stem (Barnes *et al.* 1995; Vough 2000). Pests in straw may consume up to 40% of the dry matter, and also reduce its capacity to provide energy (Barnes *et al.*1995; Vough 2000).

The factors underlying straw production are the same as those for grain, namely, relative yield balanced against quality. Yields for straw are generally ranked in the following order from high quality to low (OMAF 2002):

1. winter wheat
2. winter barley
3. two-row spring barley
4. mixed cereals
5. spring oats
6. six row spring barley
7. spring wheat

(n.b. that no data was published for rye)

Barley straw is tougher and less brittle than wheat straw and therefore lends itself for use as livestock bedding. Barley straw is also quite palatable and provides a reasonable fodder for overwintering. Cereal straws are usually ranked in terms of quality in the following order from high quality to low (OMAF 2002):

1. two-row spring barley
2. six-row spring barley
3. mixed cereals
4. spring oat
5. winter barley
6. spring wheat
7. winter wheat

(n.b. no data published for rye)

7.3.4.3 Thatch quality

For centuries thatch has been an important structural material in many parts of temperate Europe. The qualitative characters found in a premium thatch contrast widely with those of a premium straw. Thatch consumers typically prefer forms which provide adequate culm length, high culm resiliency, and aesthetic suitability. In Britain, 'long straw' (wheat specially selected and managed for thatch) is preferred in terms of aesthetics (Cox and Letts 2000). 'Combed wheat reed' (wheat straw with leaf and contaminants removed) is preferred, based, on a balance of durability and aesthetics (Cox and Letts 2000). Where reeds are available, they are generally preferred over cereals on the basis of durability (Letts 1999, 4). Letts (1999) reports that typical samples of Medieval smoke blackened thatch are composed of land-race mixtures of bread wheat, English rivet wheat (*T. turgidum*) and rye. Barley and oat are often present as well. Plant culms in these samples commonly exceed 6ft (1.8m) in length.

7.3.4.4 Threshing waste

Threshing waste, the glumes lemmas paleas, leaves, culms, grain and crop contaminants that remain after the completion of the threshing process. Threshing waste can be a high quality animal feed and can be collected from crops of wheat, barley, oat and rye. Under modern management systems, threshing waste yields may reach as high as 300-500 pounds per acre (Lardy and Anderson 1999). The feeding recommendations and quality characteristics for threshing waste are much the same as for straw. Actual feed values are fairly inconsistent and highly conditional. The carbohydrate found in the cell walls of these plant parts is generally high in cellulose and of low nutrient value. Threshing waste from coarse-awned cereals typically causes palatability problems in most livestock species and for that reason its use is discouraged (Lardy and Anderson 1999). The threshing waste of oats and barley are of limited value in animal feed and have practically no value for cattle (because of high levels of indigestible fibre which increase as both crops approach dough stage- Kernan *et al* 1979) Wheat 'cleanings' have been shown to have slightly higher feed value for ruminants (Kernan *et al* 1979). Oplinger *et al.* (2002), report that the threshing waste ("hulls") of spelt have nearly as much feeding value as do the kernels.

7.4 Implications for cereal frequencies

7.4.1 The role of management

Several points emerge concerning cereal frequency change when one examines the process of cereal production. One of the most significant concerns the role of management practice in the final determination of relative performance. Because crop production is not methodologically specific, the relative performance of a given taxon is somewhat flexible in relationship to the type of management practice employed. Although a plant's genotype is a powerful contributor to the crop's general character, ultimately crop performance is expressed through an interaction between the crop's genotype and its agro-environmental setting. Consequently, the relative performance of a taxon varies along a gradient and there are substantial overlaps in relative performance between different cereal species and subspecies under different management strategies. For instance, while it may be true that barley is best suited to short season and arid environments, bread wheat becomes an equally viable option when farmers have the capacity to supply their fields with extra moisture via irrigation. Thus, farmers can frequently adjust production goals and outcomes simply by employing different management practices or methodological controls against their traditional cultivars.

A related point concerns the observation that degree of control applied to the production process can dictate relative performance. Because the outcome of the cereal production process is adjustable via various control points, the amount of care, knowledge or management expertise exercised over the production process makes a significant difference in performance level. In other words, one achieves very little growing a taxon with a high yield potential, if one is not prepared or equipped with the proper technological tool kit to draw out that potential.

7.4.2 Relevant characteristics

This discussion also reveals three types of cereal character traits that influence cereal frequency. Firstly, it shows that adaptive traits (e.g. traits associated with winter hardiness, immunity to pests and diseases, lodging resistance, tillering capacity, sowing date, and fertility requirements) are important in determining which types of cereals are most likely to be produced. Secondly, it demonstrates that quality traits (e.g. oil content, protein content, hardness, grain density, and feed value) are important in deciding which cereals are likely to be most valued by consumers. Thirdly, it indicates that characteristics associated with profitability (e.g. storage potential, pre-harvest sprouting resistance and transportability) are important in determining which cereals are most likely to be exchanged.

7.4.3 Degrees of difference between the taxa

The agronomic evidence reveals three significant facts about performance variability. The first is that some kinds of performance characteristics are not very variable. The difference between the protein contents of einkorn, emmer, durum and premium cultivars of bread wheat, for instance, can be as little as two percent (a fraction that is really only resolvable using sensitive scientific equipment).

The second point is that, when it comes to particular traits, differences between subspecies or varieties can be substantial. In these cases the variation between lower level taxa (subspecies or varieties) can be greater than that between higher level taxa (e.g. species). The third point is that the relative performance of cereal products is conditional on the amount of processing applied. Individual differences can be minimized or maximized when high levels of technology are applied.

Integrating ancient textual evidence

Chapter 8

8.1 Introduction

This chapter seeks to examine Classical cereal preferences using evidence drawn from ancient texts. The usefulness of this type of evidence, however, depends on how closely the epithets used to describe ancient cereals correspond to the modern taxonomic categorizations used by archaeobotanists. Consequently, the chapter begins with a discussion of cereal epithet meaning before proceeding to address preferences.

8.2. The meaning of the epithets

8.2.1 Concepts and criteria for classification

Crops are classified using interpretive units and membership into each unit is delimited by a strict set of rules. The nature of these units, however, is known to change over time as different communities modify the rules to suite changing needs and individual circumstances (Senda and Tomininga 2003; Kaplin 2001; Jusu 2000; Sankey 1998; Berlin 1992; Boster 1984; Hawkes 1983). For almost a century, investigators have proposed that Classical cereal words (epithets) reflect the immediate and practically based priorities under which cereals were maintained (Thistelton-Dyer 1920; Jardé 1925). More fundamentally, they have argued that these categories vary significantly in a structural sense from modern biologically-based classification categories, and that this incongruity results in translation failure (taxonomic incommensurability) between ancient cereal epithets and modern cereal terms. There are four reasons why we should anticipate incommensurability between Classical epithets and phylogenetically based terms, as follows.

1. Lack of motivation - Classical farmers lacked a requirement for a cereal classification scheme along phylogenetic lines.
2. Lack of capacity – The state of Classical science had not attained the level of intellectual framework necessary to create a phylogenetic system.

3. Lack of proper conditions - Classical field crops were probably heterogeneous (from a taxonomic and genetic perspective, i.e. it is unlikely that they were monocultures) and consequently their typification should reflect that condition.
4. Lack of mutually exclusive characters - There are few visible characters within crops like wheat which demonstrate a capacity to enforce strict phylogenetic typification. There is often as much phenotypic (morphological) variation within wheat taxa as between them. Many of the most prominent traits that might be used as morphological markers in traditional classifications (e.g. white bran colour, dense ear shape, tall plant height, short awn length) can be distributed across species/reproductive lines (*cf.* Hammer and Specht 1997).

The expectation that folk taxonomic structures were founded upon biologically arbitrary, but culturally relevant, categories is reflected in early classification systems. Theophrastus (370-285 BC), Aristotle's peripatetic colleague, for instance, described one of the earliest known classification systems. This scheme rationalised botanical categories using gross morphological relationships (i.e. his categories were: trees, shrubs or herbs, (*Historia Plantarum*). Numerous other examples of such classifications systems can be easily cited (Pavord 2005; Berlin 1992).

We can observe the stabilizing effect of obvious morphological similarities in the Classical and modern names for wheat, barley, rye and oat. Cereal terminology at the generic level is almost frozen through time. Linnaeus, for instance, used Classical Latin epithets in his classification scheme in the 18th century (Table 8.1). The degree of correlation between cereal epithets at lower taxonomic levels (i.e. between later and earlier cereal terminology at the level of species or below), however, is less consistent and this is especially true for the terms used to describe different types of wheat.

8.2.2 The range of variation disclosed by wheat epithets

Classical authors recognized a wide range of variation in the properties and characters of wheat crops. Evidence for this is preserved within the epithets themselves. Theophrastus wrote, for instance:

"They [wheats] show differences in colour, size, form and individual character, and also as regards for their capacities in general and especially their value as a food. Some again get their distinctive names for other reasons, such as kankhrydias, stlengys, alexandrian, all of which must be distinguished by the above mentioned characters" (Theophrastus *HP* VIII.IV.3).

Tables 8.2–8.5 provide a list of Classical wheat epithets and various character traits used to distinguish cereals from one another. These lists serve: (1) to catalogue which particular traits were particularly relevant to the epithet; and (2) to illustrate the potential range or depth of relevant criteria. In other words, they demonstrate what types of characters and qualities were being used to distinguish variants, and which characters were emphasized. The tables serve as an indication to the researcher of which features were particularly important in the agro-ecosystem and/or scheme of cultivation (Meyer 1995).

There are 33 Latin and 38 Greek wheat epithets. Some of the epithets are employed in both Classical languages. The substantial length of the list is not surprising in light of the length of the time-span addressed (half a millennium or more) and the diversity of sources from which Classical agronomic authors were known to have drawn. The sizeable discrepancy between the total number of Classical epithets (71) and the number of archaeobotanical epithets (five - einkorn, emmer, spelt, durum and bread wheat) is potentially due to the following.

1. The inability of archaeobotany to resolve finer distinctions on the basis of morphological characteristics in grain and chaff (resulting in fewer, broader categories).
2. Ambiguity in the Classical epithet list (i.e. some of the epithets are interchangeable).

3. A lack of semantic equivalence (e.g. the epithets reflect dissimilar classification criteria or ontology). For example, *'robus'* is a wheat epithet (a category) based upon colour while 'emmer' is a category based upon an evolutionary relationship). Some authors argue, for instance, that Classical epithets sometimes failed even to delineate cereals from pulses (Garnsey 1999, 15).

8.2.3 Applicable wheat epithets

Which Classical epithets are directly analogous to analytical units utilized in archaeobotanical assemblages? Although a number of distinctive epithets can be identified, many appear irrelevant to the study in that they are not immediately applicable to the archaeobotanical evidence at hand. Epithets based on the criterion 'grain colour', for instance, are of little use to an analyst comparing charred grains. I propose that two classes of epithets are useful. The first type links items in the archaeobotanical assemblage to the epithet circumstantially (e.g. an epithet that uses a 'place name' that is associated with the site from which the charred cereal remains were recovered). The second type, however, provides more direct and tangible links which require no assumptions or added logic to prove them to be true (e.g. a morphological feature that can be recognized from an examination of the charred remains).

8.2.3.1 Place-based epithets (eponyms)

A substantial fraction of the epithets are obviously substantives (adjectives functioning as nouns). In this sense they are eponyms (i.e. words derived from a name). These are apparently meant to communicate geographical variations since they obviously relate to geographic areas (e.g. *'alexandrinum'* is an epithet used to describe an ancient wheat type that was cultivated in Alexandria as in:

> "There are also many kinds of wheat which take their names simply from the places where they grow, as Libyan, Pontic, Thracian, Assyrian, Egyptian, Sicilian" (Theophrastus *HP* VIII.IV.3).

It does not seem unreasonable to include eponyms in the list as they were used by Classical authors to communicate variations in the wheats which they felt were unique and merited distinction. The comparatively high frequency of these 'place-based' epithets within the epithet catalogue attests to the importance of this type of criterion in communicating variation between wheat types. Most of these substantives are Greek and, unfortunately, refer to areas outside the study region. Nevertheless, there are a few place-based epithets that relate to our study. We will apply evidence supplied by these epithets in section 8.5.

8.2.3.2 Homographs

Homographs are words that have the same spelling as another. Although homographs have the same spelling, they can potentially differ from each other in terms of: (1) meaning; (2) pronunciation; and (3) origin. Only one Classical epithet (*spelta*) is a homograph. '*Spelta*' is a rare word in Classical literature and, in fact, only occurs in two very late Latin contexts (OLD). The first instance of '*spelta*' occurs in a Syrian version of the Price Edict of Diocletian (AD 301). Here, the epithet is recorded directly alongside another (*scandula*) which is itself linked to another wheat epithet (*brace*) through a further passage in Pliny (Pliny *NH* VIII.XI.62). The implication is that all three epithets (*spelta, scandula* and *brace*) name the same type of wheat. The rarity, and late date of reference, to *spelta* may however suggest that '*spelta*' was a later name for *scandula* or *brace*.

The second record of the epithet comes from Jerome (Eusebius Hieronymus) (AD 345-420):

> "*Spelta*, which is called in Hebrew *Chasamin*: Theodotius thought it *Oaelura*, others *Avena*, others *Sigila*. *Aquila*, however, in his first edition, Symmachus, interpreted it as *Zevau* or *Zeivau*. We state it as *far* and the tribes of Italy and Italians and Pannonians, say the word *spica* or *spelta*" (Jerome [Eusebius Hieronymus] from *PL Commentaria in Ezechielem* (c) David in *Lib. Radicum*).

Note that the Latin term '*spica*' (= spike), mentioned in the above description, concurs with the peculiar spike-like nature of *T. spelta*'s ear (Percival 1974).

8.2.3.3 Epithets linked to morphologically visible traits

8.2.3.3.1 Number of grains per-spikelet

Four of the Latin and Greek epithets are names of single-grained wheat types which could potentially occur in an archaeobotanical sample from the Classical period. However, these epithets are invoked rarely by Classical authors. Furthermore, only one single-grained wheat type is stipulated within the archaeobotanical dataset (einkorn), and actual examples of einkorn in the dataset are almost as rare.

8.2.3.3.2 Epithets associated with glumes

Some of the wheats reported by the Classical authors were clearly glume wheats and are described as such in unequivocal terms. Latin authors mention the character trait in their depictions of twelve separate wheats. Greek authors, on the other hand, report seven types of glume wheats. Note that some of these epithets are potentially foreign loan words.

8.2.3.3.3 Epithets associated with the free threshing character

We have four Latin wheat epithets which are identified as free threshing. In contrast, none of the Greek epithets can be linked directly to the free threshing habit. Furthermore, where the free threshing habit is mentioned by Greek authors, passages either conflict or are too vague to be od use (see, for instance, the Greek epithet '*sitos*').

8.2.3.3.4 Category nouns

8.2.3.3.4.1 Category nouns in Latin

Category nouns are a lexical device used to communicate a general class of ideas, terms or things (i.e. broad categories). Fundamentally, they function to demarcate, co-ordinate or maintain the diagnostic protocols used in conceptual schemes. Moreover, they demonstrate a commitment to particular diagnostic conventions within a domain – the domain, in this case, is the total spectrum of cereal variants (Ahmad 2002). For our purposes, we are interested in identifying category nouns (in the epithet list) which could be analogous to particular classes or domains of carbonised wheat remains. From a comprehensive examination wheat epithets, both Jasney (1944, see also discussion in Andrews 1964) and Moritz (1958, 149) concluded that '*far*' and '*triticum*' were recognizable category nouns.

Furthermore, by contextualization, Jasney deduced that *'far'* could be reasonably translated as 'glume wheat'. This assertion is verifiable via a passage from Columella:

> "However, in land of this sort it is more suitable to sow *far* than *triticum* as it has a glume [*folliculum*] enclosing it" (Columella *RR* II.VIII.5).

Jasney (1944) additionally argued that both epithets were complementary in the sense that they enforced a dichotomy. In other words, all Latin wheat types were conceptualized under two broad umbrella headings. Consequently, it is plausible that all the different types of wheat were realized as either *'far'* or *'triticum'*. Columella, for example, grouped wheats into two categories or varieties:

> "....we commonly see four varieties [*genera*] of *far....*" (Columella *RR* II.VI.3).

> "....we know of several varieties [*genera*] of *triticum....*" (Columella *RR* II.VI.1).

Because free threshing types are produced, processed and stored differently from glume wheat types, this dichotomy is enforced by practical necessity. Each of these wheats require, at almost every stage of production and processing, separate handling. The distinction is so essential to cereal management that it was maintained in wheat classification schemes up until the time of Linnaeus (Moritz 1958). The scheme, however, violates the basic tenants of the phylogenetic scheme used by modern botanists (i.e. a glume wheat species may be more closely related to a naked species than to another husked species) and leads to a scenario whereby an array of glume wheat taxa potentially qualify under the heading of *'far'*.

At least three additional languages provide further linguistic evidence for this kind of natural or practically based taxonomic collectivization (*cf.* McFadden and Sears 1946, 109). In Italian, the incorporate folk epithet for glume wheats (einkorn, emmer and spelt) is usually *'farro'* (Szabó and Hammer 1996, 2). In Spanish, the epithet *'escanda'* is used in some cases to identify glume wheat (Pena-Chocarro 1999). In Old High German, various species of glume wheats can be understood under the term *'spelt'* (WGD, 1130). Most significantly, the modern German noun *'spelz'* directly translates as 'glume'. After reviewing the linguistic evidence, Andrews (1964), in fact, concluded that:

> "The Celts acquired spelt from the contiguous area of south western Germany and northern Switzerland, and since they extended their term *brace* to it, they acquired it without a name. Today, in most of Germany, it is called *Splez*, but also *Schwabenkorn* with allusion to the concentration of spelt in Swabia, in south western Germany" (Andrews 1964, 20).

English lexicographers imply that glume wheat species were (during certain periods) collectivized under the epithet 'spelt' by contextually linking spelts to the epithet *'far'*:

> "OE. *spelt*, = MDu. *spelte, spelt* (Du. *spelt*, WFris. *spjelte*), OS. *spelta* (MLG. *spelte*), OHG. *spelza* (MHG. *spelze, spelte*, G. *spelz, spelt*), a. late L. *spelta* (from *c* 400, mentioned as a foreign word answering to the older Latin *far*), whence also It. *spelta, spelda*, Sp. *espelta*, OF. *spelte, spealte, spiautre, espeltre, espiautre*, etc., mod.F. *épeautre* " (OED XVI.190).

Historically 'spelt' has functioned as both a noun and a verb in English. As an English noun, 'spelt' meant a type of *hwaete* (OED, first attestation AD 1000). As an English verb 'spelt' meant to husk or pound grain or beans with the intention of removing a husk. Hence, we hear of grain being 'spelted' (OED, first attestation AD 1570).

In modern Italian, peculiar types of glume wheat are designated using words which also incorporate the epithet *'far'* in their structure. Einkorn, for example, is known as *'farro piccolo'* (small *farro*) while emmer and spelt are collectively regarded as *'farro grande'* (big *farro*). This linguistic relationship between spelt and emmer is a feature of wheat words in some countries where spelt and emmer are still grown. Some investigators argue, for instance that the "Spanish term '*escanda*' is a generic term for both emmer and spelt" (Olivera 2004, 16) or that such names designate mixtures of glume wheats (Olivera 2004, 16; Pena-Chocarro 1999, 36). Indeed, crop species mixtures were and are commonplace in

Classical (e.g. Varro *RRV* I.XXXI.5; *cf* Serandon 1999; Pagano 1994) and modern folk agriculture (Altieri 1991; Jaradat *et al.* 2004; Altieri *et al.* 1987). In Latin, species mixtures were named '*farrago*' (LS). This apparent blending of terms used for spelt and emmer has led some wheat authorities to conclude that during Classical times:

> "Spelt was sometimes regarded as a variety of emmer, since they are both hulled wheats" (Sallares 1991, 349).

The implication seems to be that, during Classical times, there was either confusion or lack of capacity or motivation to discriminate between at least some glume wheat types.

8.2.3.3.4.2 An identical schema in Greek?

Because the free threshing distinction is so fundamental to traditional and Latin cereal terminology, one would expect a similar dichotomy to exist in Classical Greek (i.e. cultural or epistemological consensus). The fundamental criteria used to communicate crop variation are frequently observed to be cross cultural (Boster 1984; Berlin *et al.* 1973). Greek authors clearly possessed the capacity to see these types of diagnostic differences in describing variations within crop populations. Theophrastus, who was extremely diligent and precise in his botanical descriptions, offers a possible example:

> "Again the seed of wheat [*puros*] has several coats" (Theophrastus *HP* VIII. IV. 1).

Nevertheless, the distinction, if present at all, is not as obvious in Classical Greek as it is in Latin. It is suspected, however, in Bronze Age Greek. Halstead (1990), having identified the paucity of Linear B cereal ideograms with respect to the significantly wider range of cereal taxa known to exist at Mycenaean sites, suggested that some ideograms may, indeed, communicate such collectivizations. Specifically, with respect to the schema under discussion, Halstead (1990) hypothesized that:

"In terms of production and consumption qualities rather than Linnaean taxonomy, it might be more appropriate to group emmer and einkorn with (hulled) barley than with [free threshing] (bread/macaroni) wheat" (Halstead 1990, 233).

8.2.4 Free threshing and glume wheat types

8.2.4.1 *Fars*: Latin glume wheats

As stated above, Classical authors report the existence of a number of types of *'far'*: Columella, for example, states:

"Of *adorei* [= *far* (Pliny *NH* VIII.XIX.81-83; *cf.* Watkins 1973)] we commonly see four varieties in use: the *far* which is called *clusian* of a white and shiny appearance; that called *vennuculum*, one kind reddish the other white, but both of greater weight than the *clusian*; the three month *far* called *halicastrum* which is both excellent in weight and in goodness" (Columella *RR* II.VI.3).

From this passage, we may infer amongst the criteria used to distinguish types of *'far'* that (1) appearance; (2) weight/density of the grain; and (3) the length of maturation period were important factors. This is not to say that other criteria were not also called into play.

Nine glume wheat epithets are communicated in the Latin passages (the description of '*centigranium*' appears fanciful and '*olyura*' is most often recorded as Greek). It is possible to discern only five unique glume wheat types amongst these because four of the epithets are obvious duplications. The nine types of glume wheats are as follows.

1. '*Spelta*' was a type of glume wheat. Jerome (AD 325-420) reports that it originated in Pannonia (see above). The same author claimed that *spelta* produced a superior quality of flour. He also reports that *spelta* was relatively high yielding in terms of flour extraction rate. The epithets; *spelta*, *brace*, *scandula* and *spica*, appear to be associated with this epithet in terms of meaning but perhaps they are the names of a singular variety of wheat expressed in separate languages.

2. '*Ador*', for which we are provided with a few morphological details. Pliny claimed this to be an old word for '*far*' (Pliny *NH* XVIII.XIX.81-83). The epithet is often invoked within religious contexts (Watkins 1973). Hence, it is possible that the epithet may have been employed as a means to associate glume wheats with ancient traditions (see also Pliny *NH* XVIII.III.14). Purcell (2003) links the epithet etymologically to a reward provided to successful generals (Horace, *Odes* IV.IV.41; Pliny *NH* XVIII.8)

3. '*Alica*' was usually employed in the dual context as either a cereal product or a type of wheat. The same wheat variety may have additionally been recognised under the epithet '*halicastrum*' (possibly from *alicastrum* – see: OLD entry).

4. '*Brace*' was a type of wheat used for the manufacture of beer in the Gallic provinces (Pliny *NH* XVIII.XI.62). It is mentioned on only one occasion (Pliny *NH* XVIII.XI.62.).

5. '*Clusium*' was an infrequently mentioned type of wheat whose epithet recalls the Etruscan site of Chuisi. Its grain was characterised by Columella as white and shiny (Columella *RR* II.VI.3).

6. '*Vennuculum*' was a glume wheat type, one form of which was red and the other white. It was favoured with respect to its superior weight (Columella *RR* II.VI.3).

7. The epithet '*scandula*' is rare in Classical literature. Remarks in both Jerome (*PL*- see previous passage), and the Price Edict of Diocletian (AD 301), equate this epithet to '*spelta*'. It may be cognate with the previously mentioned Asturian Spanish term '*escanda*'. It is also tempting to posit a further association with the homophone 'Scandinavian'. According to McFadden and Sears (1946, 110, from O. Stapf), the Spanish epithet is one which was applied in Sweden for several centuries during the first centuries AD, in reference to the 'Escandians', the blond

race of people to Sweden's north. Andrews (1964, 19) argues that the epithet is a Latin equivalent for shingle or splint that was applied to the Gallic wheat, '*brace*'.

8. '*Spica*' is used in only one case (again, *PL*, previously quoted passage by Jerome). Nevertheless, the epithet suggests that this wheat was 'spike-like' in character (a particularly prominent ear character in certain forms of *T. spelta*).

9. '*Halicastrum*' was a glume wheat with a three month maturity requirement. Thus, it is likely to have been a spring sown form (Columella *RR* II.VI.3).

8.2.4.2 Greek glume wheats

Although we lack a category noun in Classical Greek which conveys the concept of 'glume wheat', Greek authors report at least three distinct wheat types with the tightly invested glume character trait:

1. '*Olura*'/ '*Olyra*' was used by Pliny to describe a single-grained type of glume wheat. Crawford (1979) reports that the epithet represents Egyptian emmer. Lexicographers suggest that that the epithet corresponds in meaning to the epithet '*zeia*' but, a suite of Classical authors also describe '*zeia*' as having two grains. Etymologists suggest that '*zeia*' may be a foreign epithet borrowed into the Greek language (DE). Pliny, in turn, leads us to believe that '*zeia*' was the name of an Egyptian wheat.

2. '*Puros*' (in some dialects '*spuros*' (DE) was a very common Greek epithet. It is used in a number of senses (LS). In some cases, '*puros*' is used to designate a type of wheat. On the other hand, it is also used by Classical authors to designate 'wheat' in the broadest sense of that term (LS).

3. *'Thrakios'* is a place-based substantive used for a specific type of glume wheat from Thrace:

"Thracian wheat is clothed with a great many husks, which is necessary for that region because of excessive frosts" (Pliny *NH* XVIII.XII.69).

8.2.4.3 *Triticums*: Latin free threshing wheats

Latin sources attest to four free threshing wheat types:

"There are several kinds of *triticum* that have been produced by various races" (Pliny *NH* XVIII.XII.63).

"We know of several varieties of *triticum;* but of this number that called *robus* or ruddy is most suitable for sowing because it is superior in both weight and brightness. Second place must be given to *siligo* which is of excellent appearance in bread. The third shall be the *trimesteri,* the use of which is most gratifying to farmers; for when, because of rains or some other reason, an early sowing has not been made, recourse is had to this. This again is a variety of *siligo*" (Columella *RR* II.VI.1).

Jasney (1942, 1944) was convinced that Classical producers had properly distinguished two free threshing wheat taxa: (1) durum wheat [(*Triticum turgidum* L. ssp. *durum* (Desf.) Husn.]; and (2) rivet wheat (*Triticum turgidum* L. ssp. *turgidum*). He also observed that, in the process of distinguishing between these two taxa, Latin authors used the epithet *'triticum'* in two different senses. Specifically, he argued that authors simultaneously used the epithet '*triticum*' either to stipulate free threshing wheat or, more precisely, to stipulate a particular variety of naked wheat (i.e. durum wheat). Moreover, adding to an already confusing situation, it appears that (within vernacular contexts) the epithet *'triticum'* was also used to mean 'wheat' in the broadest sense of the word (i.e. the genus, *Triticum,* including both free threshing and glume wheat - see OLD *triticum*). Thus, the epithet '*triticum*' had three meanings. Firstly, in the most demanding type of descriptive environment (e.g. where a farmer or miller needed to be sure that he was planting or milling a specific type of wheat), the epithet was used to designate a peculiar wheat cultivar (durum wheat). In an instance where a less precise distinction was required (e.g. during threshing operations), the epithet was used to draw a distinction between two more general categories (glume wheat and/or free threshing types). Lastly, in instances where a large degree of imprecision could be tolerated (e.g. in a case where a farmer might be comparing barley against wheat in a conversation), '*triticum*' could simply mean 'wheat'. Thus, the Latin passages attest to a system of word usage where epithet selection is dependent upon the necessity for discrimination. The further removed the speaker or observer was from a necessity to discriminate, the less specific their cereal vocabulary needed to be (for modern examples of this type of usage see Szabó and Hammer 1996; Pena-Chocarro 1999, 36; *cf.* Jones and Halstead 1995; Van der Veen 1995).

Regardless of how '*triticum*' is translated on a phylogenetic basis (i.e. as durum wheat or bread wheat or free threshing wheat, or just wheat), we may be certain that Latin authors were aware of at least four distinct types of free threshing wheat which they regarded as types of '*triticum*', as follows.

1. '*Robus*' is the first type of free threshing wheat identified in the previous passage (Pliny *NH* XVIII.XII.63). '*Robus*' means 'rust coloured' so we can be almost certain that this epithet means (a) type(s) of red free threshing wheat.

2. '*Siligo*' is described as a very white winter sown free threshing wheat with superior grain quality (LS). Pliny (*NH* XVIII.XXVII.105) reports that the 'finest' breads and pastry were produced from it. The epithet has received considerable attention as a potential analogue of bread wheat (= *Triticum aestivum* (L) ssp *aestivum*, see discussion in Sallares 1991). The epithet may also double for the name of a type of flour (OLD; LS, under entry: *siligo*).

3. '*Trimesteri*' refers to (a) free threshing wheat type(s) with a three month (days-to-maturity) requirement. Farmers definitely possessed a number of other three month forms of wheat (Theophrastus. *HP* VIII. IV. 5) but passages mentioning others are not clear with respect to their epithets (e.g. Dioscorides Pedanius *MM* II.107). Columella reports that '*trimestre*' is a three month variety of '*siligo*' (*RR*. II.VI.1).

4. '*Triticum*' is an epithet that could be employed to name a distinctive type of free threshing wheat. Pliny informs us that its grain texture was relatively hard in comparison to '*siligo*' (*NH* XVIII.XX 90). It was also employed in the manufacture of glue and copper.

8.2.4.4 Greek free threshing wheats

As previously mentioned, there are no specific references to the free threshing character in Greek nor is there an obvious category noun for 'free threshing wheats'. There are a number of possible reasons for this, as follows.

1. Free threshing wheat did not exist in Classical Greece (this is almost inconceivable in light of the archaeobotanical record which clearly attests to their production).

2. Our texts are imperfect. Hence, we lack the appropriate epithet.

3. (An) epithet(s) communicating such a distinction existed at one time but its meaning was altered through time.

4. The character trait is implied through a linked context (e.g. all wheat from Alexandria was generally understood to be of a free-threshing type).

5. Free threshing wheat was the only type (or possibly the predominant type) known to ancient Greeks. Watson (1983), for instance, cites the example of modern Arab farmers who, because they exclusively grow free threshing wheats, have no need for such a categorical distinction.

8.2.5 Chronology

Classical authors supply us with little information about how grain use and preferences changed through time and when they do it is often in the context of myth or misinterpretation. On the whole however, textual evidence seems to suggest that glume wheats were adopted before free threshing types. Pliny provides the most relevant and famous passage:

> "It [*far*] was the first food of the Latium of old times, a strong proof of this being found in the offerings of *adoria,* as we have said" (Pliny *NH* XVIII.XIX.83).

There is much to be said for Pliny's comment. '*Far*' is indeed consistently employed as an epithet in the Latin texts in religious and traditional contexts. On the other hand, the use of the epithet '*triticum*' is both later, more generic in terms of specificity and less associated with religious ceremonies marriage rites or seasonal festivals. '*Triticum*' is most frequently used in economic contexts or in discussions about the basic properties of wheat. Philologists argue that the repeated use of a term in religious or folk context reflects a long association and preoccupation with the traditional concepts underlying the term (Kuvandzhiev 1999). Furthermore, foods which take on religious affiliations can be argued to have gained religious regard through social precedent.

8.2.6 Summary

We can conclude that cereal epithet meaning varied with regard to context and the necessity for precision. Ultimately, epithet meaning was enforced by the speaker or author and his relationship with the object he attempted to distinguish as well as the depth or validity of the concepts from which divisions between different cereals were formed. Meaning was thus enforced by context or degree of distinction required.

Place-based epithets were especially prominent in both Classical languages. These emphasized the variations perceived between domestic and foreign cereal characters. Epithets based on visual differences (e.g. differences in colour) were almost equally abundant. They identify the most obvious phenotypic differences that were perceived. Epithets based upon conspicuous physiological distinctions (e.g. differences in the length of maturation period) also formed a significant portion of the Classical classification repertoire. This class of epithets identifies the chronological range of the cereal production process.

Most of the authors' descriptions of different wheats, however, are too brief or too incidental to use with complete confidence. Nevertheless, if we assume that the ultimate goal is to draw a direct analogy between wheats cited by Classical authors and wheats in our samples, *'triticum'* and *'far'* appear to be useful epithets in terms of the study question. The resulting contrast between free threshing and glume wheats in archaeobotanical samples allows us to construct a reasonable analogy between a specific cereal character and a particular wheat species. Moreover, it allows analogy on the basis of equivalent perception.

8.3 Variables affecting production and use

8.3.1 Characteristics relating to cultivation

8.3.1.1 Ease of threshing, glume tightness and kernel investment

One of the most obvious features in Classical cereal texts is that their authors rarely discuss or allude to free threshing cereals in light of some of their more obvious economic attributes (e.g. ease of processing and storage efficiency). Pliny, nevertheless, recognised that *'far'* was comparatively more difficult to thresh:

> "*Far* being difficult to thresh is best stored with its chaff [Latin = *palea*], and only has the straw and beard removed" (Pliny *NH* XVIII.LXXII.298).

In another case Columella alludes to the comparative ease of processing of naked cereal types (but note in this particular instance he uses barley rather than wheat (he is, therefore, referring to the ease of removing the palea and lemma rather than glumes):

> "And when this [barley] has ripened somewhat it should be harvested with more haste than any other grains, for, having brittle straw and grain that has no covering [Latin=*nulla vestitum palea*] it shatters quickly; and for that same reason it is more easily threshed than other grains" (Columella *RR* II.IX.15).

In this case it may be a result of a perception that cereals which lacked tightly held covering organs (glumes, or lemma and palea) were at a comparative advantage. However, covering organs seem to have been perceived in a positive light and hulls or glumes to convey certain advantages. For instance, Columella argued that glumes provided protection against excessive moisture:

> "However, in land of this sort [land where wheat is sowed out of season] it is more suitable to sow *ador* than *triticum* as it has a husk [Latin = *folliculllum* = glume but, here, probably translated incorrectly by the translator as husk] enclosing it which is tough and resistant to moisture for a longer period" (Columella *RR* II.VIII.5).

Covering organs were also recognized to improve storage potential of grain:

> "There are several causes that make grain keep: they are found in either the husk [Latin = *corium* = hide, skin, or leather strap] of the grain when that forms several coats" (Pliny *NH* XVIII.LXXIII.304).

The glumes, palea and lemma were believed to convey insect and disease resistance when the plant was in the field:

"Rust is no less common to the rest but attacks cereals more. Further, it attacks barley more than wheat for several reasons: barley is more naked whereas wheat has several coats" (Theophrastus *CP* IV.14.1).

"The following do not get worm-eaten: lupine, millet, darnel, sesame, chickpea (and all pungent seeds in general). Now *aegilops* has many coats, darnel none; darnel therefore has some other power of resistance" (Theophrasthus *CP* IV.16.2).

Glumes (in this case the author has translated them into English as 'coats') were believed to enhance the efficiency of nutrient uptake in certain cereals. For instance, Theophrastus believed that:

"Wheat does better in rainy regions and is in short most resistant to rains. It also bears better than barley on land that is not manured....In a word it [wheat/ *puros*] is stronger than barley and is sown in cool regions more than barley. The strength of wheat lies in its heat and having coats; and this is why ground worked after lying fallow for some time is a better producer of wheat than barley, since wheat masters the food, which is here stronger...." (Theophrastus *CP* III.21.4).

8.3.1.2 Relative performance

8.3.1.2.1 Barley

Barley held a privileged place in Classical cereal production. It was perceived as the oldest of human foods (Pliny, *NH.* XVIII. XIV.72) and was almost universally regarded as more productive than wheat. Because it was perceived to have both low input requirements and early maturity, barley fitted in especially well with mixed farming systems which involved livestock. Moreover, it found a place in a large variety of arable schemes by virtue of its comparatively undemanding soil and water requirements. Barley was also a principle ingredient in risk avoidance strategies as well as a low cost staple used in meeting basic nutrient demands. As such, barley was perceived as a natural element in the production cycle as a plethora of traditional adages attest (see also Columella. *RR* II. IX.16 and Palmer 1992). For example:

> "Barley is the least liable to damage of all corn, because it is harvested before the wheat is attacked by mildew (and so wise farmers only sow wheat for the larder, whereas barley is sown by the sack, as the saying is), and consequently it brings a return very quickly: and the most prolific kind is the barley harvested at Carthage in Spain in the month of April" (Pliny *NH* VII.XVIII.79).

Nevertheless, barley was thought to be subject to specific types of risks which impaired its productivity in certain environments. Pliny, for example, reported that barley was particularly damaged by late rains:

> "Corn crops when beginning to ripen are damaged by rain, and particularly barley" (Pliny *NH* XVIII.XLIV.153).

In addition, other crops were perceived to match barley in terms of specific types of productivity. Columella has provided a valuable productivity comparison between barley and wheat based solely upon labor inputs:

> "And now to reckon up the number of days' labour required to bring to the threshing floor what we have committed to the earth, four or five modii of *triticum* take up four days' work of the ploughman, one of the harrower, two of the hoer for the first hoeing and one for the second, one for the weeder, and one and a half of the reaper-a total of ten and one-half days of labour. Five modii of *siligo* require the same number of days. Nine or ten modii of *ador* call for as many days' work as five modii of triticum. Five modii of barley require three days work of the ploughman, one day of harrowing, and one and a half of hoeing, and one of reaping-six and a half days in all" (Columella *RR* II. XII.1).

Hence, we can see that, in Columella's eyes, barley was approximately equal to *ador* (*far*) in terms of a labor-based measure of productivity (note that the productivity of *triticum*, on the other hand, is viewed as comparatively low).

8.3.1.2.2 Wheat: 'far' and 'triticum'

Wheat was almost always recognized as a premium crop during antiquity and, as previously mentioned, its comparative productivity was discussed in terms of the free threshing habit. A handful of Classical passages have survived which draw distinctions between the two main groups ('*triticum*' and '*far*') on the basis of their production characteristics alone. A number of passages appear to suggest that: (1) free threshing wheat types were, in many circumstances, treated preferentially and granted the best soils; (2) both forms of wheat were sown in separate fields and with distinctive agronomic goals and production requirements in mind; (3) '*far*' was typically regarded as a particularly resilient form of wheat; (4) '*triticum*' was perceived as comparatively risk prone and more demanding; and (5) certain forms or types of '*triticum*' (i.e. free threshing wheat) were preferred in certain circumstances on account of their unique qualities:

> "Under this method consequently thin soil will be assigned to barley, as its root demands less nourishment, while more easily worked and denser earth will be allotted to *triticum*. In a rather damp place *far* will be sown in preference to *triticum*, but in soil of rather medium quality this and also barley" (Pliny *NH* XVIII.XLVI.165).

> "No grain is greedier than *triticum* or draws more nourishment from the soil" (Pliny *NH* XVIII.XX.85).

> "*Far* is the most hardy of every kind and the one that resists winter the best. It stands the coldest localities and those that are under-cultivated or extremely hot and dry" (Pliny *NH* XVIII.XIX.83).

> "*Triticum* never ripens evenly, and no corn crop is less able to stand delay as, owing to its delicacy of structure, the ears that have ripened shed their grain at once...." (Pliny *NH* XVIII.XX.91).

"*Siligo* (a type of *triticum*) I may properly designate the choicest [wheat] variety...." (Pliny *NH* XVIII.XX.85).

Nevertheless, Classical authors recommend the co-production of both wheat types, again as part of an overall agricultural strategy that apparently sought both to draw from peculiar strengths in each crop and simultaneously to minimize specific types of risk inherent in their production:

"Both *triticum* and *far* should be kept by farmers for this reason, that seldom is land so situated that we can content ourselves with one kind of seed, as some strip which is either swampy or dry cuts through it. *Triticum* grows better on the dry spot while *far* is less harmed by the wet" (Columella *RR* II.VI.4).

"In November, sow wheat of two sorts in the accustomed manner" (Palladius. *OH* 12.1).

It appears that *'far's* role paralleled that of barley's in relation to wheat. Namely, '*far*' was viewed as a complementary crop alongside '*triticum*' on farms where both types of wheat could be produced. Furthermore, '*far*' was ultimately incorporated on those farms on the basis of its relative reliability and low production requirements.

In terms of comparative storage potential it is difficult to determine which type may have been preferred. Varro (*RRV* I. LVII.1; *cf.* Pliny *NH* XVIII.LXXIII. 305) reports that there was a wide array of storage methods actively in use throughout Europe during the time he was writing (*cf.* Buxó and Pons 2000; Gransar 2000; Rickman 1980; 1971; Moritz 1958):

- storage in jars;
- storage in pits;
- storage in caves;
- storage in purpose built, stone, above ground, storage structures;
- storage where grain heaps were enclosed or mixed with a substance which contributed to preservation (powders, earthen materials or chemical substances);

- storage in wooden above ground structures situated in grain fields;
- storage in the ear;
- storage out of the ear;
- storage in the glume;
- storage in the naked condition.

Pliny (*NH* VIII.LXXIII.305) reports that grain stored in a dry, anaerobic condition, in underground pits and *in the ear,* kept the longest and was most secure from damage by pests. He, however, made no actual distinction in terms of the comparative storage potential of '*far*' or '*triticum*'.

8.3.1.2.3 Oat

Oat receives very little attention from Classical authors. Thus, we have little in the way of direct evidence from which to make performance comparisons between it and other cereal crops. It is entirely possible that oat cultivation was not widespread in the Mediterranean at the time our authors were writing. The 1st century AD author, Pliny, was aware of oat cultivation in Germany but regarded oat as a pernicious weed which was perhaps widely mixed amongst Mediterranean crops:

> "The first of all forms of disease in wheat is *avena*. Barley also degenerates into oats, in such a way that the oat itself counts as a kind of corn, inasmuch as the races of Germany grow crops of it and live entirely on oatmeal porridge. The degeneration in question is principally due to the dampness of the soil and the climate, but the subsidiary cause is contained in weakness of the seed, if it is held back too long in the ground before it shoots out. There is also some explanation if it was rotten when it was sown" (Pliny *NH* XVIII.XLIV.149).

Columella who, unlike Pliny was far more familiar with farming practices in Spain, on the other hand, reported that oat was valued for its foliage and grain:

"The same method is applied to *avena*: they are sown in the autumn; some are cut for hay or fodder while still green; and some are set apart for grain" (Columella *RR* II.X.31).

8.3.1.2.4 Rye

Rye is comparatively under-represented in Classical literature. Agricultural writers acknowledge the existence of intentionally planted rye crops (which they recognized under the names '*secale*' or '*asia*') by at least by no later than the 1st century AD. However, they provide few details about its comparative performance. Pliny, however, reported that rye could be an extremely versatile and productive crop:

"The name for *secale* [rye] in the Subalpine district of Turin is "*asia*"; it is a very poor food and only serves to avert starvation: its stalk carries a large head but it is a thin straw of a dark sombre colour, and exceptionally heavy. Wheat is mixed in with this to mitigate its bitter taste, and all the same it is unacceptable even so. It grows on any sort of soil with a hundred-fold yield, and serves of itself to enrich the land" (Pliny *NH* XVIII.XL.141).

8.3.1.3 Sowing date and days-to-maturity

Classical agronomists emphasize the relationship between phenological properties (life cycle characteristics) of crops and their suitability to particular environments and management regimes. Barley was, for instance, recognized as the earliest and shortest season crop and, consequently, where the length of the growing season was characterized by particularly favorable early season conditions and particularly unfavorable late season conditions, barley was often the recommended cereal crop. Where climatic conditions were more favorable, however, productivity seems to have become the principal parameter, and in this respect, important differences between autumn and spring sown types were appreciated.

Classical authors not only imply that there were a substantial number of types or classes of wheat and barley from which to choose but they also seem to imply that producers, in many cases, could chose between spring or winter sown forms of the cultivar:

"Again if one takes such differences [in wheat], they are quite characteristic-thus some are early, some late...." (Theophrastus *HP* VIII.IV.3).

"But there is also a kind [wheat] which takes two months; this was brought to Achaia from Sicily; it is neither prolific nor fertile, though as a food it is light and sweet. There is another such kind that grows in Euboea and especially in the region of Karystos" (Theophrastus *HP* VIII.IV.4).

"Those that are sown late are certain special varieties, of these, kinds very. A certain kind of wheat, and of barley, is called 'three months' because it takes that much time to mature...." (Theophrastus *HP* VIII.I.4).

"Of the varieties of wheat the three-months kind is finer in country with lean soil, for that food is just right for light wheat" (Theophrastus *CP.* III.21.2).

"There is actually a two-month variety in the neighborhood of Aenus in Thrace, which begins to ripen six weeks after it is sown; and it is surprising that no corn weighs heavier, and that it produces no bran. It is also used in Sicily and Achaia, in both cases in mountain districts and in Euboea in the neighborhood of Carystus" (Pliny *NH* XVIII.XII.70).

Although rapidly maturing (three month or spring sown) cultivars were part of the Classical cereal repertoire, they do not appear to have been employed as standard practice. Furthermore, the majority of passages indicate that spring forms were most commonly judged as inferior:

"Spring wheat should be planted in ground in which you cannot ripen the regular variety" (Cato *Agr.* XXXV.1).

In general, spring forms appear to have been used where a winter or autumn sowing was either not possible or where double cropping was a regular practice:

> "There are several kinds that take three months, and these, wherever they are found, are light and not prolific; their growth consists of a single 'reed' and in general they are not robust" (Theophrastus *HP* VIII.IV.5).

> "In Greece and Asia however all grains are sown after the setting of the Pleiads, while in Italy some are sown at both dates, and some have a third sowing in the spring" (Pliny *NH* XVIII.X.50).

The reasoning behind planting date decisions could be based upon labor requirements:

> "....not necessarily February 8, but whether before that date, when spring is early, or afterwards, when winter goes on after that day, countrymen should find themselves torn between innumerable anxieties and should finish off all primary tasks which cannot be postponed. Three month wheat must be sown...." (Pliny *NH* XVIII.LXV.239).

In other cases planting date decisions were based upon specific considerations of the crop's productive capacity or particular properties which might be gained or exaggerated by sowing at a particular date. Pliny, for instance, informs us that the best type of '*siligo*' was made from spring sown varieties:

> "....and starch is made from every kind of *triticum* and *siligo,* but the best is made from three-month varieties" (Pliny *NH* XVIII.XVII.76).

8.3.2 Characteristics relating to grain and flour use

8.3.2.1 Grain

8.3.2.1.1 Weight

Grain weight was a matter of considerable interest in the ancient world and the concept of 'test weight' was clearly in place. Some Classical agronomists appear to have been under the impression that grain weight was largely determined by local environmental conditions. Theophrastus, for instance, believed:

> "The produce of the sunny and well-ventilated countries with thin soil is the lightest, whereas that of cold and rainy countries is heavier because the grain there has more plentiful and powerful food. This is why Sicilian wheat is said to be the strongest of all wheat brought to Athens by sea, whereas the Boeotian is held to be of still a heavier character (as we said in the *History*), for the land is fat and the climate cold, and the other produce is similarly heavy; and at Pissange is found the wheat we mentioned that causes 'bursting', which is evidently heavy to excess. On the other hand the Pontic is the lightest and hardest of the wheat, although the climate there is cold, because both seed and the soil are lighter and the snow helps to bring about better concoction...." (Theophrastus *CP* IV.9.4).

> "At the present the lightest in weight among the kinds of wheat imported to Rome is the wheat of Gaul, and Chersonese, as they do not exceed twenty pounds a peck if one weighs the grain by itself. Sardinian grain adds half a pound to this figure and Alexandrian a third of a pound or more-this is also the weight of Sicilian wheat-while that of Southern Spain scores a whole pound more and that of Africa a pound and three quarters" (Pliny *NH* XVIII.XII.66).

> "In Italy north of the Po, a peck of *far* to my knowledge weighs 25 pounds while in Chusi it weighs an even 26 pounds" (Pliny NH XVIII.XII.67).

"But heavier still than this is the Boeotian [wheat]; in proof of which it is said that the athletes in Boeotia consume scarcely three pints, while, when they come to Athens they easily manage five" (Theophrastus *HP* VIII.IV.5).

There is some evidence to indicate that heavier grains (grains with higher test weights) were perceived as more desirable. Hesiod, one of our earliest authors stated:

> "Make Demeter's holy grain sound and heavy" (Hesiod *Ops et Dies* 466).

Columella seems to have welcomed high test weight as an indication of high quality.

> "There is also a second variety of barley which some call *distichum* and others Galatian, of extraordinary weight, so much so that when mixed with wheat it makes excellent food for the household" (Columella *RR* II.IX.16).

This preference for high test weight appears based on number of grounds. Pliny, for instance, clearly felt that elevated kernel weights of '*siligo*' (a '*triticum*' as opposed to a '*far*') provided '*siligo*' with a comparatively greater flour yield (*NH* XVIII.XX.85). There is, nevertheless, evidence of an overall preference for 'heavy' cereals that is based upon a belief that heavier grains conveyed superior nutritional characteristics and that they were able to satiate the appetite more effectively than lighter grains.

8.3.2.1.2 Weight vs. volume

Throughout the Classical and Roman periods, kernel dimension and weight featured jointly in the evaluation of grain. Although grain was measured directly in units of volume, the customary unit of volumetric measurement was ultimately a function of grain weight. For example, the Roman grain measurement unit, the *modius* (1/6 of the Greek *medimnus* or 8 Greek *choenikes*), was equal to the volume of 1 Roman pound (= 6.7kg) of wheat grain. Theoretically, volumetrically-based measurement methods should result in an overall preference for cereal types with larger grains. Galen, indeed, records a method by which the dimensions of grain could be deceitfully altered to achieve greater returns:

> "When our peasants are bringing in corn from the country into the city in wagons, and wish to filch some away without being detected, they fill earthen jars with water and stand them among the corn; the corn then draws the moisture into itself through the jar and acquires additional bulk and weight" (Galen *NF* I.XIV.56).

We possess numerous representations of the device used to measure grain in this way (the *modius*). Most survive from examples illustrated on coinage or in stone reliefs. All seem to suggest that a *modius* was a metal urn-shaped vessel (but note, examples have been discovered which indicate that it could also be a truncated wooden pail - Ciarallo and de Carolis 1999). Presumably, the volume of the *modius* was fixed for all types of grain. Classical authors make no mention of whether the *modius* was adjusted or recalibrated from crop to crop or year to year to reflect annual variations in the weight or size of individual grains. Nor are we informed of price adjustments offered for subtle differences in grain moisture content or environmentally determined differences in grain weights (i.e. we are not provided with direct evidence that there was a connection between grain price and crop test weight).

8.3.2.2 Flour

Although wheat was probably the most esteemed grain in bread flours, it was not necessarily its only ingredient. Barley seems always to have retained a significant a role but for what purpose is not always clear. Xenophon in the 5th century BC (*Memorabilia* II.VII.6) reports that the production of either flour was managed under separate industries in his time. Cato reports in the 2nd century (*Agr.* 168) that pearled barley (barley de-hulled and with the ends of the kernel removed (= Latin, *'polenta'* or Greek, '*(p)tisana*') could be a common ingredient in bread flour (Cato *Agr.* 168). A preference for bread made from barley flour, nevertheless, was perceived as anachronistic by later authors such as Pliny, who commonly relegated barley to the role of livestock feed writes:

"Barley bread was much used in earlier days, but has been condemned by experience, and barley is mostly fed to animals...." (Pliny *NH* XVIII.XV.75).

"But when barley bread used to be made, the actual barley was leavened with flour of bitter vetch or chickeling; ...." (Pliny *NH* XVIII.XXVI.103).

Rye flours are rarely mentioned in a Mediterranean context until after the 2nd century AD. Nevertheless, rye shows up on a listing of standard Roman grains in Diocletian's Price Edict in AD 301. Classical authors have failed to provide even a single report of oat in the context of flour.

8.3.2.2.1 Strength and bolt

Strength and degree of processing or sifting ('bolt') appear to have figured prominently in determining: (1) the possible range of uses for any particular flour; and (2) the comparative value of flour. Columella informs us, for instance, that premium flours were made from flours of a relatively soft form of *triticum* - *siligo*:

"Common wheat flour [*siligo*] makes bread of the highest quality and the most famous pastry" (Pliny *NH* XVIII.XX.86).

Columella goes on to explain, in the same passage that, when '*siligo*' was bolted, its value increased twice again in relation to an equal amount of unbolted flour. Comparatively harder flours offered offsetting properties in spite of the qualitative premium granted to softer types such as '*siligo*'. Ultimately, hard wheat types produced more loaves upon baking than '*siligo*' (Pliny *NH* XVIII.XX.89). Evidently, several grades of 'hard wheat' were available on the market. Pliny, for example, indicates a preference for hard wheat flours derived from Africa:

"*Similago* is made from hard wheat [Latin = *triticum*], the most highly esteemed coming from Africa. A fair return is half a peck from a peck with five sixteenths of a special flour [Latin for 'special flour'= *pollen*]" (Pliny *NH* XVIII.XX.89).

8.3.2.2.2 Flour colour

Classical authors display a preoccupation with flour colour. Overall, the authors seem to display a preference for white. Columella, for example, provides the example of a Galatian wheat that was valued explicitly for its whiteness (Columella *RR* II.IX.16). The exact reasons for the preference remain obscure but possible factors include the following.

1. Prestige – A preference for white breads was linked to individuals of elevated social status (Juvenal *Satires* V.74; see also King 1986; Goody 1982).

2. Price – There appears to have been a positive relationship between degree of flour separation, flour price and colour. The more a flour was sifted (the greater the time and energy expended), the more impurities that were removed (the greater the waste component), the whiter the flour became. Consequently, highly sifted flours were more expensive.

3. Digestibility – The presence of indigestible bran in a flour is primarily signaled by colour.

Amongst wheats, Classical authors generally report two grain colour categories: ruddy (red) and white:

"The top place in Italy is taken by a mixture of Campanian *siligo* with that grown at Pisa, the former being reddish but the chalk-like Pisa variety whiter and heavier" (Pliny *NH* XVIII.XX.86).

Amongst barleys, three colours are mentioned:

> "The grain [of barley] itself, too, presents certain differences, being long and thin, or else short or round, white, black, or, in some instances, of a purple colour. This last kind is employed for making *polenta*: the white is ill adapted for standing the severity of the weather." (Pliny *NH* XVIII.XVIII.78).

In some cases, superior grain colour appears to be associated with certain wheat growing districts:

> "For my own part I should not rank any of them with Italian wheat for whiteness and for weight, for which it is particularly distinguished" (Pliny *NH* XVIII.XII.63).

> "....Sophocles in his play Triptolemus praised Italian corn before all kinds in the phrase of which the literal translation is: 'And that happy Italy grows white with bright white wheat' and also today the Italian wheat is especially distinguished for whiteness, which makes it more surprising to me that the later Greeks had made no mention of this corn in his play" (Pliny *NH* XVIII.XII.65).

Despite a preference for white flours, however, some authors report that white cereal varieties were comparatively poor in terms of reliability and productivity:

> "Speaking broadly all white varieties [speaking in the context of cereal grain] are weaker and more delicate"....(Theophrastus *CP* III.22.2).

The preference for white flour was not necessarily universal. In some cases, the preference for white had to be weighed against offsetting effects. In the example below, a preference for white is balanced against a preference for lightness:

> "The bread called *artopticeus* differs from that baked in ovens and furnaces. If now, you make it with hard yeast, it will be white and good to eat dry; but if with dissolved yeast, it will be light but not so white" (Athenaeus *DN* III.113).

Additionally, Classical millers were not necessarily bound to the natural colour-character of the grain. They appear to have held the capacity to mitigate flour colour by means of blending or bleaching. In Cyprus, for example, (where Pliny implies that white wheat types were apparently not locally available) white wheat grains were imported from distant countries to be blended into the locally produced dark flours:

> "Cyprus wheat is a dusky colour and makes black bread, and consequently the white Alexandrian is mixed with it" (Pliny *NH* XVIII.XXII.68).

8.3.2.2.3 Extraction rate

The relationship between the percentages of the various flour grades obtained from the grain is expressed as 'extraction rate'. Of interest is the fact that Classical authors clearly recognized variations between the extraction rates of different types of grains. Furthermore, advancements in milling technology meant that extraction rates were subject to change through time. Rising expectations about flour purity, for instance, presumably left millers with the on-going problem of coping with the less desirable fraction, and a genuine decrease in 'bread flour' yield from wheat species.

Moritz (1958) argues that by the Classical period, advances in technology had produced improvements to the milling process which resulted in the capacity to create routinely a variety of flours grades where previously there had only been only one. Milling technology had also become a significant factor in the acquisition of new and peculiar properties from grains which had previously remained latent. Additionally, flour conditioning had reached an unprecedented level of sophistication which may have allowed a number of new flour products to be produced and come on line for consumers.

Although Moritz (1958) concluded that technological innovations in milling are difficult to date precisely, it is clear that advanced milling technologies were readily available in some parts of the study region (e.g. the Mediterranean) by no later than about the1st century AD. Perhaps the most influential development was the capacity to set the width of the gap between the upper and lower milling stones. This development allowed millers to: (1) control flour particle size; and (2) manufacture a consistent product for the first time (Peacock 1987; Runnels and Murray 1983).

Developments in flour mills were naturally accompanied by parallel innovations in flour sieves. However, because sieves are also employed to separate weeds and other impurities from unprocessed grain, improvements in flour sieving technology are also very difficult to date. Moritz (1958) argued that it is almost impossible to determine when the actual practice of flour sieving began on the basis of archaeological remains. The first direct indication of flour sieving is attested from a set 5th century BC Hippocratic writings that draw a clear distinction between sifted and wholemeal flour (Blümner 1979). Plautus (*Poenulus* 513) mentions a *cribum pollinarium* that Moritz (1958, 165) interpreted as a 2nd century BC instrument for sieving milled barley (hence *pollen* = ground *polenta*).

Producing pure white flour is a tedious, labor intensive process that ultimately depended upon the evolution of a professional class of bakers (Rickman 1980; Moritz 1958), an event which Pliny (*NH* XVII.28.107) claimed took place before the first quarter of the 2nd century BC. Both Pliny (*NH* XVIII.72-87) and Cato (*Agr.* 85) concur on the best method to obtain white flour. Specifically, they advocate that the manufacture of white flour was a two-stage process: firstly, slightly moistened grain was ground; and then, the resulting product was sifted repeatedly. Moritz (1958, 168-176) argued that only one grade of flour was regularly produced in Rome before the 1st century AD but that this, nevertheless, yielded three separate ground-products which could be used or marketed in different ways:

1. *furfures* = bran - a product most generally thought fit only for animals or slaves.
2. *secundarium* = seconds - a product used to make second rate bread;
3. *flos* or *pollen* = white flour – a product used to make the finest of breads.

One additional operation for millers of this period was to blend or re-formulate different cereals or cereal components to achieve the desired results. Classical bakers are known to have modified flour leavening capacity, colour, texture, weight and flavor by blending. In certain cases, millers even modified the properties of grains before grinding. '*Alica*', for instance, was a kind of ground semolina made from a '*far*' (Pliny *NH* XVIII.XXIV.12). Only the whitest grains of a specified maturity were employed for its manufacture. During its preparation, grains were par boiled, and then bleached using an expensive sulphurous clay. Having been dried in the sun, the modified grain was then milled to a highly specific grade. Three types of '*alica*' are reported by various authors, the quality of which was judged by final particle size (Karagöz 1996). The resulting semolina, meal, or flour was then prepared as either porridge, stuffing or bread. Judging from the amount of attention paid to the product, it must have been very popular, so much so that Pliny protests about fraudulent imitations (Pliny *NH* XVIII.XXIX.117).

The number of products manufactured from Classical flours appears to be correspondingly immense (Dalby 2000; Dalby and Graineger 2000). The shear variety of votive cakes deposited at the Sanctuary of Demeter and Kore (primarily from the middle of the first century AD) attests to the remarkable range of the Classical baking repertoire (Brumfield 1997; *cf.* Bookidis *et al.* 1999). Athenaeus in the 2nd century AD catalogues over 100 recipes for cakes and breads, dividing them into classes:

> "But Pontianus anticipated him and said: 'Tryphon of Alexandria, in Plant Life, names five different sorts of bread and if I remember rightly as follows: raised bread, unleavened bread, bread made with fine flour, with groats, with unbolted meal (the last he declares is more a laxative than that made of refined flour), bread made from rye, of *far*, and of millet'...." (Athenaeus *DN* III.109).

We are even informed of breads that are derived from flours whose main ingredients were pulses (Athenaeus *DN* III. 111), or doughs made exclusively from cereal bran:

> "....while bread made of bran is called *brattime* or (by Amerias and Timachidas) *eukonos*" (Athenaeus *DN* III.114).

The *Re Coquinari*, a compendium of recipes ascribed to the 5th century AD author, 'Caelius Apicius' deals heavily with popular sauces and flavorings that were intended to accompany an ever evolving range of breads whose peculiar nutrient and culinary features depended as much upon the mode of processing and preparation as which types of cereal ingredients were used:

> "In order of merit, the bread made of refined flour comes first (as per healthiness) after that comes bread of ordinary wheat and then the unbolted, made of flour that has not been sifted. These are accepted as the most nourishing. Again, Philistion of Locris says that bread made of highly refined flour tends to promote bodily vigour more than bread made of the coarse; but he rates the latter second and after that the bread of ordinary wheat flour. Nevertheless, bread of the finest meal has a poorer flavour and less nourishment. All fresh bread is more digestible than bread that has been dried up, besides being more nourishing and more juicy, further it encourages pneumatic action and is easily assimilated. Dry bread on the other hand, is surfeiting and hard to digest, and bread that is very old and dry has less nourishment, acts as an astringent in the bowels and has a poor taste. Bread baked in the oven ashes is heavy and hard to digest because the baking is uneven. That which comes from a small oven or stove causes dyspepsia and is hard to digest. But bread made over a brazier or in a pan, owing to the admixture of oil is easier to excrete, but steam rising from the drying makes it rather unwholesome. Bread baked in large ovens, however, excels in all good qualities, for it is well flavoured, good for *thestomac*, easily digested, and readily assimilated" (Athenaeus *DN* III.115).

The lesson to learn is that we have probably underestimated the breadth of the Classical flour vocabulary and, in doing so, we have probably also underestimated the level of dietary related permutations for particular cereal grains (Purcell 2003, 329-336; Vickery 1980; Balfet 1975; Arnott 1975). Indeed, Classical authors convey an image of a society that was preoccupied with food and the subtleties of its preparation:

"Sophisticated and complex tastes were being called for, treatments which indicate a discerning palate, not a diet of porridge and salt fish" (Wilkins and Hill 1999, 436).

8.3.2.3 Nutritional value

The nutritional preferences held by Classical authors vary considerably, and they are generally expressed in terms of the cereal product rather than in terms of the individual cereal ingredients. Some authors report a bias against flours used for leavened breads, for example:

"....and likewise that people who live on fermented bread have weaker bodies, inasmuch as in the old days outstanding wholesomeness was ascribed to wheat the heavier it was" (Pliny *NH* XVIII.XXVI.104).

Others argue that wheat is more nutritional than barley but, in general, there is little agreement:

"That barley is best which is white and cleane, but it is less nourishing than wheate" (Dioscorides Pedanius *MM* II.108).

8.3.2.4 Groats, gruels and thickening agents

Gruel is a type of cereal-based soup, porridge or paste made by cooking coarsely ground grains or groats in a boiling liquid such as water or milk. Classical authors concluded that gruels were the basis of early Mediterranean diets:

"Barley is the oldest among human foods, as is proved by the Athenian ceremony recorded by Meander, and by the name given to gladiators, who used to be called 'barley-men'. Also the Greeks prefer it to any other grain for porridge" (Pliny *NH* XVIII. XIV.72).

Barley groats (*alphiton*) are indeed mentioned in 9th century BC Greek epics (*Illiad* II. II.631; *Odyssey* II. 355). Valerius reported that:

"early Romans were so much more interested in moderation that they consumed more '*puls*' [cereal gruel] than bread" (Valerius *VM* 2.5.5).

Although cereal products had taken on a number of different forms by the Classical period, whole grained products such as groats probably persisted in the mainstream of Classical diet. The epithet *alphita* (barley groats) is communicated throughout Classical times as a metaphor for 'one's daily bread' (LS). We hear also of *'oulai'* (an archaic Greek epithet for whole kernel barley) sprinkled over the heads of sacrificial victims and employed as a topping over roast meats (Burkert 1985, citing *Ta Hiera Sacra*, Apollonius Sophistes). Indeed, whole grain preparations derived from both wheat and barley seem to have retained a place in the Classical diet as thickening agents and fundamental components of soups and stuffings (e.g. Latin, *tragum* and *amulum* LS). Societies or peoples whose diets centered on whole grained foods, nevertheless, were generally perceived as inferior. By the 2nd century BC, Plautus was able to cast Carthaginians in a disparaging light by metaphorically calling them porridge eaters (*pultiphagonides*):

"This comedy is called the 'Carthaginian', in the Latin, Plautus has called it "the *Puls*-eating Kingsmans" (Plautus *Poenulus, Prologia* 54).

8.3.2.5 Beer

A range of alcoholic drinks is mentioned by Classical authors. 'Mead', a drink made by mixing honey with beer, was one of the commonest. Its precise relationship to beer remains unclear as the term appears to embrace a number of drink variations depending on the amount of honey used, the length of time spent in fermentation, and how the beverage was subsequently mixed. Although Romans and Greeks display a clear preference for wine, beer was manufactured by tribes in the provinces and is likely to have been plentiful in most Mediterranean cities (note that mythologists typically argue that cereal alcohols used for intoxication purposes in Greek cultures derive from northern cults and evolved into the wine of Dionysos in the southern Greek climate - McGovern *et al.* 1996). Diocletian's Price Edict fixes the price of beer- *'cervesia'*, *'camum'* and *'zythum'* at the very low price of one *denarius* per pint. Pliny reports that the Gauls made a beer from a *'far'* they called *'brace'*:

> "The Gallic provinces have also produced a special kind of *far*, the local name for which is *brace*, while with us it is called *scandala*. It has a very glossy grain" (Pliny *NH* XVIII.XI.62).

Classical authors also report that the Gauls used barley to produce beer. Diodorus mentions a specific type of beer made from barley (*cf.* Stika 1996, for a possible Celtic brewery in Germany):

> "The land produces neither wine nor oil, [on account of its temperate climate] and as a consequence those Gauls who are deprived of these fruits make a drink out of barley which they call *zythos* or beer" (Diodorus Siculus *DS* 1.I.34.10).

Tacitus reports a similar practice in Germany, but adds that that the drink could be fermented from an assortment of other grains:

> "A liquor for drinking is made out of barley or other grain [*ex hordeo aut frumento*] and fermented into a certain resemblance to wine" (Tacitus *Germania* XXIII. 1).

Beer is also reported to have supplied leaven for baking. Pliny believed that a unique leaven garnered from the manufacture of Gaulish beer was responsible for the delightful character of the breads from that region:

> "When the corn of Gaul and Spain of the kinds we have stated is steeped to make beer the foam that forms on the surface in the process is used for leaven, as a consequence, those races have a lighter kind of bread than others" (Pliny *NH* XVIII.XII.68-69).

There is a curious omission of the so-called corn dryers (for the production of malt for brewing beer or for the drying of grain) in Classical agronomic texts (*cf.* Van der Veen 1989; Hillman 1982).

8.3.2.6 Grain prices

Despite the vast corpus of research which addresses the topic of Classical grain prices, we really lack sufficient data to make generalized comparisons about grain prices across chronological periods in Europe because of the following.

1. Most of our data concern the price of 'wheat' or 'barley' in the most general sense. We lack a clear understanding of the meanings of the specific epithets employed and thus the actual grains implicated in those prices.

2. Much of our data result from records of prices within controlled markets. These prices seldom reflect local free-market conditions and thus actual demands (Rickman 1980). Note, moreover, that analysts such as Sirks (1991, 21), for instance, have concluded that subsidized grain formed no more than 15% of the grain portion required to feed densely populated cities such as Rome.

3. Most reports are of extraordinary prices brought about by unusual market conditions (e.g. famines, gluts or politically motivated benefactions to the urban grain supply (Pliny *NH* XVIII.IV.15).

4. Most prices apply solely to particular urban nuclei such as Rome.

5. Almost all our direct price comparisons are between very distant geographic regions rather than between adjacent localities. In such comparisons, grain prices are probably largely a function of the distance to market. We know, for instance, that, in the first century AD, the price of a *modius* of Italian wheat varied from a high of 32 *As* in Rome to as little as 16 *As* in the rural countryside. In Africa, at the same time, the price varied between 9 and15 *As* (Adkins 1994).

6. The agronomic authors, on whom we depend for precise information about types of grain, have almost nothing specific to say about the trade or the comparative prices of cereals (Forbes and Foxhall 1995, 77).

7. There is almost no data to suggest to what extent reported prices are reflective value-added processing.

We know that a number of different types of transactions were taking place. Smith (2004, 84) identified five general categories of economic transfer in the Classical textual record: (1) redistribution, within the unit of production; (2) gift, without expectation of return; (3) taxes, obligatory transfers from individual to state; (4) tribute, transfers from state to state; and (5) theft and plunder. None of these types of transaction, however, was necessarily exclusive to a particular date or region. Furthermore, we have little actual data from which to assess a precise history of such transactions throughout or across the various regions of Europe.

There are numerous accounts of grain trading and of individual transactions and it is commonly believed, nevertheless that by 6th- 5th century BC, great fleets of grain merchants plied the Mediterranean in the service of many coastal cities. Xenophon states that:

> "So deep was the love of corn that on receiving reports that it is abundant anywhere, merchants will voyage in quest of it: they will cross the Aegean, the Euxine, the Sicilian sea; and when they got as much as possible, they will carry it over the sea" (Xenophon *OE* XX.27).

The Greek colonization of places like Sicily is often argued to have resulted from efforts to ensure a supply of grain for sister cities back on the mainland. Casson (1954) argued that the size of the Hellenistic grain trading fleet surpassed even that of the England's merchant fleet in the days of the East Indiamen and China Clippers. Strabo (*Geography* IV.5.143) reports that pre-conquest Britain exported large amounts of grain from the 1st century BC. Images placed on coins minted by Cunobelin (c. AD 10) suggest that the marketing of cereals could have been a wide-spread and possibly 'state-sponsored' activity of late Celtic tribes of the southern portions of the island (van Arsdell 1989).

It is clear, and it should be emphasized that wheat was a comparatively expensive and sought after commodity in antiquity. From the 2nd century BC onwards there were increasing pressures throughout much of the ancient world to grow wheat as a cash crop (*cf.* Wightman 1985) but we should not necessarily assume that conditions were uniform. To ensure at least the basic rations for the army, Romans levied a tax known as the *annona militaris*, which in the early Republic and Imperial periods, was probably typically paid in kind, calculated as a percentage of the crop (see: section 5.2.6.5 for the various ways grain taxes could be paid or appropriated). From the time of the Republic, there was also free grain market at Rome and simultaneously a bureaucracy maintained under Senatorial supervision which sought to both guarantee adequate supply and control prices. Tacitus (*Annals* IV; AD 23-28) argues that the bureaucracy was never really effective which suggests that market demand was the overriding variable in the market.

The Price Edict of Diocletian (AD 301) attempted to set a maximum price for all goods and services all over the Empire. The interpretation of the cereal epithets used in the document suffers from the usual problems encountered when translating grain epithets but most inter-generic price relationships are clear. The relative values are listed below in order of increasing price as they appear on most of the versions of the document that have been recovered thus far.

- *Frumentum* (price = 100 denarii/modius). This epithet is variously translated as 'corn', 'wheat' or 'grain' (e.g. *triticum vel alia frumenta* Col. *RR* VIII IX.2; *sunt prima earum frugum genera: frumenta, ut triticum, hordeum, et legumina, ut faba,cicer* (Pliny *NH* XVIII.VII.9). Its position at the head of the list may reflect: (1) an inferior grade of wheat; (2) a wheat/cereal: or (3) wheat at a subsidised price.
- Barley (price = 60 denarii/modius).
- Rye (price = 60 denarius/modius).

- Spelt-(price = 100 denarius/modius). The actual epithet employed is '*spelta mundae*' (i.e. cleaned spelt). Andrews (1964, 20) speculates that this is imported German spelt, shipped with the hulls removed as a routine measure to reduce transportation costs. Note that its cost is curiously listed as equivalent to that of *frumentum*.
- *scandula* or [*sive*] *spelta*. (price = 30 denarii/modius). The meaning is unclear. The listing could represent: (1) uncleaned spelt or (2) a *spelta/scandula* medley; equally (3) it could reflect the fact that the two epithets essentially name/designate the same type of wheat but with different origins. Note the 70% discount relative to other forms of wheat.
- Oat (price = 30 denarii/modius).

8.3.2.7 Chaff and straw

We know from written records that cereal chaff could be regarded as a valuable product and that it could be regarded as an item of commerce (Van der Veen 1999). Records such as *Ostraca* from the site of Mons Claudianus in Egypt (Van der Veen 1998) prove that chaff might even be imported where not locally available. Chaff had a number of uses. It was commonly used as an animal feed. Pliny reports that chaff was used to replace hay in areas where there was a perennial shortage of grass (*NH* XVIII.LXXII.296-297). In such cases, it could be chopped or ground to improve its quality:

> "The majority of countries use chaff for hay; the thinner and finer it is and the nearer to dust, the better, and consequently the best chaff is obtained from millet, the next best from barley, and the worst from wheat, except for beasts that are worked hard" (Pliny *NH* XVIII.LXXII 299).

Classical authors report that chaff was also used as a temper in mudbrick, clay, plaster and mortar. Threshing waste was used as fuel. Bran culled from the milling process was sometimes set aside to be used in distinctive food products or even as component in folk medicines. Straw and dried leaves were utilized as bedding, hay or bound into thatch.

Pliny gives praise to the wheat of Selunite (in Sicily) which, he reports, produced a very fine straw (*NH* XVIII.XII.64). As is the case today, barley straw was recognized as the superior type of cereal straw:

> "Its [barley's] chaff is one of the best, indeed for straw there is none that compares with it" (Pliny *NH* XVIII. XVIII.79).

8.3.2.8 Livestock production

Classical authors report that cereals were incorporated into animal management systems in a number of different ways: (1) as a forage supplement to native pasturage; (2) to produce a supply of hay, straw or silage; and (3) as feed grains. In areas where barley production was regularly undertaken, Classical authors report that barley was almost always employed as the main animal grain on account of its reliability and relative productivity. On the basis of its nutritive value as forage or feed-grain, barley was clearly more popular than wheat (Columella *RR* II.IX.14). Barley was recognized to out-yield wheat in terms of biomass and grain. It required fewer inputs to produce. In areas where soil fertility was a bit better, barley was intermixed with glume wheats and legumes to create a *'farrago'* (a green forage, fodder or hay):

> "*Farrago*, on the other hand, is so called from a crop where a mixture of barley, vetch and legumes has been sowed for a green feed, either because it is cut with iron [iron = *ferrum* ≈ *farrago*] or for the reason that it was first sowed in a *far*" (Varro *RR* VI.XXXI.5).

> "Certain species of wheat [*tritici*] are only sown to make fodder for cattle, and are known by the name of '*farrago*, or mixed grain" (Pliny *NH* XVIII.X.50).

The practice appears to have many variations (for a modern day example see Jadarat *et al.* 2004). Columella reports a *'farrago'* which included oat:

"The above plantings are to be made, in our opinion, for the sake of man, and then come several kinds of cattle fodder such as Medic clover, vetch, mixed fodder of barley and oats" (Columella *RR* II.X.24).

'Cattle-mash' (a crop intended for pasturage after a primary crop of grain had been harvested) is reported to have included a companion planting of vetch. In Africa, a variation of this was produced using barley (Pliny *NH* XVIII.XL.142).

Classical authors also report the grazing of animals on newly germinated stands of barley, wheat or oat. The practice not only provided foraging animals with valuable green stock but also improved the quality of the forthcoming straw:

"At Babylon however they cut it down [cereals] twice always and as if it were systematically, and after that they let the sheep on to it; for in that case it makes its straw, but then otherwise it runs wildly to leaf...." (Theophrastus *HP* VIII.VII.4).

"Excessive luxuriance in corn-crops is corrected by grazing cattle on them, provided the corn is still in the blade, and although it is eaten down even several times it suffers no injury in the ear. It is absolutely certain that if the ears are lopped off even once the grain becomes longer in shape and hollow inside and worthless, and if sown does not grow. Nevertheless at Babylon they cut the corn twice and the third time pasture it off with the cattle, as otherwise it would make only leaves. Even so the exceptional fertility of the soil returns crops with a fifty-fold increase, and to more industrious farmers even a hundredfold" (Pliny *NH* XVIII.XLV.161).

In some cases, a grain harvest was demanded from a stand which had been previously grazed. However, this required that grazing animals be removed at a critical plant-growth stage:

"Mixed forage should be sown in land that is worked every year, very heavily manured and twice ploughed. It turns out best when sown with ten *modii* of horse-barley to the *iugerum* about the autumnal equinox; but when the rains are threatening, so that, being watered by showers after sowing, it may come up quickly and gather strength before the severe weather of winter. For in cold weather, when other forage has failed, this provides excellent cut fodder for oxen and other animals; and if you care to graze it frequently, it holds out even up to the month of May. If, however, you wish to take grain from it, cattle must be kept off after the first of March, and it must be protected from every kind of harm so as to be capable of bearing seed. The same method is applied to oats: they are sown in the autumn; some are cut for hay or fodder while still green; and some are set apart for grain" (Columella *RR* II.X.31).

8.4 Implications for cereal frequency

Several points emerge from the discussions undertaken above. The first of these concerns the type of rules that were used to stipulate categorical divisions between different types of wheats. This is important since categorical divisions can ultimately affect the way wheat taxa are grouped, distinguished, measured, prioritized and handled. The second point concerns the extent of perceived cereal variability at the time the authors were writing. This is important because there can be a relationship between the range of perceived variation in a taxon and its respective utility – a high number of linguistic sub categories (e.g. epithets denoting types or varieties of wheat) can indicate: (1) a comparatively large number of novel types or novel features within types; (2) the need to differentiate between variants in the group because producers and consumers have highly specialized preferences, (3) elevated levels of experience based on longstanding use; and (4) elevated levels of utility relative to another less differentiated group. A third point concerns the state of technological knowledge in Classical farming societies. This is important because, as discussed in earlier chapters, the state of technology can govern accessibility to different kinds of performance traits. The forth, and final, point concerns the Classical authors' direct perception of cereals relative to one another. This gives us insight into how they were ultimately prioritized

8.4.1 Cereal classification and extent of the variability

The sections addressing Classical epithets indicate that Latin wheat cultivars were differentiated on the basis of practical differences rather than scientifically determined concepts like phylogeny. A prominent categorical division appears to have been used to distinguish glume wheats ('*far*') from free threshing wheats ('*triticum*') on the basis of their fundamental processing differences. However, because both of the ancient epithets denote functional differences, rather than phylogenetic differences, either can be used to designate multiple species. In other words, both functional groups could have consisted of more than one (archaeobotanically recognizable) taxon. The far reaching implication of this observation is that the meaning of Classical passages concerning '*far*' or '*triticum*' can extend to more than one species of glume or free threshing wheat.

The detailed review of the epithets, while admittedly lacking in its capacity to resolve which epithets precisely embrace which taxa, nevertheless, demonstrates the wide range of performance variability that was recognized at the time the authors were writing. Crucially, it indicates that Mediterranean producers, consumers and exchange agents were probably taking advantage of varietal differences in '*fars*' and '*triticums*' to accomplish their goals. What emerges is a picture of a cereal agriculture that has become increasingly more focused on minor differences between taxa.

8.4.2 Technological thresholds and hidden potentials

The level of technological expertise available to producers during any one period is an important factor in determining cereal frequency because advances in agricultural technology opens up new horizons for producers. Although a lack of evidence for conditions in each country (and each archaeological phase) prohibits us from drawing equally sharp distinctions between technological thresholds in all the countries of the study area, textual and archaeological evidence combine to indicate that, by the Classical period, the technological potential of Mediterranean agriculture was impressive, being broadly on a par with that which we witness in many traditional farming communities at the turn of the

18th century AD. This seems to rule out inadequate 'technological know-how' as a major factor constraining cereal change in the Classical Mediterranean.

8.4.3 Classical reasoning underlying cereal choices

Classical authors imply that demand for wheat flowed from a universally accepted consumer preference for wheat as an ingredient in food, and advised that barley be grown mainly for its usefulness as a livestock feed. Barley was also perceived to be useful on light, sandy soils, or on soils which were judged to be of inferior fertility. It could be employed as a short season alternative should the primary crop fail. It held a reputation for dependability and low risk, and its production was advised in situations where labor was commonly in short supply. Barley was judged to require less maintenance than wheat and to ripen more evenly than wheat.

Conversely, Classical authors advised that wheat should be preferentially grown on any site where wheat production was possible or feasible. Wheat production was advised for places where winter temperatures were mild or where there was adequate snowfall to shelter young plants from winterkill. Spring cultivars could be employed where winter temperatures were too cold for autumn sown varieties. There was a range of wheat varieties to choose from and each had a specific role. It is clear that, in many places, wheat grain was simultaneously marketed as a cash crop, employed for food purposes or grown as a livestock feed. Wheat was considered a heavy feeder relative to barley but was generally thought to be more tolerant of moisture and heavy soils. It was frequently advised for sowing: (1) after 'ploughdown' of a pasture crop; (2) amongst pulses as a mixture; or (3) following a pulse crop in continuous rotation.

Free threshing types were almost always preferred when wheat was intended to be used as a food. However, free threshing types were thought to be more difficult to grow than glume wheats. Glume wheats were recommended for situations where the level of environmental stress was relatively high (e.g. on land with low fertility or sites with frigid temperatures). Glume wheats were most commonly associated with a particular type of agronomic goal (food security) and seldom used in premium wheaten products. They seem to occupy a parallel niche to that of barley. For instance, Classical authors report that glume wheats were commonly fed to livestock, relegated to less fertile land and used in fermented cereal products. The authors additionally report that the production and use of '*far*' (glume wheat) preceded that of '*triticum*' (free threshing wheat) as was the case with barley. This assertion is additionally supported by the use of the epithet '*far*' in early folk traditions, early literature and traditional religious contexts. (*cf.* Kuvandzhiev 1999).

Discussion

Chapter 9

9.1 Introduction

Three types of cereal frequency change were observed in this study: (1) a shift in relative proportions away from barley to wheat, which is chronologically associated with the Roman period; (2) a shift in relative proportions away from emmer to spelt which, having begun in the late Bronze Age in a number of regions, continues into the Iron Age and Roman periods; and (3) a shift in relative proportions away from spelt and/or emmer to free threshing wheat, which appears to gain momentum in particular countries during the Roman Period.

Each of the three shifts is addressed individually in section 9.2. The discussion of each shift begins by describing how it was manifested in spatial and chronological terms. This is followed by a consideration of the various lines of evidence and how they contribute to an understanding of the shift. Finally, an interpretation of the shift is offered based on the evidence. Section 9.3 summarises how each of the shifts can be viewed as part of a single overall process rather than as a series of independent events.

9.2 The changes in cereal frequency and their interpretation

9.2.1 The shift from barley to wheat

9.2.1.1 Temporal and spatial variations

The shift to an increasing proportion of wheat relative to barley applies most clearly to Britain, France and Greece. It is less obvious in Germany and Switzerland and there are few indications of a shift from barley to wheat in either Italy or The Netherlands. In Britain, analyses suggest that barley was especially prominent during the Iron Age with an abundance of samples displaying relatively high concentrations of barley grain for most phases. In turn, samples with a wealth of wheat grains were mainly associated with the Roman period. There was an especially dramatic fall in the relative amount of barley items in British samples during the mid Roman period (c. 2^{nd} century AD) but (as previously mentioned), the Iron Age to Roman shift from barley to wheat could be a sampling artefact as many samples from the mid and late Roman period derive primarily from storage contexts at a limited number of sites. However, as the trend towards wheat is also apparent in several adjacent countries it implies that the trend is genuinely chronological. In France, as in Britain, barley occurred most frequently in Iron Age samples, while Roman samples tended to be richer in wheat items. As in Britain, there was an especially noticeable drop in the relative number of barley rich samples from the mid Roman Period onwards. In Greece, there was a slight contrast between the composition of the Iron Age and Roman samples, with Roman samples having a slightly higher proportion of wheat than barley. It should be noted however, that the absolute abundance of barley and wheat grains in Greek samples was almost equal and large samples with high proportions of wheat were derived from one site which is actually just beyond Greece's modern national border (Nicopolis). This makes the Greek trend difficult to substantiate without additional supporting evidence.

Barley grain was especially ubiquitous in the German samples, in absolute and proportional terms and, although the proportion of wheat in German samples appeared to increase through time, the relative position of barley in Germany remained relatively unchanged into the Roman period. The dates and number of Swiss samples rich in barley grain was also slightly skewed in the direction of the Iron Age and the relative quantity of wheat-rich samples increased slightly during the Roman period. It should be noted, however, that a disproportionate number of the Swiss samples are of Roman date. Consequently, the analysis of Roman Switzerland lacks comparative material from the Iron Age. In Italy and the Netherlands, there was no evidence to indicate that a shift from barley to wheat took place.

9.2.1.2 Environmental and agronomic factors

Patterns in the spatial distribution of barley and wheat indicate that ecological factors were a powerful influence in regulating the trend to wheat. Because the entire study area is characterised by south-north/east-west rainfall gradients, ecological models predict that short season, drought avoidant crops like barley are best suited to southerly regions like Italy and Greece. Therefore, in both of these areas, farmers would have been reluctant to switch to cereals which were less well adapted to short seasons and drought. On the other hand, because the study area is also characterised by a temperature gradient (which shortens the crop growing season as one travels north, especially in the heart of the continent), ecological models also predict that short season crops like barley would be well suited to northerly areas like The Netherlands, Germany and Switzerland. Likewise, long season crops like wheat would be expected to have prevailed over barley in areas where farmers had the opportunity to grow cereals in a more stress free environment and where there was a comparatively lengthy growth season (e.g. Britain and France).

Ecological models additionally predict a relationship between soil quality and the capacity to shift from barley to wheat. A transition to wheat would be most easily accommodated in places with soils which are particularly well suited to nutrient demanding crops and, indeed, the shift to wheat was most dramatic in countries like France and Britain where soils are known to be particularly favourable to wheat. At the same time, the shift to wheat was muted in countries within the north European Plain and the Mediterranean (which are generally characterised as having light, infertile or coarse soils, less favourable to long-season nitrogen-demanding crops such as wheat). Barley might have been preferred in cold regions because warm cereal preparations like gruel are naturally preferred in cold climates, and because barley is especially useful for gruel.

9.2.1.3 Socio-economic factors: technological innovation and market development

There are also indications that socio-economic divisions played a role in influencing the shift from barely to wheat, especially when one examines the way the shift is ordered in terms of the advancement and spread of technology and market complexity. The use of barley, for example, is associated with simple Iron Age subsistence farming communities which seem to have been slow or reluctant to adopt innovations in production, culinary science and trade by virtue of their distance from the Mediterranean (where innovations tended to emerge).

Barley production was maintained in places and archaeological phases: (1) where farming communities were conservative in terms of material culture; (2) where production was small scale; (3) where agricultural expansion was less critical (probably because of adequate yields and lower population densities); (4) where farmers had relatively less exposure to the flow of new ideas and technologies; (5) where farmers had comparatively little opportunity to access an efficiently functioning market; and (6) where there was comparatively little capital and thus comparatively less opportunity to expand production through costly technological inputs. Alternatively, failure to shift to wheat may be due to the fact that subsistence farmers in fringe areas had little incentive to incorporate technological inputs because of strong environmental barriers which limited the effectiveness of additional management inputs or technology (or which increased the amount of input required and thus the cost). Barley may also have integrated better into the less settled lifestyle of subsistence farming communities because it takes less time to maintain, ripens more evenly than wheat and is much more flexible than wheat in terms of its management requirements - important traits for subsistence farmers who can be preoccupied with livestock at crucial points in the production year.

By contrast the switch to wheat is most pronounced in (1) later phases; (2) countries where highly structured markets developed around urban nuclei; (3) in places where innovative technology provided farmers with added capacity to produce a marketable surplus; and (4) in places where the marketing of grain was well established from Iron Age times.

Because barley was never entirely abandoned in any region, the trend towards wheat production seems to have been more a shift in emphasis than a total rejection of barley. Furthermore, because the shift towards wheat was greatest when farmers were provided with greater agricultural technology and increased market compensation, the shift seems to have been enabled by these factors. Finally, the fact that the shift takes place early in areas which a have high potential to grow wheat indicates that environmental factors constrained the shift in areas where it did not take place.

9.2.1.4 Socio-economic factors: agricultural expansion

There are definite reasons why farmers may have favoured wheat when they were forced to expand onto new soils or to increase production or income. Firstly, wheat is more useful than barley in the sort of agricultural expansion which involves lengthening the agricultural cycle by extending the growth season over a longer period of time (thus making more production possible). Secondly, wheat is an obvious choice for farmers pressed for higher production, because it responds positively to technological inputs and management controls which, in turn, draw greater yields from existing cultivars than previously possible (i.e. technology unlocks hidden potential). Thirdly, wheat is more useful in a greater number of products and agricultural systems than barley so the range of possible uses increases as well as the potential profit (which pays for taking the additional risk of growing a longer season cultivar).

Finally, since lack of sufficient variability can constrain farmers' ability to change or adapt to shifting conditions, crops which have a wide range of diversity, or an enhanced capacity to change (by incorporating new genes or new combinations of genes) are particularly advantageous to farmers. The complex genome of wheat provided that potential and, in so doing, it offered producers the means to increase the number of options which could be exploited to make expansion successful and profitable.

9.2.1.5 Evidence from Classical texts

There is evidence to indicate that wheat was perceived, by Classical authors, to have a greater number of production, consumption and exchange uses than barley. The breadth of the Classical vocabulary for wheat indicates: (1) that a comparatively greater number of wheat cultivars were available; (2) that there was a disproportionate amount of attention paid to wheat cultivars; and (3) that producers, consumers and exchange agents were particularly sensitive to subtle variations in wheat plant and grain type.

Classical authors indicate that wheat was universally preferred to barley as a food staple, and advised that producers should switch over to wheat whenever possible mainly on account of high consumption demand. In the Mediterranean at least, consumer demand for wheat seems to have been very strong from a very early date even though barley's comparatively low cost must have provided some incentive to remain tied to barley. Classical authors report that the strong preference for wheat resulted from a developing preference for bread over gruel. Although bread from barley is mentioned in the ancient literature (and wheat and barley flour mixtures are also mentioned regularly), the textual evidence seems to indicate that barley was perceived to be more useful in gruels and as livestock feed. In characterizing tribal cultures as 'porridge eaters', Classical authors provide direct evidence of the traditional social stigmas attached to cultures which did not eat bread. Furthermore, in almost every Classical cereal recipe, chroniclers allude to the general superiority of wheat as an ingredient, whereas barley is only occasionally mentioned. Archaeological and textual evidence also combine to indicate that trading for wheat began relatively early in the Mediterranean – a region where wheat production would have been disproportionately expensive but where the well developed infrastructure and generally higher standards of living combined to provide greater opportunity to produce, distribute and import premium grains.

9.2.1.6 The main contributing factors

To summarise, the factors driving the shift from wheat to barley appear to relate to a series of developments which made the production of wheat more possible. While barley offers the capacity to outperform wheat in areas characterised as having relatively high levels of plant stress, its range of practical applications is narrower than that of wheat. Barley, therefore, was no match for wheat once farmers began to adopt technological innovations and management strategies which enabled them to reduce plant stress and thus grow greater amounts of wheat than previously possible. Furthermore, once cereal markets began to develop and spread, farmers were provided with compensation to grow long-season, high-risk cereal crops in order to meet the demands of: (1) local consumers; (2) cereal processors such as bakers; (3) tax collectors; (4) occupying armies; and (5) grain merchants.

9.2.2 The shift from emmer to spelt

9.2.2.1 Temporal and spatial variations

Assemblages from Britain and France (and to some extent the Netherlands) display the greatest increase in the relative proportions of spelt during the study period. British farmers were well on a path to replacing emmer by the opening phases of the Iron Age and, by the early Roman period, spelt had outpaced emmer in many areas. During the Roman period spelt became the dominant wheat grain in most areas of Britain. The replacement of emmer by spelt was, however, somewhat more delayed in Britain's highland zone, which may suggest reluctance on the part of highland farmers to abandon a traditional grain.

Assemblages from Germany and Switzerland indicate that the relative proportions of emmer and spelt shifted in favour of spelt between the Iron Age and Roman periods but, in both of these countries, the shift was more tempered than in Britain and France (perhaps because it was initiated at an earlier date). There was no evidence of a shift to spelt in Italy or Greece.

In France, spelt is represented across a relatively large number of sites, periods and phases. In the French samples, the relative quantity of spelt was comparatively high in the Gallo-Roman (c. 50-30 BC), Julio-Claudian (c. 10 BC-AD 70) and Flavian-Antonine phases (c. AD 70-250). Emmer was subordinate to spelt on many sites by as early as the final Hallstatt (c. 600-320 BC) and early La Tène phases (c. 320-200 BC).

Analysis of the Dutch samples showed that samples rich in spelt grain, while not especially frequent, were mostly from Roman phases. Emmer grain and glume bases persisted on many Dutch sites until the Late Roman phase. Swiss samples suggest that there may have been a slight shift from emmer to spelt between the Iron Age and Roman periods but the nature of the shift was different from that in Britain and the Netherlands. Swiss samples rich in spelt glume bases were predominantly Roman.

The pattern in Germany was even more difficult to assess. Samples rich in emmer or spelt grains appear to have been equally common in both periods whilst samples rich in emmer grains were most common in the Hallstatt phase. Contrastingly, samples rich in spelt glume bases were associated with the Iron Age while samples rich in emmer glume bases were mostly associated with the Roman period. It should also be noted that it is difficult to interpret the cereal frequencies in the northern part of Germany because of a dearth of samples and sites. In Italy and Greece, there was very little spelt but the number and size of the samples for each of these countries is also relatively small.

9.2.2.2 Environmental and agronomic factors

Two aspects of spelt's distribution suggest that ecological divisions within the study area played a role in regulating the chronological and geographical character of this shift. Firstly, the shift to spelt was most dramatic in a belt midway between two zones with distinctive temperature and rainfall parameters – the Mediterranean, with its hot dry summers, and the northern European Plain with its short growing season. This suggests that farmers were more likely to switch to spelt in ecological areas where there was comparatively little risk of heat, cold or drought stress. Secondly, spelt was most abundant on Europe's loess soils (i.e. southern Britain, northern France, parts of the Netherlands, and southern Germany). Because these are some of the most productive wheat growing soils in the world, it suggests that the shift to spelt was most easily achieved in areas where the probability for nutrient stress was comparatively low.

The shift to spelt may reflect a desire to specialise in wheat cultivars which were better adapted to specific environmental conditions. The fact that the geographical distribution of spelt was much narrower than that of its predecessor, emmer, (a taxon which ranged across the whole of Europe during the previous interval) suggests that farmers had begun to practise cultivar specialisation. In other words, spelt producers were interested in shifting away from widely adapted cultivars, like emmer, to cultivars that were better matched to their own specific environmental conditions. Because environmental specialisation is linked with the ability to respond positively to a particular environment, and because this ability is further linked with a motivation to achieve higher yields, it suggests that a desire to obtain greater yield was one of the main goals of spelt farmers (*cf.* Annicchiarico 2002).

Nevertheless, there is also evidence which indicates that the shift to spelt results from dietary specialisation. Increased frequency of spelt is chronologically correlated with the baking of bread which presumably diffused into Europe from a similar direction to spelt (a southeast to northwest direction). As a hexaploid wheat, spelt behaves in a similar fashion to bread wheat in the baking process. Spelt is genetically very similar to bread wheat (differing from bread wheat by as few as three genes) and its storage proteins are also closely related to those of bread wheat. Crucially important is the fact that spelt contains a copious amount of gluten in its endosperm which allows a greater range of baking products to be manufactured than is possible with emmer. Thus, even if the preference for spelt is not specifically related to a preference for light leavened breads, spelt delivered the capacity to expand wheat's culinary role.

9.2.2.3 Socio-economic factors

Spelt began to supercede emmer in much of Europe: (1) during a period in which European farming was being performed at the small scale subsistence level; (2) probably before the bulk of technical innovations were adopted by the bulk of European farmers; (3) before the initial phases of the Iron Age expansion of trade with Mediterranean communities; (4) before population nucleation gave rise to proto-urban centres like oppida; and (5) before the development of a money-based economy added impetus to grain trading.

It is therefore difficult to imagine that the shift to spelt was explicitly connected with either technical prowess or market development. It is interesting to note that spelt was largely absent from countries where both of these characteristics were likely to have been of especially critical importance (Roman Italy and Greece).

9.2.2.4 Evidence from Classical texts

Etymological evidence supplied by the Classical texts suggests that Central European farmers introduced spelt to Mediterranean peoples rather than the other way around. The etymology of the epithet 'spelt' specifically relates to peoples who spoke a language from the Celtic and/or Germanic language group rather than Greek or Latin. Classical texts also indicate that once Mediterranean farmers were introduced to spelt, they found spelt to be functionally redundant in terms of the package of wheats previously in their possession. In other words, they did not feel that spelt had a unique functional role relative to the emmer cultivars that were already in their cereal repertoire. This does not necessarily imply that Mediterranean farmers viewed the two species as precisely equivalent but it strongly suggests that excluding spelt would not have resulted in a gap in terms of desired performance (in the Mediterranean).

Using these facts together with spelt's phytogeography provides a useful starting point for again arguing that spelt was ill suited to Mediterranean climes. The vast array of different wheat epithets suggests that Classical farmers had knowledge of a huge range of potentially valuable wheat cultivars to choose from and that they were also aware of potentially useful properties of wheats grown in foreign lands. Thus, availability or unfamiliarity were not at issue if Classical farmers had wished to replace emmer with a superior alternative. Farming, food preparation and grain exchange were taking place against a backdrop of specialisation, heightened consumer tastes and increased expectations on the part of cereal traders, so there were also forces at work that could have encouraged the use of spelt if it displayed a potential to confer unique or extraordinary quality. Finally, Classical agronomists specifically argued that farmers should experiment with new varieties, so cultural conservatism should not have been a barrier to the adoption of spelt if it had proved to be extraordinary in any way.

Because the shift from emmer to spelt represents a continuation of the previous focus on glume wheats (in spite of the fact that a closely related free threshing alternative existed), we can conclude that the free threshing trait was not particularly valued amongst central European communities especially during the Iron Age. This was probably because spelt's tightly held glumes offset any possible advantage provided by the free threshing habit. Indeed, Classical authors reported that grain investments protected wheats against a number of potential environmental threats such as cold, insects and diseases. Thus, in areas and phases where glume wheats persisted (e.g. the Iron Age and Britain), there was probably more of a need to grow wheats which offered protection against these types of plant stress than to take advantage of the benefits offered by the free threshing trait.

Finally, there is circumstantial evidence in the Classical Greek and Roman literature which indicates that social conservatism may have played some role in delineating which areas and phases witnessed a switch from emmer to spelt. Because Classical authors report that glume wheats held powerful cultural and symbolic value, and because this shift is fundamentally a shift from one glume wheat to another (as opposed to a shift from glume wheat to free threshing wheat), it may suggest an established and culturally driven phenotypic bias toward glume wheat types (thereby excluding the selection of a superior free threshing alternative).

9.2.2.6 The main contributing factors

The shift to spelt seems to result from two types of specialisation: environmental and dietary. Firstly, because there is a link between spelt and the moderate environmental conditions (rainfall, temperature etc.) of the central European 'loess belt', the shift to spelt represents a 'better match' than emmer to environmental conditions. Secondly, it demonstrates specialisation within a commodity category (for wheat types with a high gluten content useful for bread making). It is especially significant to note that the shift to spelt involves a major genetic shift (from tetraploid to hexaploid wheat types). This is noteworthy because it links hexaploid wheat with moderate environments, comparatively late agricultural practices and comparatively more discretionary consumer preferences. In turn, the shift also seems to suggest, that tetraploids were best suited to phases (like the Iron

Age) and places (like the Mediterranean) where there was a comparatively high level of plant stress, and fewer means to relieve it.

9.2.3 The shift from emmer and spelt to free threshing wheat

9.2.3.1 Temporal and spatial variations

Analyses distinguished three different types of regional patterns in the shift to free threshing wheat. Firstly, in Italy and *possibly* Greece, there were high numbers of samples with significant quantities of free threshing wheat from the earliest phases of the study period, and the relative quantity of free threshing wheat does not appear to have increased through time. Secondly, in northern France, Germany and Switzerland, there were modest numbers of samples with comparatively high relative quantities of free threshing wheat items from the beginning of the study period, and the relative quantity of free threshing wheat increased only gradually up to the 2nd century AD. Finally, in Britain and the Netherlands, free threshing wheat was rare in most samples and phases but it was slightly more abundant in Roman samples.

In Greece and Italy, the shift is best characterised as a shift from emmer to free threshing wheat rather than a shift from spelt to free threshing wheat mainly because there was so little spelt in the Greek and Italian assemblages. In Greece, free threshing wheat was less common than emmer until the Archaic phase but it became increasingly more common thereafter, especially in the interval between 150 BC and the turn of the millennium (note that the Romans took political control of Greece in c. 150 BC). In Italy, the proportion of free threshing wheat was relatively stable from as early as the 6th century BC.

In France free threshing wheat was a consistent element in cereal samples from all phases except the Hallstatt, but samples with high concentrations of free threshing wheat became especially frequent by the last Roman phase (AD 250-450). In Germany, samples of free threshing wheat were most common in the Roman period, but there was a substantial number of Iron Age samples with high concentrations of free threshing wheat. In Switzerland, free threshing wheat and/or emmer grains were present to greater or lesser degrees throughout both periods, but examples of free threshing wheat chaff were mostly associated with late Roman samples.

In Britain, spelt largely dominates samples from the Roman period, but the relative quantity of free threshing wheat increased considerably in the 2nd century AD. In the Netherlands, samples rich in free threshing wheat were comparatively rare but, where they were reported, they tended to be associated with the Roman period rather than the Iron Age.

9.2.3.2 Environmental factors

The fact that there was an almost universal shift to free threshing species throughout Europe indicates that environmental differences had little influence over the trend. Analyses indicate that the Mediterranean countries had already begun the transition to free threshing wheat before the study period began, and that (although there are differences in chronology and emphasis) the trend to more free threshing wheat applied almost universally in the western provinces. In Gaul and Germania Superior (northern France, western Switzerland and southern Germany), for instance, free threshing wheat increasingly came to dominate a significantly greater proportion of cereal production, at the expense of traditional glume wheat cultivars like emmer and spelt, over the span of the study period. Although free threshing wheat items are rare on Roman sites in Germania Inferior (south western Germany and the southern Netherlands) and Britain, it is clear that free threshing wheat was increasing produced or increasingly available as an import during the Roman period (*cf.* Ammianus Marcellinus XVIII 2.1-4).

Our inability to make precise taxonomic distinctions between free threshing wheat items deters us from recognising which free threshing species are represented in the assemblages of the different countries and periods. In fact, we cannot, with confidence, even distinguish hexaploid (bread wheat) from tetraploid (durum wheat) mainly because we lack rachis remains necessary for a precise diagnosis in most assemblages. By employing phytogeographical inference, however, it is possible to propose that hexaploid free threshing wheats (such as bread wheat) were likely to be relatively more important in temperate countries of Europe. The same type of phytogeographical reasoning also indicates that free threshing wheat species found in the Mediterranean were by and large of the tetraploid variety.

9.2.3.3 Agronomic factors

It is probable that a preference for the free threshing trait was the deciding factor in motivating producers to shift to free threshing species. There are several reasons to suspect this. The first is the fact that the shift is always in one direction; we do not witness even a single instance during the study period where free threshing wheat decreases through time in favour of a glumed competitor. Secondly, the shift occurs across species lines. In other words, there are two independent shifts in the same direction: (1) from spelt to free threshing wheat; and (2) from emmer to free threshing wheat. A third and, somewhat related piece of evidence, is the fact that free threshing cultivars gain popularity in both the tetraploid and hexaploid lines. This indicates a preference for the free threshing trait across broad genetic, temporal and spatial contexts.

The main advantages of free threshing species relate to processing time, transportation costs and storage volumes. Free threshing species are, by their very nature, less costly to process because their glumes do not enclose the grains after they have been threshed. Their grain is also less costly to transport than glume wheat spikelets, since glumes increase the volume of transported grain. Finally, their grain is less costly to store because it takes up less storage volume.

It should be noted, however, that glume wheats could be transported and stored in a dehusked state and there are archaeobotanical examples of the bulk storage of cleaned glume wheat grain. However, the effort and time required to dehusk bulk quantities is considerable. Nevertheless, modern agronomists report that glumes increase the amount of free space between grains in storage which lowers the amount of heat generated in storage. Agronomists additionally indicate that the glumes can add to the feed quality of grain. Glumed species are therefore more cost effective for livestock feed. Additionally, although the subject is not specifically considered by modern agronomists, it can be argued that tightly held glumes provide the producer versatility in storage because they allow a choice of whether to store the grain in its glume or in a clean state.

9.2.3.4 Socio-economic factors

Free threshing species can be linked with: (1) comparatively late chronological phases; (2) consumer preferences with respect to wheats with high baking quality; and (3) low processing, transportation, and storage costs. This explains the early linkage of free threshing wheat with countries such as Greece and Italy and the late linkage with countries like Britain and The Netherlands. The pattern suggests that free threshing wheats were preferred in places and phases where producers focused on profitability and in countries and phases where customers were prepared to offset the added costs of growing free threshing species by offering a higher return in the market. Consequently, a switch towards free threshing wheat seems to have required: (1) a means to enable the relaxation of production cost with respect to glumed competitors; and/or (2) a means to increase market return with respect to glumed competitors offering similar grain quality.

9.2.3.5 Evidence from Classical texts

Classical authors suggest that free threshing species were less adapted to the contemporaneous farming environment for several reasons: (1) tightly held glumes provided added protection against a whole range of pests; (2) tightly held glumes protected the grain from unseasonable cold stress; (3) glume wheats could be grown on light soils (which became less favourable once there was a means to bring heavy soils into cultivation); (4) glume wheats took less time to maintain. On the whole, Classical agronomists considered the production of free threshing wheat a luxury.

On the other hand, they also report that free threshing wheats were superior to glume wheats in terms of grain quality. They repeatedly state that free threshing wheat was used as an ingredient in the finest breads and the most highly prized foods. Furthermore, they never recommended free threshing species for use as livestock feed because they were so expensive to produce. In stating this, they thus imply that free threshing wheats were better suited to farmers who intended to raise grain for profit simply because subsistence farmers have: (1) simpler needs; (2) fewer means to compensate for the risks associated with growing poorly adapted species; and (3) insufficient technology to buffer against environmental threats or to use in creating economic opportunities.

9.2.3.6 The main contributing factors

It is difficult to argue that free threshing species conferred a substantial production advantage over glume wheats because free threshing wheats expose producers to considerably greater degrees of risk while the grain is in the field and in storage. Moreover, the advantages conferred by the free threshing trait relate only to post-harvest handling of grain. Post-threshing processing is not especially critical to farmers who consume their own grain (and therefore have no need to rush grain to market) because it can be done at the convenience of the producer.

The disadvantages of growing free threshing species seem to outweigh the advantages for producers who grow grain primarily for home consumption. However, free threshing species may have been favoured in: (1) countries where the farming of free threshing species posed little risk to producers; (2) in phases where producers of free threshing wheat could be compensated for exposing themselves to extra risks through benefits provided by a well developed free market; or (3) in phases or countries where slight differences in production costs became critical because of the motive for profit or intense market competition.

9.3 The overall pattern: three types of specialisation

Each of the three 'shifts' described above is related to a particular type of specialisation. The Iron Age opens with specialisation for environmental factors, which played a major role in regulating cereal distribution mainly because farming was initially practised at an essentially subsistence level. Producers were relatively constrained by environmental factors because they had few technological means to increase production beyond existing levels. Specialisation for greater yield and grain quality grew when the benefits of technology began to accumulate (throughout the Iron Age and Roman periods). This encouraged producers to favour species which responded positively to technological inputs. Finally, specialisation for profitability emerged (during the Late Iron Age but primarily during the Roman period) with the development of the grain market.

9.3.1 Specialisation for environmental factors

In the early Iron Age most European economies were operating at a subsistence level. The dominant cereal pattern was mostly driven by the relationship between the cereal plant's broad genetic character and environmental stress. In other words, production was constrained by the inherent inadequacy of cereal species to overcome environmental barriers and farmers' incapacity to moderate or remove barriers through technology or management. Because farmers possessed few technological means to eliminate or obviate environmental barriers, they employed crop types which had particularly high levels of stress resistance or the potential to avoid stress through their natural growth cycle. During this stage, short-season stress-avoidant crops like barley were particularly dominant in countries and regions where annual growth conditions tended to be relatively stressful or variable, and consequently there was an emphasis on yield stability rather than yield potential. Wheat, on the other hand, tended to be concentrated into areas with comparatively lengthy growth seasons, highly desirable soils and adequately distributed supplies of moisture. Wheat was also better represented than barley in places: (1) where the approach to cereal production was more technically advanced thus providing the means to alleviate crop stress; and (2) where there were well developed cereal markets which allowed farmers to assume more risk (because farmers are more apt to take risks where it is moderated by market rewards). It was not until environmental factors were alleviated that wheat was able to gain in importance.

9.3.2 Specialisation for greater yield and grain quality

Escalating market complexity and an attendant rise in the use of technical inputs seems to have provided farmers with additional capacity to draw on hidden genetic potential and to expand production beyond previous levels. Producers began to: (1) extend production onto previously intractable soils; (2) open new market channels; and (3) apply greater levels of management control to achieve yield potential. Having probably reached a genetic plateau with traditional varieties, they also began to search for new cereal varieties and to calculate which taxa offered the best yield stability, yield potential and quality when grown with the aid of technological inputs. It is during this stage that hexaploid species like spelt began to undermine the dominance of tetraploid species like emmer, mainly because they required more in terms of stress relief than their diploid and tetraploid competitors.

Evidence for this can be found in the way the shift is expressed; as was the case with the shift from barley to wheat, the shift from emmer to spelt was muted in two distinct areas: the first was the Mediterranean and the far north. Both areas have an inherent tendency to crop stress factors which are particularly limiting (low soil moisture and low soil nutrient levels). Consequently, farmers had less opportunity to exploit technology as a means of moderating plant stress. Therefore, they had a tendency to remain tied to cultivars which were stress avoidant. In other words, farmers had comparatively less opportunity to specialise in long-season, high-potential cultivars.

In contrast, the more temperate countries of Europe offered conditions conducive to a wider range of cereal crops some of which offered high yield potential. Farmers in these areas therefore had a greater opportunity to select crops which respond well under management because: (1) soils here are naturally more nutrient rich; (2) the production environment offered optimal climatic conditions; (3) the growth season was comparatively long; and (4) farmers were not necessarily constrained by a requirement to grow cereal types which confer high levels of resistance to drought, cold or nutrient stress. In essence farmers were far more likely to take advantage of high potential cultivars like spelt than to continue on with tetraploid taxa which, although better adapted in terms of the natural environment, are less likely to convey high yield potential or elevated consumer quality when additional growth inputs are supplied.

9.3.3 Specialisation for profitability

Later, especially during the Roman period, producers were confronted with an even greater range of alternatives as a genuine agricultural commodities market developed and spread. Producers gradually became more aware and more preoccupied with consumer and distributor preferences. They began to view the 'cereal market' as composed of many submarkets and customer segments each with distinct subtleties, requirements and opportunities. They became conscious of even the most subtle differences between taxa and started to develop awareness of aspects like grain quality which had a direct effect on how much of a cereal the consumer would buy. At the same time, they were faced with the issue of profitability, and the prospect of paying for distinct inputs like transportation costs. With profit in mind, producers began to take into account the fact that the market was interested in transforming their raw material into a wide range of forms. As the number of potential uses accumulated, so did the desire for cultivars which had the capacity to appeal to cereal processors such as millers. Likewise, as preparation methods diversified, so did the potential range of cereal products. Thus, there was a need for cultivars which could be used in specialised contexts. Finally, as technology became more sophisticated and accessible, so did the need for cultivars which offered a high degree of response when technology was applied as a means to extract hidden potential. It was at this time that demand for free threshing cereals began to develop because free threshing species held the capacity to confer extra profit as well as to convey quality. Thus, we witness a relationship between free threshing wheat and places like the Mediterranean and phases like the Roman period because wheat was more apt to be treated as a market commodity. In contrast, the desire to grow free threshing cultivars was slower to develop in places like Britain, The Netherlands and Germany because the motive to grow cereals for profit was muted by the fact that a grain market was slow to develop and farmers were hesitant to abandon subsistence strategies.

9.3.4 Spatial variations in the overall pattern: an explanation

So changes are primarily motivated by socio-economic prerogatives which determined which types of cereals traits were the most valued. The pace of change, however, was regulated by environmental parameters. If the character of the production environment of each country is viewed in terms of its potential for imposing plant stress, the relative ranking of each cereal species within each country can be visualised along a sliding scale ranging from high stress to low stress, with two bands of high stress environments in the southernmost and northernmost latitudes and a relatively stress-free band in the latitudes between. This allows us to estimate crop frequency based on the ability of each type of crop to cope with environmental stress factors and to identify where change could be most easily facilitated. Crucially, we can see that environmental stress increases as one travels north or south from middle latitudes. Farmers, therefore, react by growing stress resistant species such as barley. Conversely, as one travels in the opposite direction (towards the most favourable environments), farmers are more able to grow less stress-resistant species like bread wheat which have more to offer in terms of yield and grain quality.

It is on this basis that farmers in the most favourable environments were amongst the first to shift to less stress tolerant crops. Nevertheless, once farmers in high stress areas developed the technical capacity to relax environmental stress (or the capacity to compensate farmers for dealing with stress factors through a cereal market), they too began to shift over to stress-susceptible species in a broadly similar manner. Thus we see a broadly similar sequence of cereal change in all areas but proceeding at different rates in different environmental zones.

Chapter 10

Conclusion

10.1 Aims of the thesis and summary of research

The aim of this research has been to identify changes in cereal frequencies during the Iron Age and Roman periods in Europe, and to understand the underlying factors responsible for these changes. Using sample-by-sample correspondence analysis, three distinct types of frequency change were identified, and several alternative causes were then considered – namely, that frequency changes reflect changes in: (1) production, (2) consumption, (3) exchange, (4) some combination of these elements, or (5) some other cause. In Chapter 9, it was argued that the cereal shifts primarily resulted from a desire or need to adapt production to a market that was developing in terms of its overall complexity and degree of refinement. In turn, this encouraged producers, consumers and exchange agents to adopt cereal taxa which more effectively addressed specific problems and needs. At different times and in different places, changes allowed producers, consumers and exchange agents to:

1. use environmental resources efficiently;
2. reduce exposure to risk or uncertainty;
3. achieve greater returns with respect to both yield and quality;
4. achieve higher market returns.

10.2 Trajectories of change: risk management

The fact that the direction of cereal changes are the same in each geographic region suggests that certain taxa were valued early while others were more valued later. Broadly speaking, we witness three overlapping trajectories (seriated patterns) in the countries studied:

1. a genus shift from barley to wheat;
2. species shifts, within wheat, from diploid to tetraploid (largely before the Iron Age) and, where environmental conditions permitted, to hexaploid taxa;
3. sub-species shifts, within wheat, from glumed to free threshing taxa.

In all cases, these shifts were from stress tolerant to stress intolerant taxa. Moreover, where stress tolerant cereals were retained in the agricultural scheme, they progressively became marginalised or relegated to secondary roles. Barley, for example, took on the primary role of animal feed, emmer was down-graded for use as an ingredient in lower status products like gruel or unleavened bread, and glumed wheats were priced lower than free threshing competitors in the market.

10.3 Demands of the market: specialisation and elasticity

At the same time as the market was becoming more refined, the spectrum of uses for cereals was widening, and the range of regional cuisines expanding. For instance, during the Iron Age, bread was added to Italian cuisines to complement a traditional diet of gruel. Advances in processing technology enabled a greater range of cereal ingredients to be produced. Moreover, as millers and bakers gained knowledge and technical prowess, they began to create and demand finer quality grades of flour. In parallel with this, the basic configuration of agriculture became more sophisticated as management options such as irrigation and varietal selection came to agriculture's foreground. The available agro-environment was also expanding as, for instance, when the introduction of iron ploughshares made farming on heavy soils technically feasible. These changes stimulated the need for cultivars which complemented and extended the range of cereal use beyond that of 'traditional' types. Cultivars that offered 'elasticity' (the capability to be re-adapted or re-configured to specialised roles) were especially favoured whilst less versatile types were at a disadvantage.

10.4 Responses to diminished risk and increasing demand

The trend towards greater levels of specialisation was chronologically constrained by farmers' inability to overcome environmental barriers, the greatest obstacle to agricultural change. However, with time, producers, consumers and exchange agents gained the necessary tools to erode environmental barriers through two distinct means. Firstly, technical innovations enabled farmers to reduce constraints on plant growth (stress factors). Secondly, market developments enabled consumers to compensate farmers for growing cereals which were less adapted to stressful environments and which, in turn, made the production of stress susceptible cereals much more likely. Geographic differences also affected the timing of the shifts due to the fact that the mechanisms for dealing with environment were introduced or assimilated at different dates in different places. Because levels of plant growth stress are distributed unequally, farmers in different areas were also confronted with different levels of risk to overcome before changing.

10.4.1 The shift from barley to wheat

The shift from barely to wheat occurred primarily because wheat offers greater elasticity than barley. This elasticity is demonstrated by the fact that wheat can:

1. have a greater range of uses;
2. be grown over a greater time range;
3. offer up a greater number of genetic variants;
4. enhance productivity when technological inputs are provided.

For example, although barley can potentially be used to bake bread, it cannot be used to bake leavened bread without additives. There are relatively few instances where barley is a superior substitute for wheat as a culinary ingredient. Barley's drought avoidant life cycle also limits its capacity to take advantage of the full range of photosynthetic opportunities open to longer season crop like wheat. Farmers and breeders have also been better able to capitalise on wheat's inherent variability and complex genome to produce an unprecedented range of useful cultivars. Wheat's geographic distribution also suggests that wheat is more productive than barley because wheat is the predominant crop in areas where agricultural productivity is generally high. Barley production, on the other hand, is closely associated with countries and climates of below-average productivity.

10.4.2 The shift from lower to higher ploidy levels in wheat

The superiority of hexaploid wheat over tetraploid types (and to a lesser extent tetraploid over diploid) in a complex socio-economic setting is demonstrated by:

1. the relatively high number of variants (cultivars) generated;
2. their occupation of a major or highly desirable adaptive zone;
3. their relative dominance of the major adaptive zone for a sustained period;
4. the substantial breadth of their geographic range;
5. their high population density during the most intense production, consumption and exchange phase.

Diploid (and tetraploid) taxa, on the other hand, have comparatively fewer cultivars and currently occupy very narrow geographic areas, characterised by stressful conditions where agriculture is technologically restricted. As discussed in section 6.5.6.3, polyploidy confers a range of advantages to domesticated species by: (1) enhancing universally advantageous agronomic traits; (2) increasing variability through higher levels of heterozygosity; and (3) conferring novel agronomic traits through gene interaction. In this way, polyploidy extends the exploitive potential of wheat by extending variability and bestowing increased flexibility in terms of use.

10.4.3 The shift from glumed to free-threshing wheats

Unlike the previous two shifts, which involve a move towards increased variety and flexibility, the shift to the free-threshing trait in wheat is the result of selection for a particular characteristic. This particular shift, consequently, reflects a shift from an emphasis on risk avoidance – the protection afforded by tightly investing glumes – to increased profitability in a market economy – a reduction in the cost of processing and transport. As such, it is an alternative type of adaptation to economic pressure. In other words, the shift involves paring down the range of alternatives (specialization) rather than broadening of the range of potential applications (diversification).

10.5 Cereal change as a socio-economic process

We can conclude, from the directional nature of change, that producers, consumers and exchange agents were not merely cycling back and forth between a fixed package of ancestral alternatives. Rather it appears that they were reaching for taxa which might accommodate new and old demands in a better and more efficient manner. Social and economic factors were driving cereal change in the direction of greater choice, quality, yield and productivity but refinements were constrained by environmental stress factors which required risk minimising adaptations. When stress factors were relaxed, or when farmers were remunerated for taking risks, change was enabled. Although the effects of stress were progressively reduced through time, stress seems to have remained a constant constraint on change as demonstrated by the fact that stress resistant taxa like barley were never entirely abandoned. Yet, having achieved some degree of food security, most communities seemed to have wished to move on to exploit the potential of less stress resistant cereals (like wheat and, in particular, hexaploid free threshing wheat) to a greater degree.

When farmers exhausted the developmental potential of 'traditional' types, they shifted to 'new' taxa. Again, elasticity was an important advantage as levels of refinement in production, consumption and exchange progressively increased. Each newly adopted taxon needed to be more responsive than its predecessor to an accumulating range of different demands and priorities. Small differences between cereal taxa became more significant to the achievement of production, consumption and exchange goals, conferring an advantage to taxa which offered variability. The adoption of hexaploid allopolyploids (e.g. spelt and bread wheat), for instance, allowed cereal users to exploit the advantages of the A, B, and D genomes simultaneously without suffering the expense of producing three wheat species individually. Provided with conditions of relaxed stress, allopolyploid species could also confer the benefits of hybridity and polyploidy simultaneously. This is almost certainly why we witness shifts from lower to higher ploidy taxa. Finally, the shift to free threshing types of allopolyploids, demonstrates that farmers generally came to a common solution with respect grain profitability. Having reached a profitability plateau with their traditional glume wheat cultivars, they consistently narrowed their preferences (within the prevailing allopolyploid species) in the direction of the variants which conferred ease of threshability.