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Interpretation of archaeological plant remains: Ethnographic models from Greece

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ABSTRACT: The potential of ethnographic models for the interpretation of archaeological plant remains is explored. Crop samples, collected from a present-day community in Greece which still farms by traditional methods, form the basis of a case study. Samples from different stages in the crop processing sequence can be distinguished by statistical analysis of the weed seeds therein. Ways of applying this ethnographic model to archaeological samples, using weed seed characteristics of relevance to the processing sequence, are evaluated.
KEYWORDS: ethnographic model, crop processing, Greece, weed seeds.

1 INTRODUCTION

As Hillman (1981, this volume) has demonstrated, ethnographic studies of present-day agricultural practices can be useful aids to the archaeobotanical study of a wide range of archaeological questions. This paper deals with one aspect of the interpretation of plant remains - that of crop processing - and the light which can be thrown on this by an ethnographic study. Crop processing may be pursued as a study in its own right, to identify activity areas and to determine the functions of buildings or of sites (cf. Hillman 1981, this volume), or it may be considered a necessary preliminary study to the use of archaeological plant remains as indicators of other agricultural practices (cf. Jones 1981).

Husbandry practices such as choice of soil, tilling methods, time of sowing, fallowing, rotation, irrigation and so on all have their effect on the weeds which grow in cultivated fields. At best, however, on an archaeological site, one can expect to find, accompanying the crops, evidence only of those weeds which were in seed at the time of harvest. In addition to this, it is likely that not all these weeds will have been harvested - short plants and those which are obvious in the field, for example, may have been left behind (cf. Hillman's "C" classification of weed species - this volume). Finally, weeds will have been removed at different stages of crop processing (cf. Hillman's "B" classification of weed species - this volume). It is useful, therefore, to distinguish samples resulting from different stages of crop processing so that, when comparisons of weed seeds from different samples are made, it is possible to compare like with like. This is the taphonomic role of a crop processing study, to use the terminology of palaeontology and archaeozoology.

The ethnographic work discussed here was carried out on the Aegean island of Amorgos. All the samples collected were from crops cultivated by traditional methods. Ploughing was by means of ox-drawn ard and, although fertilisers were in use, no weed killers were applied to the crops. Only crops which had been subjected to traditional processing techniques were sampled. Crops grown, for both human food and fodder, included bread wheat (Triticum aestivum), macaroni wheat (T. durum), hulled six-row barley (Hordeum vulgare), oat (Avena sativa), pea (Pisum sativum), lentil (Lens culinaris), common vetch (Vicia sativa) and grass pea (Lathyrus sativus) or mixtures of these.

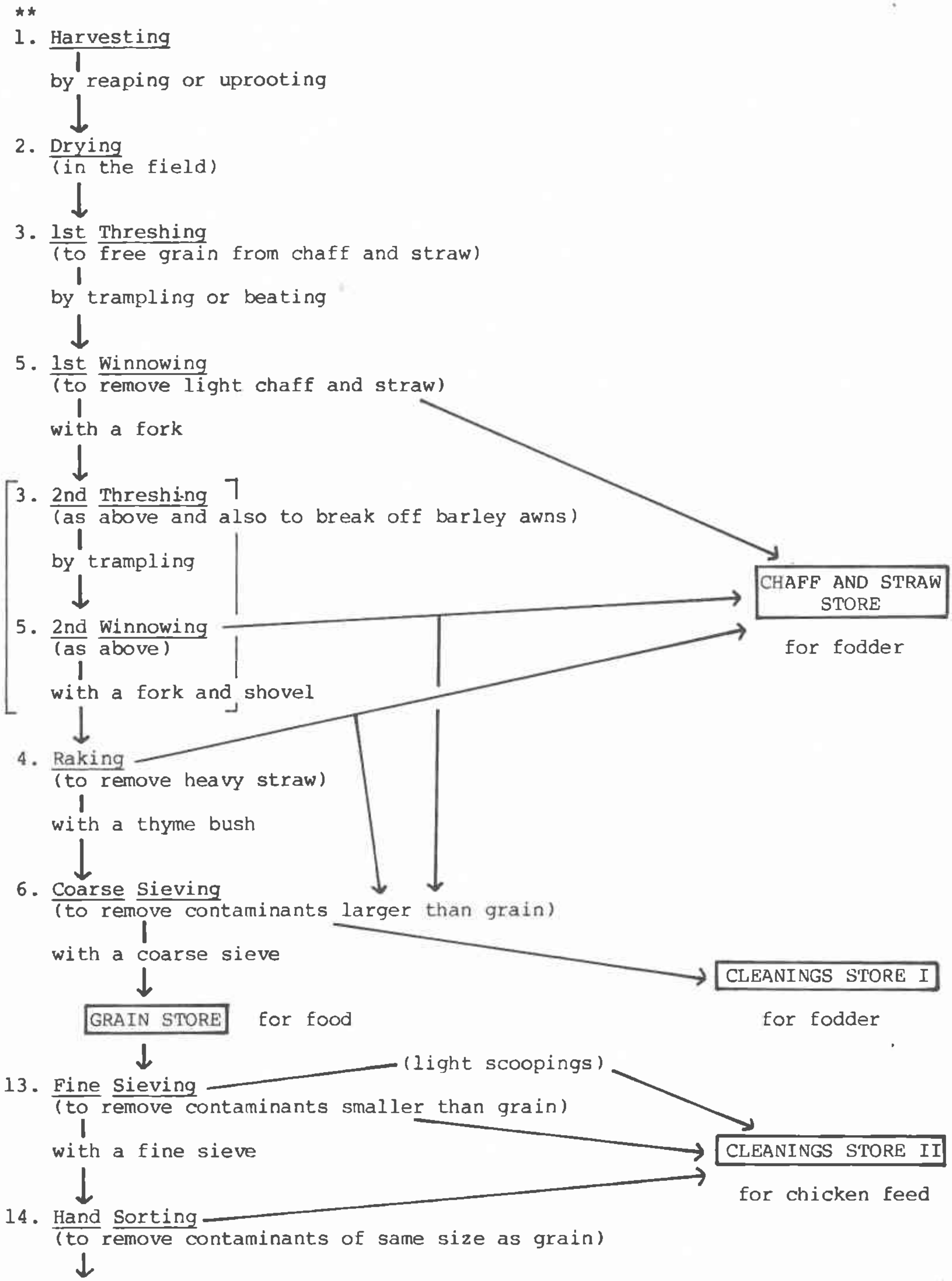


Figure 1. The processing sequence for free-threshing cereals and pulses*

* the sequence is described for cereals but applies to pulses also
** the numbering of stages is after Hillman 1981, Figs. 6 and 7

2 CROP PROCESSING SEQUENCE

All the cereals and pulses intended for dry storage were processed in a broadly similar way and, indeed, in a manner very similar to that described for free threshing cereals and pulses by Hillman (1981) for Turkey. It should be noted that no glume wheats are grown today on Amorgos; all the cereals and pulses are free-threshing. As this factor has, perhaps, the greatest effect on the processing sequences (see Hillman 1981, 1983, this volume) one of the major sources of variation in crop processing has been removed. The processing sequence, as observed on Amorgos was as follows (see also Fig. 1); parallel stages in Hillman's crop processing sequence (Hillman 1981 Figs. 6 and 7) are indicated by numbers in brackets.

2.1 Reaping

Cereals were reaped with a sickle (stage 1) and the straw cut quite low. Pulses were uprooted using a blunt sickle (stage 1) or reaped with a scythe. After reaping, cereals were tied in bundles and pulses piled in heaps and both were left in the field to dry for a few days (stage 2). They were then transported to the threshing floors.

2.2 Threshing

Threshing to release the grain was usually accomplished by trampling with the hooves of animals driven around a circular threshing floor (stage 3). Occasionally, threshing might be done with a long stick which was used to pound the crop in the courtyard of the house. It should be noted that threshing with animals and, on Amorgos at least, threshing with a stick have no effect on the composition of the harvest (cf. Hillman 1981: 153). Both serve merely to release grain from chaff and seeds from pods - no separation of crop or weed components is involved.

2.3 Winnowing

The next stage in the process was the separation of the chaff and straw (leaf, stem and pod in the case of pulses) from the grain. This was done by winnowing (stage 5) - the threshed crop was tossed into the air with a winnowing fork, light chaff and straw were carried aside by the breeze and the grain and heavier chaff and straw fragments fell straight downwards. Small crops could be winnowed simply by lifting handfuls and allowing them to fall.

2.4 Second threshing

This followed the first winnowing and was carried out under two circumstances only: firstly, when the crop was too large to be accomodated in a single threshing, more crop was added and threshed with the same purpose as before and, secondly, crops rich in barley were threshed a second time to break off the barley awns (hummeling).

2.5 Second winnowing

If a second threshing was needed, the crop was again winnowed to separate light straw and chaff from the heavier components of the crop. In the final stages of winnowing, fragments of straw etc. were raked off the top of the grain pile usually using a thyme bush as a small hand rake (stage 4). Winnowing, then, was the first processing stage which affected composition (cf. Hillman 1981: 155) as it involves the separation of light straw and chaff from grain. These may be considered, respectively, the major by-product and product of winnowing - the former was stored as fodder and the latter usually received further processing.

2.6 Coarse sieving

Coarse sieves were used which allow grain to pass through them while retaining large straw fragments, weed heads, unthreshed ears and pods etc. (stage 6). Coarse sieving was the most likely stage to be omitted. It was often not performed on fodder crops and might also be omitted if winnowing was very thorough. Coarse sieving could be used as follows:

(i) As winnowing proceeded, the lightest chaff and straw fraction was blown to one end of the threshing floor and grain tended to accumulate at the other. Between these two areas was an ever-diminishing pile of grain and heavier straw fragments. This was often sieved to speed up the separation of straw and grain.

(ii) Rakings from the top of the grain pile were often similarly sieved as they contained significant amounts of grain.

(iii) The fully winnowed grain was itself sieved.

Grain (the product of winnowing and coarse sieving) and chaff (the by-product of winnowing) were bagged separately and were usually put into storage at this stage for later use as human food and animal fodder. The coarse sieve by-product (cavings) was usually kept for immediate use as fodder.

2.7 Fine sieving

Fine sieves which retained the grain but allowed small weed seeds etc. to pass through were used for grain cleaning (stages 7 and 13) piecemeal throughout the year. For instance, grain was sieved just before it was sent to the mill for grinding into flour and pulses just before cooking. Fodder crops were not usually fine sieved. As the crop was sieved using a circular motion, light components such as straw, pods and weevil-infested seeds collected on top and could be scooped off. Such scoopings (chob - stage 13) were often mixed with the residue from the bottom of the sieve (the fine sieve by-product) which was fed to chickens.

2.8 Hand sorting

Any weed seeds, straw nodes etc. which had not been removed by earlier cleaning were picked out from crops destined for human consumption (stage 14) immediately before grinding into flour or cooking.

2.9 Cross-cultural applicability

Some comment should be made on the cross-cultural and archaeological applicability of this sequence. As Hillman has already pointed out (1981, this volume), it is clear from ethnographic and ethnohistoric accounts and also on a priori grounds that crop processing can only be achieved practically in a limited number of ways, given a traditional technology. Though the details may vary and, in particular, the implements used, the processing stages remain essentially the same and so, more importantly, do their effects on composition. Thus, the effect of winnowing is to separate the light component of the threshed crop from the heavy component, regardless of whether it is performed with a fork, a basket or by hand. Similarly, sieves, regardless of how they are made, must be of very specific mesh sizes if they are to achieve the separation desired. It is difficult to envisage a method of separating chaff from grain which does not involve wind as the agent of separation and which does not take more energy than is provided by the food being cleaned. Likewise, to remove every small weed seed without the use of sieves would be excessively time-consuming. Moreover, the sequence of processes is unlikely to vary much. For example, it would be extremely difficult to sieve before winnowing as an unwinnowed crop is very bulky.

3 SAMPLING

To analyse statistically the effects of crop processing on the composition of the products and by-products of each processing stage, many large samples are needed (Hillman 1981: 126) but it is clear from the description above and more especially from Hillman's (1981, this volume) work that the processing sequence is complex and a large number of products and by-products are generated at the various processing stages. Moreover, a range of cereal and pulse crops is grown and processed for storage.

To collect enough samples of all products and by-products for each crop would, therefore, require more time than is available in one harvest season. Moreover, many of the short-lived products and by-products are unlikely to be preserved archaeologically and many of the by-products are, in any case, often mixed with the by-products of other stages. The collection of samples was limited, therefore, to a small number of products and by-products which are relatively long-lived and unlikely to be obscured by mixing. Partly because of their longevity, they are also the stages most likely to come into contact with fire (cf. the products and by-products marked "F" for exposure to fire in Hillman 1981 Fig. 6) and so be exposed to the possibility of preservation by charring. The products and by-products sampled are discussed below.

3.1 The winnowing by-product

As the by-products of the first and second winnowing were almost always amalgamated and, as both had been selected by the same agent (i.e. by wind), no attempt was made to sample them separately. Rakings and the by-product of coarse sieving were sometimes amalgamated with the winnowing by-product. Their effect on the generally much larger winnowing by-product, however, may be small. In any case, as this type of mixing is likely to have occurred in the past, it is of interest to know whether or not a sample can be identified as primarily a winnowing by-product despite contamination. This by-product was sampled because it went into storage as animal fodder and was, therefore, exposed to the risk of accidental charring, for a long period. It can also be used as fuel (Hillman 1981 Fig. 6).

3.2 The coarse sieve by-product

Although different categories of material might be coarse sieved, all the by-product was usually mixed together in one pile, but usually kept separate from other by-products. Again, no attempt was made to sample these various types of by-product separately. As with winnowing, they were selected by the same agent - in this case, the mesh size of the coarse sieve. Similarly, the coarse sieve by-product may be slightly contaminated by rakings and sweepings but, again, these are likely to have only a minor effect on composition and to be within the range of variation expected archaeologically. This by-product is, perhaps, the least likely, of those chosen for sampling, to be found archaeologically. It is relatively short-lived, though it may be stored for a short time before its use as fodder. It may also be used as fuel (Hillman 1981 Fig. 6).

3.3 The fine sieve by-product

As fine sieving was carried out piecemeal throughout the year, it would have been impossible to collect sufficient samples of fine sieve by-product during the harvest season alone. For this reason, the threshing floor product (which may have been both winnowed and coarse sieved or just winnowed; again such variation is likely in ancient crop processing) was collected and sieved, using a fine sieve provided by one of the farmers. A fine sieve by-product and product were generated by sieving reasonably thoroughly, in the manner of the local women. The fine sieve by-product, which passed through the sieve, was collected. This by-product was sampled because it is likely to be charred. If used as chicken food, it is not kept for long but, in the absence of domestic fowl, it is likely to be thrown directly onto household fires (Hillman 1981 Fig. 6). Fodder crops were also fine sieved because, though this was not done by the villagers, it may have been done in antiquity, especially as the crops concerned are all thought to have been grown for human consumption in the past.

3.4 The fine sieve product

That part of the threshing floor product which was retained by the fine sieve was also sampled because it frequently goes into store (Hillman 1981 Fig. 6) although, on Amorgos, the threshing floor product was usually stored before fine sieving. While in storage it is subject to charring. Also, especially in wet areas, grain may be kiln-dried, before storage, thus increasing the likelihood of charring (Hillman 1981 Fig. 6) and, of course, it is liable to get burnt during cooking.

3.5 Variation between samples

A total of 216 samples was taken from the four major products and by-products. It is important to note that each of the three processing stages sampled relies on a single selective agent to achieve separation of the major product and by-product - wind in the case of winnowing and mesh sizes in the case of coarse and fine sieving. So, winnowing will remove the light components from the heavy, coarse sieving the large components from the smaller and fine sieving the small components from the larger. This is true regardless of when in the sequence each process is performed or what material it is performed on.

Thus there are two major sources of variation between samples: (a) the last process to which the sample was subjected and (b) the previous processing "history" of the sample i.e. the sequence of processes through which the sample had passed before the last process. This study concentrates on the first source of variation for three reasons:

(i) That to subdivide products and by-products further according to their histories would reduce the number of samples in each category.

(ii) It is doubtful whether such similar products and by-products could be distinguished on the basis of sample composition.

(iii) Sample histories are likely to be relatively constant. There will be differences, such as the number and thoroughness of winnowings, the occurrence or not of coarse sieving and so on, but the basic order of the processes is unlikely to vary. Winnowing precedes sieving as an unwinnowed crop is too bulky to sieve satisfactorily and coarse sieving is likely to precede fine sieving, since the reduction in bulk is greater.

Interestingly, the inhabitants of Amorgos themselves classify the by-products of processing not according to the stage from which they were derived but according to their composition as this determines their different uses as winter fodder, immediate fodder for work animals, chicken feed and so on. Coarse sievings, for example, are locally referred to as "kondala" literally meaning "straw nodes". Such amalgamations of by-products as occur are usually between those of similar composition, which is encouraging news for the archaeobotanist interested primarily in the effect of crop processing on composition. Mixing between similar products and by-products from different crops is also more likely than is mixing of products and by-products from different stages.

Predepositional mixing at the refuse disposal stage remains a possibility but mixing between by-products of different stages, if not of different crops, should still be detectable. Thus the absence of mixing cannot be assumed but it is possible to demonstrate empirically whether or not it has occurred. Mixed samples should have characteristics intermediate between two or more by-products. It is difficult to see how, for instance, the mixing of any combination of products and by-products could imitate a fine sieve by-product. Only the intermediate products of processing stages could be satisfactorily replicated by mixing, in the correct proportions, the product and by-product to which they give rise. However, archaeological context may still permit distinction between them and they are likely to be comparatively rare.

4 ETHNOGRAPHIC MODEL OF CROP PROCESSING

The products and by-products of each crop processing stage differ in the proportions of crop seeds, chaff and straw (pods and stems for pulses) and weed seeds (Hillman 1973, 1981; Dennell 1974, 1978). Both cereal and pulse seeds occur on archaeological sites but, whereas the charred remains of cereal chaff and, to a lesser extent, straw are encountered frequently, the equivalent components for pulses, i.e. fragments of pods and stems, are rarely found. In order to find some method of differentiating between the products and by-products of different stages of crop processing applicable to both types of crop, it was decided to concentrate, initially at least, on the evidence from crop and weed seeds. Note that, in contrast to archaeological studies, there is no problem ethnographically in distinguishing those species which were growing as weeds in the fields (cf. Hillman's "A" classification of plant species, this volume).

4.1 Data selection and modification

As a first step in the analysis, the commonest weeds in the Amorgos samples were selected by excluding species present in less than 10% of samples. This reduced the number of species from 103 to 39, but only excluded about 1% of the total number of weed seeds.

Rare species were excluded firstly, because time and effort could more profitably be spent accurately identifying the commoner species. Secondly, the inclusion of such rare species, unless they were potentially very precise indicators, could result in "noise" which obscures rather than enhances any overall pattern in the data (cf. Dagnelie 1978: 223). Thirdly, the total number of seeds excluded in this way was small; where most species are found in only a few samples, the number of variables can be reduced by eliminating classes of species rather than individual species (Hillman this volume).

Although a minimum of 300 weed seeds per sample was aimed at, some fine sieve by-products contained fewer than 50 weed seeds (average 350). Samples of coarse sieve by-products, on the other hand, sometimes contained over 2000 weed seeds (average 880), because weed seeds in coarse sieve by-products tend to be found in heads, and so collection of a reasonable number of heads may produce large numbers of seeds. In order to eliminate this extraneous variation which is not related to any difference in the relative frequency of different types of weed seed, sample size was standardised by using percentages of weed seeds.

Also, since the statistical procedures used in this study assume normality of the variables used, the weed percentages were transformed by taking square roots to make them more normally distributed (cf. Sokal and Rohlf 1969: 384).

4.2 Discrimination of processing groups

Discriminant analyses (using the "direct" method from SPSS, Klecka 1975) were carried out taking the four major products and by-products as the predefined groups to be discriminated and using, firstly, percentages of weed seeds then, secondly, square roots of these percentages as the discriminating variables. The purpose of the discriminant analysis is to reduce the discriminating variables to three composite discriminant functions which maximise the statistical separation of the four predefined groups. A varimax rotation of the discriminant functions was performed to facilitate interpretation of the functions. The discriminating variables contribute to the discriminant functions to varying degrees and the "loadings" of discriminating variables on each discriminant function can be taken as a measure of their contribution to that function. On a particular discriminant function, variables which load high (whether positively or negatively) contribute more than those which load low. The eigenvalues of the discriminant functions are cited as a measure of the functions' relative ability to separate groups of samples and Wilk's lambda, at the start of each analysis, is cited as a measure of the discriminating power of the variables used. The higher the eigenvalues, the greater the functions' ability to separate groups and the lower Wilk's lambda (which was highly significant at less than 0.01 in all the following analyses), the more discriminating power there is in the variables. Another measure of the discriminating value of the functions is given by their ability to reclassify the samples correctly.

Table 1. Discrimination of processing groups

Variables Used	Eigenvalues of Discriminant Functions			λ	%
	1st	2nd	3rd		
A % weed seeds	6.06	2.13	0.66	0.027	86.1
B$\sqrt{\%}$ weed seeds	8.05	3.55	1.22	0.011	93.5

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

The discriminant functions derived from the analysis using weed percentages had very high eigenvalues and Wilk's lambda was low at the start of the analysis (see Table 1A) - 86.1% of samples were correctly reclassified. Using square roots of weed percentages, the three discriminant functions had even higher eigenvalues and Wilk's lambda at the start of the analysis was lower (see Table 1B): 93.5% of samples were correctly reclassified. Thus, the four products and by-products can be very successfully discriminated on the

Table 2. Loadings on discriminant functions using square roots of weed seed percentages

Weed Species	Discriminant Function 1st	2nd	3rd	Weed Seed Category
Galium aparine	0.730	0.056	-0.055	BFH
Lolium temulentum	0.624	-0.053	-0.076	BFH
Lathyrus annuus	0.471	-0.253	-0.135	BFH
Lolium rigidum et al.	-0.426	-0.190	-0.027	SHL
cf. Vicia sativa ssp. nigra	0.379	-0.043	-0.068	BFH
Gladiolus italicus	0.314	0.001	-0.101	BFH
Scandix pecten-veneris	-0.302	-0.218	0.219	SHH
Bifora testiculata	0.293	-0.099	-0.143	BFH
Muscari comosum	0.255	0.230	0.042	SFH
Tetragonolobus purpureus	0.238	-0.167	-0.046	BFH
Anchusa azurea	0.232	-0.139	-0.109	BFH
Malva sylvestris	0.216	-0.184	-0.021	SHH
Phalaris coerulescens	-0.209	-0.001	-0.106	SHH
Hirschfeldia incana	-0.192	-0.079	-0.041	SHL
Plantago lagopus	-0.161	-0.138	-0.133	SHL
Avena sterilis	-0.138	-0.134	0.008	BHH
Hordeum murinum ssp. leporinum	-0.138	0.020	0.068	SHL
Convolvulus altheoides	0.097	-0.067	-0.057	BFH
Sinapis arvensis	-0.019	0.490	0.027	SFH
Melilotus sulcata	0.014	0.420	-0.127	SFH
Chrysanthemum coronarium	-0.021	0.354	-0.183	SFH
Sherardia arvensis	-0.293	0.347	-0.127	SFH
Calendula arvensis	0.017	-0.298	-0.276	BFH
Buglossoides arvensis	-0.040	0.257	-0.003	SFH
Silene vulgaris	-0.197	0.219	0.125	SHH
Picris cf. pauciflora	0.074	0.127	0.137	SFH
Medicago cf. turbinata	0.105	-0.111	0.079	BHH
Galium verrucosum	0.010	-0.094	0.018	BFH
Cichorium intybus	-0.032	-0.078	0.760	SHH
Crepis cf. foetida	-0.066	0.084	0.607	SHL
Sonchus asper	-0.180	-0.229	-0.494	SFL
Papaver rhoeas	-0.232	-0.126	0.478	SHL
Rapistrum rugosum	0.175	0.061	-0.285	BFH
Hedypnois cretica	0.044	0.163	0.269	SHH
Lathyrus aphaca	-0.084	0.171	0.190	BFH
Rumex pulcher	0.135	0.041	0.156	SFH
Chrysanthemum segetum	-0.081	0.094	-0.131	SHH
Bromus sterilis	-0.064	-0.052	-0.105	SFL
Ornithogalum narbonense	0.019	0.089	-0.091	SFH

highest loading for each species underlined

BHH = big, headed, heavy BFH = big, free, heavy SHH = small, headed, heavy
SHL = small, headed, light SFH = small, free, heavy SFL = small, free, light

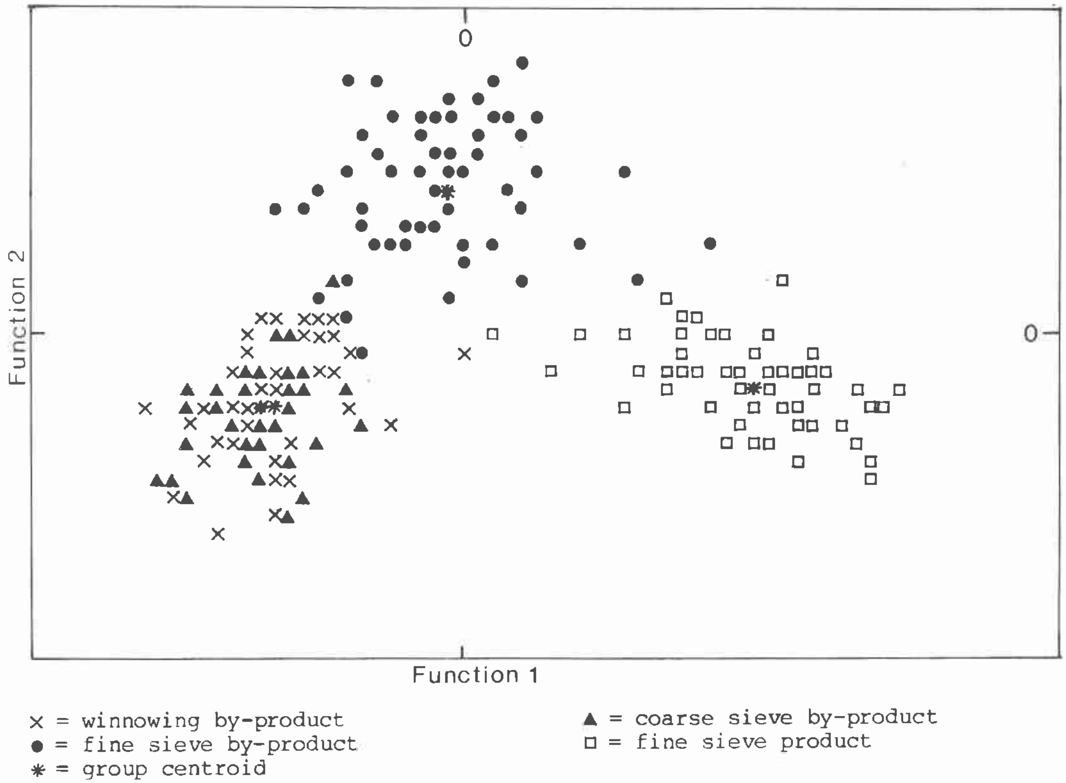


Figure 2. Discrimination of processing groups using square roots of weed seed percentages

basis of weed seeds alone. However, the explanatory power of a solution depends on the interpretability of the discriminant functions. It is worth, therefore, examining the varimax rotated solution of the latter analysis in relation to weed seed characteristics and crop processing groups (see Table 2, Fig. 2).

The first function (which places fine sieve products at the positive extreme and winnowing and coarse sieve by-products at the negative extreme) has relatively high positive loadings mostly for large-seeded weeds and relatively high negative loadings for weeds with seeds commonly remaining in "heads" or with appendages. The second function (which separates off fine sieve by-products positively) has relatively high positive loadings for small-seeded weeds and relatively high negative loadings for big or headed weed seeds. The third function, which primarily separates winnowing by-products (negatively) and coarse sieve by-products (positively), tends to have relatively high positive loadings for weeds whose seeds remain in "heads" and relatively high negative loadings for free, light weed seeds. The loadings of the weed seeds on the functions are, therefore, consistent with the processing groups used in the analysis.

4.3 Effect of numbers of weed species used

In order to explore the effects of excluding rare weed species, the above analysis was repeated several times removing the four least commonly occurring species each time. When only the three commonest weed species were used, 50.5% of samples were correctly reclassified and the addition of four further species produced a dramatic

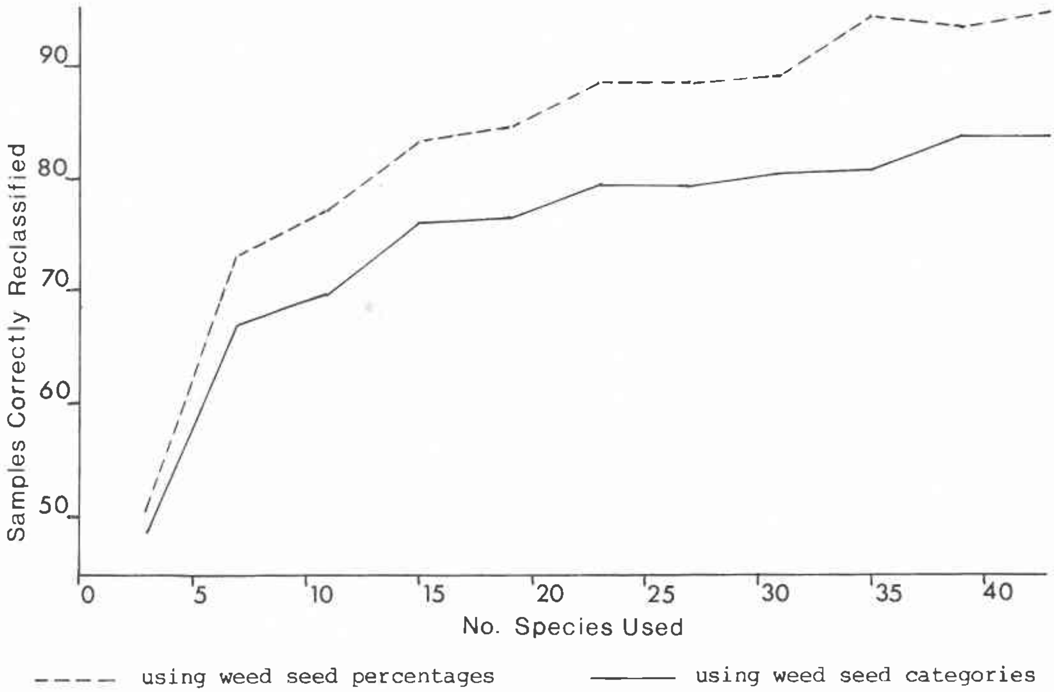


Figure 3. Effect of using different numbers of weed species for discrimination

improvement to 73.2% (see Fig. 3). Little is gained, however, by increasing the number of species from 15 to 43. For this group of samples and for this problem, therefore, the use of the 39 weed species occurring in at least 10% of samples is more than adequate and inclusion of rarer species would have been distinctly less cost effective.

4.4 Individual treatment of crop processing groups

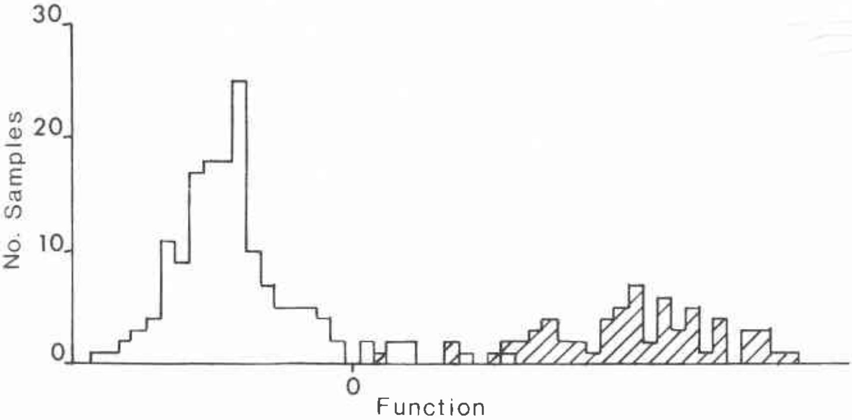
Four discriminant analyses were also performed, each comparing one processing group (e.g. winnowing by-products) with the remaining three. These analyses discriminated the individual groups successfully - and fine sieve products, for instance, were correctly reclassified in 98.6% of cases (see Table 3D, Fig. 4).

The discriminant functions are also reasonably interpretable. The function which discriminates winnowing by-products negatively from other processing groups has high negative loadings for weeds with light seeds and high positive loadings for those which are heavy. Similarly, on the function which discriminates coarse sieve by-products negatively, weeds with seeds in heavy heads load high negatively and those with free or light seeds high positively. Fine sieve by-products are discriminated positively on a function on which weeds with small, free, heavy seeds load high positively and those

Table 3. Discrimination of each processing group from all others

Group Discriminated	Eigen-value	λ	%
A winnowing by-product	1.79	0.359	94.4
B coarse sieve by-product	2.33	0.300	94.0
C fine sieve by-product	3.26	0.235	97.7
D fine sieve product	6.64	0.131	98.6

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified



▨ fine sieve product □ by-products

Figure 4. Discrimination of fine sieve product from by-products

with large seeds load high negatively. Finally, weeds with big, free, heavy seeds load high positively on the function which positively discriminates fine sieve products from the by-products, while weeds with small seeds or seeds in heads load high negatively.

Thus, the way in which weed seeds are distributed amongst the various products and by-products of crop processing is again related to certain characteristics of the seeds themselves. This is important because it is unlikely that exactly the same weed species will occur archaeologically as occur in ethnographically collected samples. We therefore have to rely on characteristics of the weeds which can be applied to other species.

Table 4. Discrimination of crop processing groups for cereals, pulses and subsample using square roots of percentages

	Eigenvalues			λ	%
	1st	2nd	3rd		
A pulse	16.49	4.12	2.57	0.003	99.1
B cereal	15.39	9.71	1.95	0.002	99.1
C 50% sub-sample	12.38	5.28	1.53	0.005	97.2

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

4.5 Separate Treatment of Cereals and Pulses

When discriminant analysis was applied to the four groups of products and by-products, treating samples from cereal and pulse crops separately, one source of variation in the weed seeds associated with crop samples was effectively removed. In both cases, 99.1% of samples were reclassified correctly (see Table 4A and B). In fact, only two samples, a pulse fine sieve by-product (reclassified as a coarse sieve by-product) and a cereal coarse sieve by-product (reclassified as a winnowing by-product) were incorrectly reclassified. For both cereals and pulses, the first function is largely interpretable in terms of seed size, the second in terms of the tendency of seeds to stay in "heads" and the third in terms of lightness of seed. These interpretations fit well with the positions of the groups in relation to the discriminant functions (see for example Fig. 5).

The fact that the discrimination was so successful for both cereals and pulses again indicates a consistent relationship between the types of weed seeds found in samples and the status of the samples in the processing sequence. A 50% random subsample provided equally convincing results (see Table 4C).

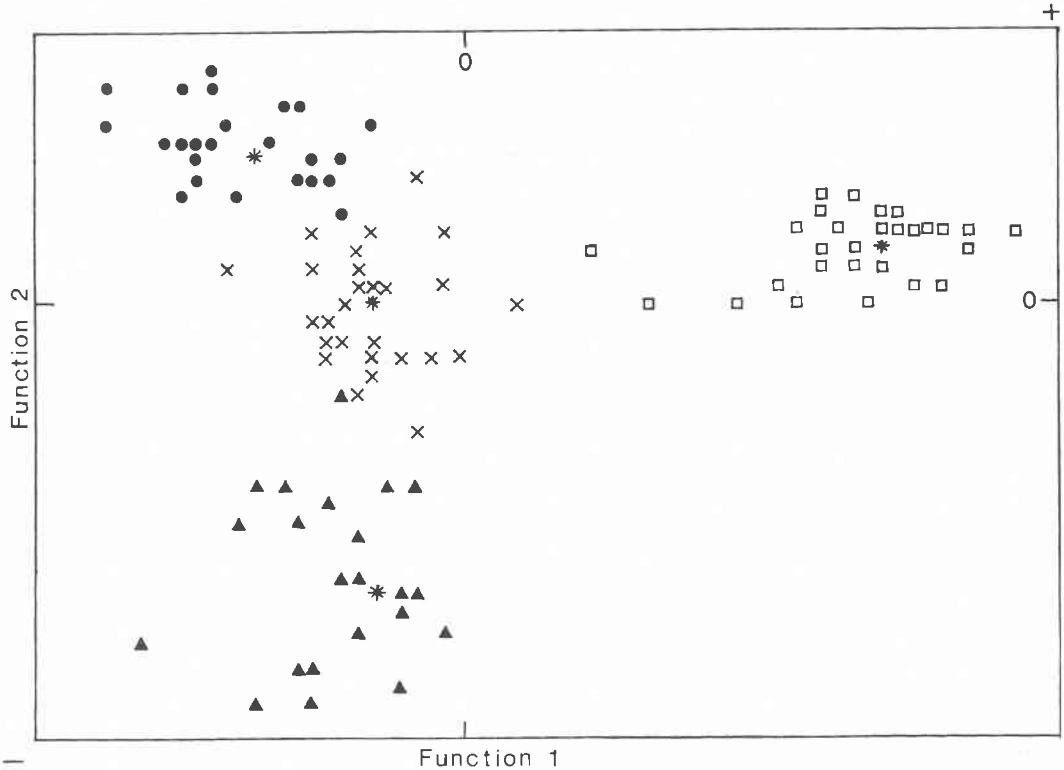


Figure 5. Discrimination of processing groups for cereals using square roots of weed seed percentages

key as for Fig. 2

5 ARCHAEOLOGICAL APPLICABILITY OF MODEL

I will now examine ways in which these methods of analysis could be applied archaeologically. It is highly unlikely that two separate case studies, whether archaeological or ethnographic, will yield exactly the same range of weed species but this does not preclude the use of ethnographic models in the interpretation of archaeological samples. In fact, such models can be made widely applicable, both temporally and geographically, by considering weed characteristics rather than individual species.

5.1 Choice of weed characteristic variables

Three characteristics of weed seeds seem to be most relevant to crop processing:

(i) Size of seed - this is most relevant to fine sieving since small seeds tend to pass through the sieve and large seeds to be retained. Seed size will, therefore, be defined relative to the size of the fine sieve mesh.

(ii) Tendency of seeds to remain in heads, spikes or clusters despite threshing (sometimes because the seeds are slightly immature) or to retain large projections - this is most relevant to coarse sieving since seeds in heads etc. tend to be retained by the sieve while free seeds pass through.

(iii) Aerodynamic qualities of seeds, including density, shape and presence or absence of features such as wings or hairs - this is most relevant to winnowing.

This simple classification could be refined, if necessary, to take account

Table 5. Discrimination using weed characteristic variables

Variable Type	Eigenvalues			λ	%
	1st	2nd	3rd		
A %ages (all weeds)	3.50	1.04	0.10	0.099	74.1
B %ages (extremes)	4.74	1.54	0.03	0.066	76.9
C weighted indices	4.23	1.44	0.00	0.078	80.6
D weed seed categories	4.55	1.80	0.32	0.049	83.8

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

of any seeds large enough to be retained by the coarse sieve, heads small enough to pass through the coarse sieve or heads light enough, despite heavy seeds, to be removed by winnowing (cf. Hillman's "B" classification of weed species, this volume). There are a number of ways in which these weed seed characteristics could be used and these are discussed and evaluated here.

For each sample, the percentages of big, headed and light seeds were calculated and used as discriminating variables in a discriminant analysis of the four processing groups used previously. Discriminant functions with high eigenvalues were extracted, Wilk's lambda at the start of the analysis was low (see Table 5A) and 74.1% of samples were correctly reclassified.

Weeds with more or less neutral seed characteristics, i.e. with middle-sized seeds, with seeds which sometimes remain in heads and are sometimes free and with seeds which are neither light nor heavy, were included in the calculation of percentages. The analysis was also repeated excluding weeds with neutral seed characteristics. This gave slightly better results (see Table 5B) and 76.9% of samples were reclassified correctly.

To take more account of the varying degree to which weed seeds possess a certain characteristic, each species was scored for each characteristic on a scale from 1 to 5, for increasing size, increasing tendency to stay in heads and increasing heaviness. The square root of the percentage of seeds of each species was multiplied by the species score for a particular characteristic and these products were summed for each sample (cf. the "weighted averages" method of plant community ordination, Whittaker 1978). Thus three "weighted indices" were created, for each sample, which broadly measure (i) the overall size (ii) the tendency to stay in heads and (iii) the aerodynamic properties of the weed seeds. The discriminant analysis was then repeated using these three indices. The results were also good (see Table 5C) and 72.7% of samples were correctly reclassified.

However, the three weed seed characteristics do not operate entirely independently and this may have an even more important effect than the degree to which a species possesses a single characteristic. For example, light seeds which also tend to remain in heads will probably not be removed by winnowing. So, weed seeds were grouped into categories such as big, heavy and headed (BHH); small, free and light (SFL) and so on, so as to take account of all three characteristics simultaneously (see Table 2). The square roots of percentages of weed seeds in each category were summed for each sample, thus creating six (there were no big, light seeds) new variables for each sample. These six variables were then used as the discriminating variables in a discriminant analysis of the four processing groups.

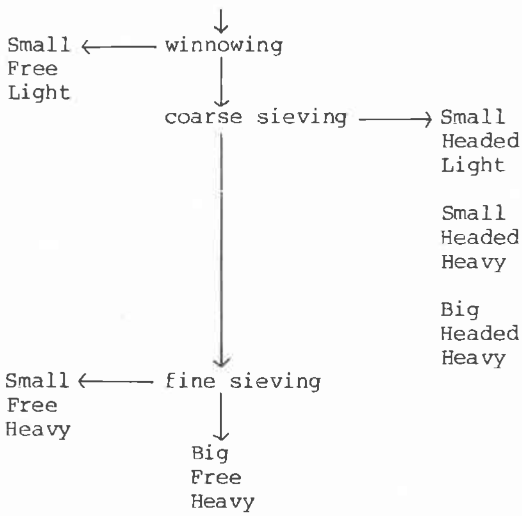


Figure 6. Processing sequence indicating effects on weed seed categories

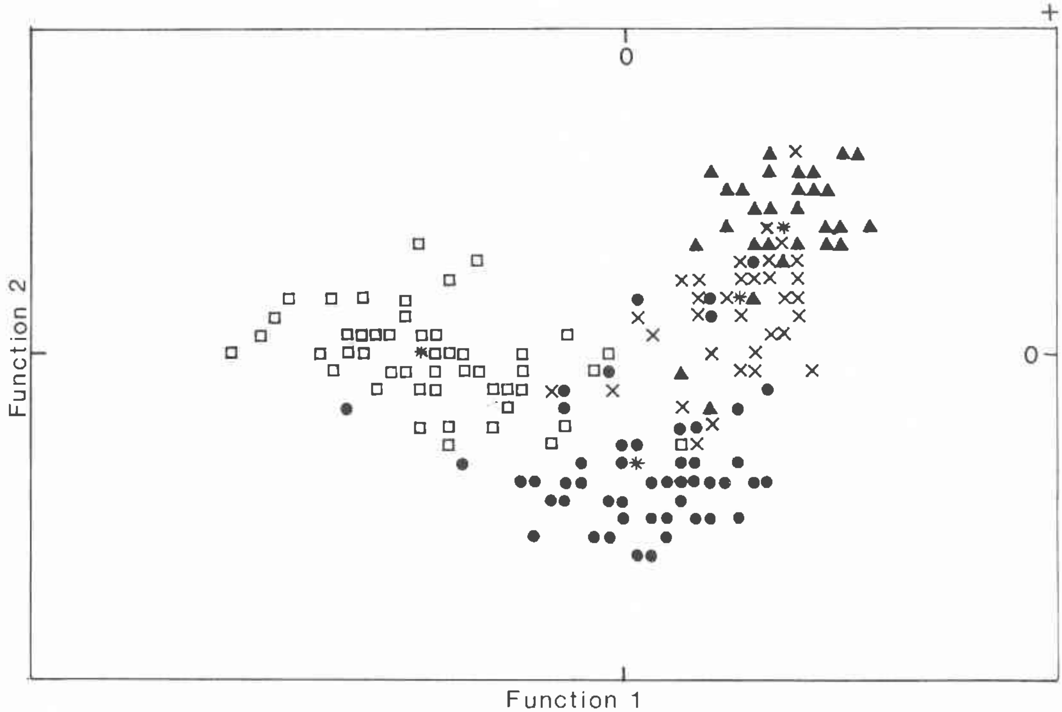


Figure 7. Discrimination of processing groups using weed seed categories key as for Fig. 2

The result is that Wilk's lambda at the start of the analysis was low and three functions with high eigenvalues were extracted (see Table 5D): 83.8% of samples were reclassified correctly. This itself is a very satisfactory result is even more satisfactory when one examines the way in which the six variables load on the three discriminant functions. Let us first consider what would be the expected effect of crop processing on these categories of weed seeds (see Fig. 6). Clearly, small, free, light seeds (SFL) should largely be removed by winnowing and so end up with the winnowing by-products. The seeds which tend to remain in heads (SHL,SHH and BHH), regardless of whether their seeds are light or heavy, big or small, should be removed by coarse sieving and remain with the coarse sieve by-products. Small, free, heavy seeds (SFH) would be mostly removed by fine sieving and so stay with the fine sieve by-products leaving big, free, heavy seeds (BFH) with the fine sieve products.

Table 6. Loadings on discriminant functions using weed seed categories

Weed Seed Category	Discriminant Function 1st	2nd	3rd
Big,Free,Heavy	<u>-0.789</u>	0.094	-0.045
Small,Free,Heavy	-0.090	<u>-0.795</u>	0.112
Small,Free,Light	-0.002	0.001	<u>0.784</u>
Small,Headed,Light	0.333	0.476	0.066
Small,Headed,Heavy	0.338	0.335	-0.515
Big,Headed,Heavy	0.060	0.263	0.259

loadings >0.75 underlined

The results of the discriminant analysis are consistent with these expectations (see Table 6, Fig. 7). Big, free, heavy seeds load high negatively on the first function which separates fine sieve products

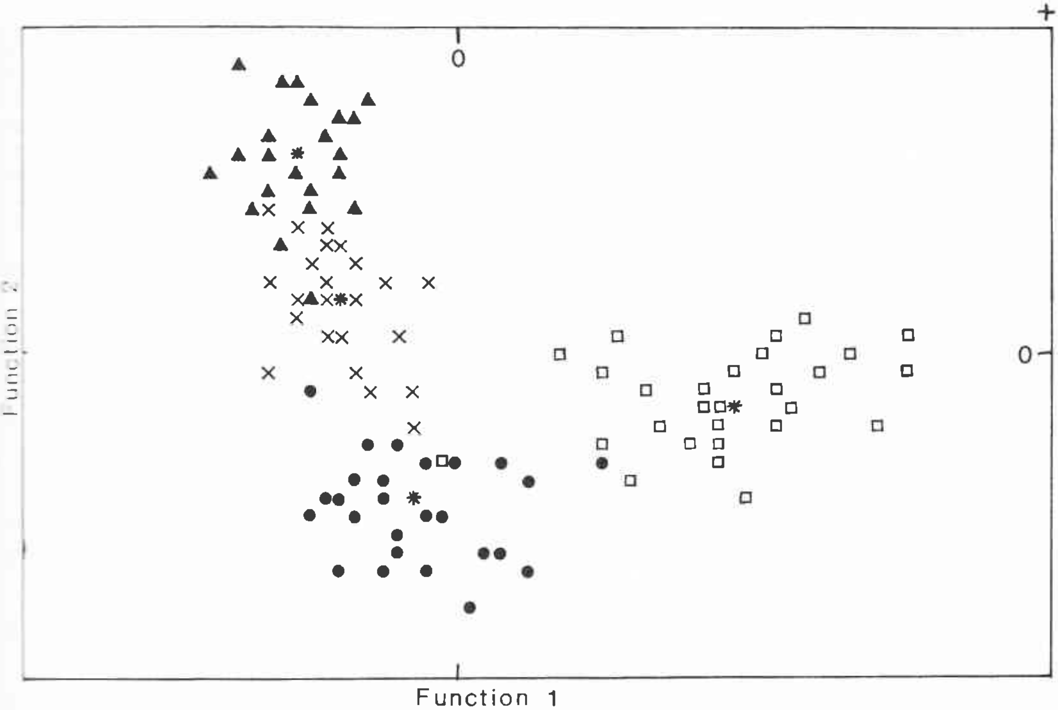


Figure 8. Discrimination of cereal processing groups using weed seed categories key as for Fig. 2

negatively from the by-products. Small, free, heavy seeds contribute most and negatively to the second function which separates fine sieve by-products negatively from other by-products and products. Lastly, it is the small, free, light seeds which load high positively on the third function which separates winnowing by-products positively from the other groups. The weeds which remain in heads do not load high on any of the discriminant functions and coarse sieve by-products occupy a comparatively neutral position on all functions.

5.2 Effect of number of weed species used

The effect of using different numbers of weed species was again examined with results similar to those for the analysis of ungrouped weeds (see Fig. 3). So again, the use of the 39 weeds present in at least 10% of samples is more than adequate.

Table 7. Separate discrimination of cereal and pulse processing groups using weed seed categories

Crop	Eigenvalues			λ	%
	1st	2nd	3rd		
A pulse	5.55	1.65	0.41	0.041	87.2
B cereal	8.56	3.06	0.43	0.018	90.7

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

5.3 Consideration of other variables

Broadly similar results were obtained when cereals and pulses were treated separately. As before, the results were improved by the elimination of this source of variation (see Table 7, Fig. 8): respectively 90.7% and 87.2% of samples were correctly reclassified.

The analysis was also repeated using, firstly, the ratio of number of weed seeds to number of crop seeds and, secondly, the ratio of weight of weed seed to weight of crop seed, in addition to the six weed seed categories. This improved the results slightly (see Table 8) but not as much as might have been expected. Although products might be expected to have very little weed seed and by-products very little crop seed, in fact, coarse sieve by-products often contain a lot of crop seed and winnowing by-products little weed seed.

Table 8. Discrimination of crop processing groups using weed seed categories and ratios of crop to weed seeds

Ratio	Eigenvalues 1st	2nd	3rd	λ	%
A ratio no. crop to weed seed	4.56	1.83	0.32	0.048	84.3
B ratio wt. crop to weed seed	4.69	2.08	0.33	0.043	83.3

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

To explore the usefulness of chaff and straw remains, in the interpretation of crop processing for cereals, a number of further discriminant analyses were performed. Note that models based on chaff and straw from the Amorgos cereals, which are free-threshing, can be applied archaeologically only to other free-threshing cereals. The most durable parts of the chaff and straw of free-threshing cereals are the rachis and the culm nodes, so both rachis internodes and culm nodes were counted and expressed as a percentage of total internode or node plus grain. The percentages of rachis internodes were calculated separately for wheat and barley. Macaroni and bread wheat grains could not be easily distinguished and so a single ratio was calculated for wheat. The percentages of culm nodes were calculated for all cereals together.

The first analysis used only three variables; percentages of wheat and barley rachis internodes and the percentage of culm nodes. Seven samples with fewer than ten grains plus rachis internodes or culm nodes were excluded from the discrimination, as were the eight samples from oat crops. The former, however, were included in the reclassification. Only the first function contributed significantly to the discrimination (see Table 9A)

Table 9. Discrimination of crop processing groups using chaff and straw variables

Variables Used	Eigenvalues 1st	2nd	3rd	λ	%
A chaff & straw only	30.03	0.14	0.02	0.028	73.7
B with no. crop:weed seed	31.11	0.16	0.05	0.026	73.7
C with wt. crop:weed seed	31.08	0.48	0.14	0.019	82.8
D with weed seed categories	43.11	3.36	1.86	0.002	97.0
E with weed categ. & no. ratio	43.51	3.40	2.00	0.002	99.0
F with weed categ. & wt. ratio	44.07	3.82	1.86	0.002	97.0

λ = Wilk's lambda at start of analysis
% = percentage of samples correctly reclassified

though Wilk's lambda at the start of each analysis was low. In the rotated solution each variable loads high positively on one discriminant function and, on all functions, winnowing and coarse sieve by-products are situated positively and fine sieve products and by-products negatively. This reflects the fact that most of the straw and chaff is removed by winnowing and coarse sieving, before the process of fine sieving. However, only 73.7% of samples were correctly reclassified. Although there is a 100% correct reclassification of samples into two groups i.e. winnowing and coarse sieve by-products on the one hand and fine sieve products and by-products on the other, there is poor reclassification within these groups (see Table 10).

Table 10. Percentage correct reclassifications of different processing groups using chaff and straw variables (excl. oat)

Actual Group	Predicted Group			
	A	B	C	D
A	84.0	16.0	0.0	0.0
B	25.0	75.0	0.0	0.0
C	0.0	0.0	14.0	55.6
D	0.0	0.0	7.4	92.6

A = winnowing by-product
B = coarse sieve by-product
C = fine sieve by-product
D = fine sieve product

The discriminant analysis was repeated using other variables in addition to chaff and straw. The first variables to be added were the ratio of the numbers of crop to weed seeds (which had little effect - see Table 9B) or the ratio of the weight of crop to weed seed (which improved the results slightly - see Table 9C). The results were less satisfactory, however, than those, for cereals, based on weed groups alone (see Table 7B). This suggests that, for free-threshing cereals, weed seed characteristics are more diagnostic of processing stages than are chaff, grain and overall weed proportions. This is not the case for glume wheats, however (cf. Hillman 1981 Fig. 5, this volume).

When chaff and straw variables were used in conjunction with weed groups, 97.0% of samples were reclassified correctly (see Table 9D). In this instance, the further addition of the ratio of weight of weed to crop seed produced little improvement, but the addition of the ratio of number of crop to weed seeds did (see Table 9E and F): 99.0% of samples were correctly reclassified. In fact, in the latter case, only one fine sieve by-product was misclassified as a fine sieve product. The rotated functions of this last discrimination are also reasonably interpretable (see Table 11) which

Table 11. Loadings on discriminant functions using chaff, straw and other variables

Variables	Discriminant Funct.		
	1st	2nd	3rd
barley internodes	0.889	0.181	0.143
wheat internodes	0.563	-0.092	-0.137
BFH weed seeds	0.008	0.901	0.006
SFH weed seeds	0.044	-0.031	0.935
SHH weed seeds	0.064	-0.392	-0.668
straw nodes	-0.346	0.113	0.157
no. crop:weed seed	-0.047	0.077	0.326
SFL weed seeds	0.482	0.081	0.226
SHL weed seeds	0.233	-0.216	-0.233
BHH weed seeds	0.112	0.148	-0.163

loadings >0.5 underlined
BHH = big, headed, heavy
BFH = big, free, heavy
SHH = small, headed, heavy
SHL = small, headed, light
SFH = small, free, heavy
SFL = small, free, light

suggests that they may be generally applicable. For example, the wheat and barley rachis internode percentages load high positively on the first function which separates off winnowing and coarse sieve by-products positively (see Fig. 9). Big, free, heavy seeds load high positively on the second function which separates off fine sieve products positively. Small, free, heavy seeds load high positively and small, headed, heavy seeds negatively on the third function which mostly separates off fine sieve by-products positively, especially in relation to coarse sieve by-products.

So, the chaff and straw components considered here, especially in conjunction with other variables based on weed seed characteristics, can contribute to the study of the processing of free-threshing cereals. The weed seed characteristics discussed, however, should be applicable to glume wheats also since weed seeds are likely to be less affected by the differences between the sequences for these two types of cereal than are the chaff and straw components.

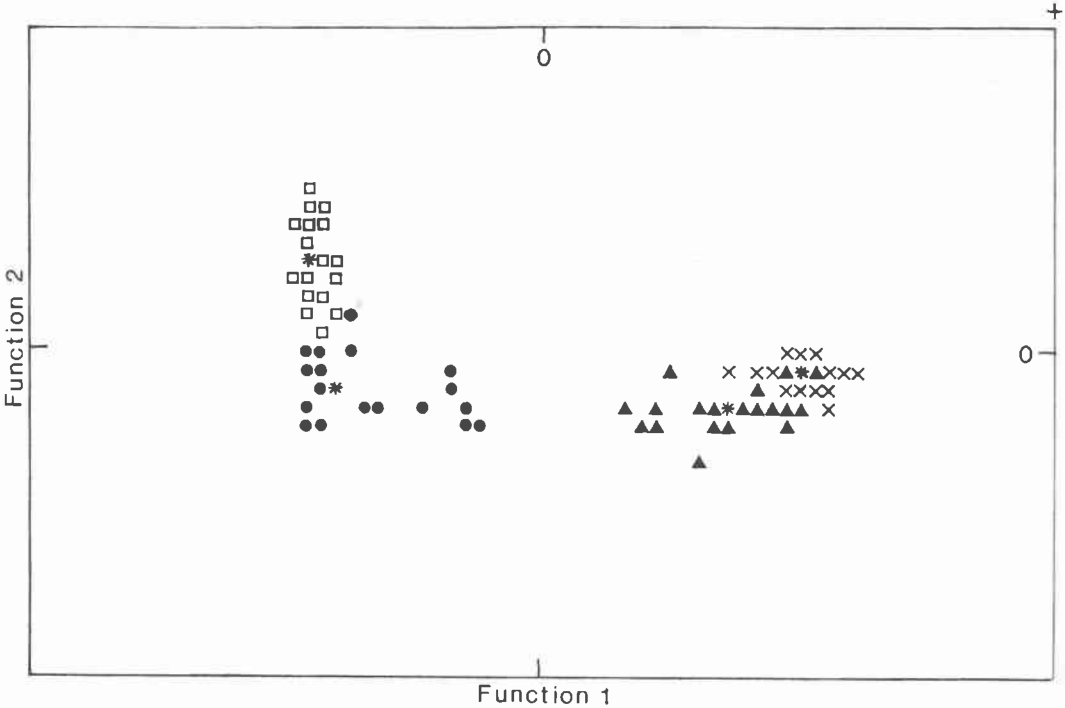


Figure 9. Discrimination of cereal processing groups using chaff, straw and other variables
key as for Fig. 2

6. CONCLUSION

This model of crop processing based on the statistical analysis of ethnographically collected samples can now be used in the interpretation of archaeological samples. The intermediate products of each processing stage (and the by-product of hand sorting) can also be modelled so that these too may be compared with archaeological samples. Using weed seed characteristics, it is possible to compare archaeological and ethnographic samples of plant remains directly. This may be done by taking ethnographic samples as control groups to which the archaeological samples are compared by discriminant analysis classification procedures. The conclusions drawn from the ethnographic study, particularly with regard to weed seed characteristics and the relative usefulness of different composition characteristics, can also be applied indirectly. This may be done through internal analysis of the archaeological samples, using principal components analysis to understand the relationship between crop processing variables and using cluster analysis to group samples according to these variables. The results of these applications, however, must await a later communication.

It is also clear from the present study that it is easier to identify a sample as the product or by-product of a particular stage than to identify the precise methods used: for example, it may be possible to identify a winnowing by-product but to be unable to tell whether the crop was winnowed with a fork or basket. Though a disadvantage to a detailed study of crop processing, this can be an advantage in other respects. For example, in order to identify activity areas, functions of buildings etc., it is more important to know the processing stage than the method used. Similarly, when weeds are used as indicators of husbandry practices, it is helpful to filter out the variation in weed seeds shown here to result from crop processing.

Because products and by-products of similar stages have similar compositions, regardless of the precise methods used, the ethnographic model can be used in this way for archaeological sites where the exact methods of crop processing are not usually known.

ACKNOWLEDGEMENTS

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