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The Cereal Grain Trade in the United Kingdom: The Problem of Cereal Variety [and Discussion]

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The cereal grain trade in the United Kingdom: the problem of cereal variety

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[Plate 1]

The production of cereals in the United Kingdom has increased steadily over recent years from 12.6 million tonnes in 1964 to 21.8 million tonnes in 1982. During this period, the United Kingdom's accession to the E.E.C. in 1973 caused a reverse in the milling industry's policy of including only a small proportion of home-grown wheat with imported wheat in breadmaking grists. Home-grown wheat is now the major constituent of mass produced bread.

Since the passing of the Plant Varieties Rights Act in 1964, plant breeders have been able to collect royalties on the sale of seed of their varieties; this led within a decade to a large number of high yielding varieties on offer to the farmer. Thus during the period of adjustment to home-grown wheat after 1973, the milling industry had to select from a wide range of varieties of different milling and baking qualities. Selection was aided by the offer of a 'premium' (extra payment) for wheat of the right variety. The millers' problem then was to be able to check that the wheat received was of the variety claimed by the supplier.

Investigations of the heterogeneity of gliadins by electrophoresis had been conducted by several workers, but a refined procedure was developed that used starch gel electrophoresis that was able to distinguish most varieties of wheat grown in France and the E.E.C. Different electrophoretic patterns were obtained from individual grains of different varieties: grains of the same variety gave similar patterns irrespective of growth environment. Subsequent developments of variety identification by electrophoresis have improved the resolution and time of analysis.

Use of electrophoresis to check the varietal composition of grain being supplied to a British miller revealed that contracts that specified varietal content were usually, but not always, complied with. It was found that the miller was able to seek financial reimbursement from his supplier to compensate for the poorer grade of wheat received in about one in eight deliveries from France; and in about one in seven deliveries from the British farmer. Farmers have now adjusted to growing, storing and supplying varieties separately, such that the current frequency of erroneous grain delivery is about one in 50.

The impact of variety identification by electrophoresis in barley trading has been less than in wheat trading. This is partly because it is sometimes possible to verify a purchase through examination of grain morphology, and partly because the alternative electrophoretic analysis is often impractical, because of frequently large numbers of barley varieties carrying identical hordein proteins.

Introduction

The production of cereals in the United Kingdom has risen steadily in recent years (see table 1); and it is predicted that this rise will continue.

There are several reasons for this trend, but the main impetus is the desire of successive governments, through the mechanism of the Common Agricultural Policy of the E.E.C., to ensure a plentiful supply of food. It would then be expected that the cereals' processing industry, an essential link in this chain of supply, would be relieved of the need to obtain its raw materials from outside the E.E.C. Although this is to some extent true, there is still the problem of obtaining raw material of satisfactory quality.

TABLE 1. CEREAL PRODUCTION IN THE UNITED KINGDOM FROM 1964 TO 1982

year of harvest	wheat Mt	barley Mt	others Mt	total Mt
1982 (forecast)	10.3	10.9	0.6	21.8
1981 (provisional)	8.7	10.2	0.7	19.6
1980	8.5	10.3	0.7	19.5
1975 to 1979 (average)	5.7	9.2	0.8	15.7
1970 to 1974 (average)	5.0	8.6	1.4	15.1
1965 to 1969 (average)	3.7	8.6	1.4	13.7
1964	3.7	7.4	1.5	12.6

sources: Home-Grown Cereal Association (H.G.C.A.) press notice no. 3/83.
H.G.C.A. cereal statistics 1981
H.G.C.A. annual report 1968-69

TABLE 2. CEREAL USE IN THE UNITED KINGDOM

	1964-65	1981-82
total of all cereals/Mt	20.7	19.0
wheat/Mt		
total	8.1	8.8
human consumption	5.5	4.9
animal feed	2.4	3.4
barley/Mt		
total	7.6	7.3
human consumption	1.3	1.9
animal feed	5.9	4.8

sources: H.G.C.A. press notice no. 3/83.
H.G.C.A. annual report 1968-69.

Millers, and other cereal processors, are currently in the position of having to select home-grown cereals carefully. Grain trading contracts now frequently specify a particular variety of cereal, this being the simplest method of regulating potential quality. Of the range of tests conducted on supplies of cereal before further processing, those used to identify the variety of cereal are of increasing importance.

The purpose of this paper is to elaborate the need for tests to identify varieties, the nature of the tests and the consequences of applying them.

CEREAL USAGE IN THE UNITED KINGDOM

In 1964-65, an arbitrarily chosen year representative of grain trading and use before the United Kingdom's accession to the E.E.C., the total national consumption of cereals was 20.7 million tonnes (see table 2). This comprised mainly wheat (8.1 million tonnes), nearly as much barley (7.6 million tonnes), oats (1.3 million tonnes) and the remainder maize.

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Seventeen years later in 1981-82, during which time home production of wheat and barley nearly doubled, cereal consumption had declined slightly to 19.0 million tonnes. Of that the proportion of wheat used was higher, largely because of its allocation to animal feeds, in lieu of oats and imported maize.

Wheat for human consumption has declined mainly because of increased affluence, which is shown by the public's preference for more meat-based meals, and its reluctance to buy large quantities of such basic foodstuffs as flour and bread. The increase in human consumption of barley is because of the recent development of a large export market for malt.

Table 3. Sources of cereals used in the United Kingdom

	1964-65		1981-82	
	imported	home-grown	imported	home-grown
	Mt	Mt	Mt	Mt
wheat total				
human consumption	3.7	1.8	1.6	3.3
animal feed	0.6	1.8	0.1	3.3
barley total				
human consumption	0.1	1.2	0	1.9
animal feed	0.2	5.7	0	4.8

sources: H.G.C.A. press notice no. 3/83.
H.G.C.A. annual report 1968-69.

Other changes are to be found when the amounts of imported and home-grown wheat used in the United Kingdom are compared (see table 3). Seventeen years ago, and typical of the period preceding accession to the E.E.C., an amount of wheat (3.7 million tonnes) equivalent in size to the national wheat harvest, was imported mainly for breadmaking. Some home-grown wheat would be mixed (gristed) with imported wheat, but the bulk of the home-grown wheat was milled for cake and biscuit flour, or used for animal feed. By 1981-82 the reverse was true. Only 1.6 million tonnes (and forecast to be 1.3 million tonnes in 1982-83) were imported for breadmaking. The greater part of a grist for breadmaking flour is, and will probably continue to be, obtained from home-grown wheat.

A more colourful way of expressing this change is to describe the typical British loaf in 1964-65 as comprising 25% British wheat, and 75% imported wheat. The imported wheat would have been gathered from any exporting country, but the largest amount was taken from Canada. Other major suppliers in 1964-65 were Australia, Argentina, the Netherlands, France and the U.S.A. (see table 4). Today, the ratio of British to imported wheat in the typical loaf has been reversed. Canadian wheat is the most reluctantly relinquished by British millers, but wheat from all other countries is now used less frequently.

The reason for this change from imported to home-grown wheat lies in the Common Agricultural Policy, which seeks to use financial mechanisms to modify free market forces within the E.E.C. A 'threshold price' is set for wheat (and all cereal) imports from non-member states. These represent minimum import prices for foreign grain and give farmers in the E.E.C. a generous margin of protection. The difference, calculated daily, between this 'threshold price' and the world price of wheat, defined as the price of wheat being offered in the Rotterdam market, is the import levy. The levy is essentially a form of tax placed on importers of grain from countries outside the E.E.C. On May 1, 1983, this stood at 71% of the world market

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price (see table 5); it is an effective means of encouraging millers to buy wheat from within the E.E.C.

The E.E.C. also applies a second financial device, referred to as the intervention price. Provided that certain minimum standards of quality are complied with, the government guarantees to purchase surplus grain at the prevailing intervention price, when the market is depressed through oversupply. Thus, with the Government guaranteeing minimum purchase prices, and the grain consumers being given disincentives to purchase elsewhere, arable farmers are much encouraged to grow cereals.

Table 4. Origins of wheat imported into the United Kingdom

	1964-65 Mt	1981-82 Mt
Canada	2.3	1.5
Australia	0.5	0
Argentina	0.4	0
The Netherlands	0.3	0
France	0.2	0
U.S.A.	0.2	0.2
others	0.2	0.1
total	4.1	1.8

sources: H.G.C.A. cereal statistics 1982.
H.G.C.A. annual report 1968-9.

Table 5. Wheat prices on 1 May 1983

	price £ t^{-1}
threshold price	163.20
milling wheat ex farm	136.54
intervention price	124.49
world price	95.36
import levy	67.84

The significance of the quality of home-grown wheat

The adjustment the millers needed to make to the proportions of home grown wheat being used in bread flour grists was not sudden, because import levies were introduced gradually over $4\frac{1}{2}$ years until fully instigated in July 1977. An adjustment had to be made, nevertheless, because home-grown wheat is of poorer baking quality than most other types of wheat on the world market, and particularly poorer than Canadian wheat.

Of the two main reasons for this, the first lies in differences of climate and husbandry. Canadian wheat is valued for its high protein content, low level of α-amylase, high yield and quality of flour and uniformity throughout a cargo of thousands of tonnes. Home-grown wheat does not have these particular attributes and it is especially notorious for its variability. Thus segregation of the grain and gristing becomes ever more important to achieve consistency in flour quality, an increasingly important requirement of bakers, and other flour users, intent on automation as a means of achieving more efficient production.

The second reason is the choice made by the arable farmer of the variety of wheat he grows, and it is on the significance of this that the remainder of this paper will be concerned.

During the 1960s one variety of wheat predominated in the British wheat harvest. That variety was Cappelle-Desprez, that consistently made up over 70 % of seed sales of winter wheat between the years 1956 and 1969 (Stewart 1972). It was popular with farmers because of its consistently high yield (then), stiff straw, and good disease resistance.

Despite having a soft textured endosperm, Cappelle-Desprez was habitually used by millers to blend with Canadian wheat in breadmaking grists. To check the variety of the delivered wheat was unnecessary: there was little chance of it being other than Cappelle-Desprez, and it formed only a minor part of the grist anyway.

Then, in the early 1970s, a radical change took place in the number and quality of varieties of wheat (and barley) being grown, due to the passing in 1964 of the Plant Varieties Rights Act. This legislation entitled the breeders of plant varieties, registered on a national list, to collect a royalty on the sale of seed of their varieties. Plant breeding in Britain became a business venture from then on, leading within a decade to a cornucopia of high yielding varieties, with a wide range of agronomic characters for the farmer to choose from, and also a wide range of milling and baking qualities to frustrate the milling industry.

The astute reader will have noticed that this proliferation of wheat varieties coincided with the period of time from 1973 when the Common Agricultural Policy started to apply financial pressure on the millers to buy home-grown wheat. The millers' problem at this time became acute, for a number of reasons.

In general, the baking quality of the new varieties is inherently poor, as can be seen in table 6, that shows the occurrence of different varieties in the British harvest, by grade of breadmaking quality. The grades, as defined by the Home-Grown Cereals Authority, are for varieties that are respectively preferred (I), adequate (II) and unsuitable (III) for a breadmaking grist. Maris Huntsman, in particular, is an example of a popular, high-yielding, grade III variety grown for animal feed, and that, if used for breadmaking, would produce loaves of low volume, an irregular crumb structure, and because of its high α-amylase content, sticky dextrins which impede automated bread production.

The millers also had a problem because the lifetime of each new variety is short in most instances. Given that Flinor, for example, occurred significantly in four harvests, and Bounty, after dominating the 1981 harvest, will virtually be absent from the 1983 harvest, it is not surprising that millers complain that they must continually readjust to new varieties as they replace the old.

The policy of the milling industry is to encourage the cultivation of better quality varieties by offering extra payment (a 'premium') for grain of the right variety, to help offset the disadvantage to the farmer of a lower yield. In some cases, extra payment would be offered for grain of a mixture of varieties, but exclusive of certain specified detrimental varieties. Such requirements of varietal description, together with other required quality characters, would then form the basis, in a contract, of an agreement for a premium payment.

An indispensible part of milling practice is then the inspection of grain on offer, before it is accepted. Alone among the specifications in the contract, varietal composition could not, at first, be checked. The distinctive morphological characters, which traditionally distinguish wheat varieties, are to be found in the fine structural detail of the wheat flower, in the growing crop. Once harvested, the grain of different wheat varieties is very similar in appearance. Therefore, if he who is responsible for inspecting grain as it arrives at the mill suspected that, despite the contract, grain of the wrong variety had been delivered, he would have no

Table 6. The occurrence of wheat varieties in the United Kingdom harvest by year and breadmaking grade

variety	occurrence in harvest year % 1974	1975	1976	1977	1978	1979	1980	1981	1982
grade I									
Bouquet	9.2	13.7	14.6	9.3	6.1	—	—	—	—
Flinor	—	10.0	8.8	5.6	5.7	—	—	—	—
Maris Dove	—	3.7	—	—	—	—	—	—	—
Maris Freeman	—	3.2	5.5	6.2	—	—	—	—	—
Mega	—	3.3	5.5	5.6	—	—	—	—	—
total grade I	9.2	33.9	34.4	26.7	11.7	0	0	0	0
grade II									
Armada	—	—	—	—	—	5.1	7.7	7.4	8.2
Atou	5.0	9.1	9.4	6.0	3.9	—	—	—	—
Avalon	—	—	—	—	—	—	—	5.1	38.1
Bounty	—	—	—	—	—	—	10.5	26.1	9.0
Cappelle-Desprez	8.4	3.2	—	—	—	—	—	—	—
Champlein	6.9	6.1	3.4	—	—	—	—	—	—
Flanders	—	—	—	8.0	15.1	17.3	17.1	12.8	5.3
Kador	—	—	—	—	—	9.8	6.3	3.1	—
total grade II	20.3	18.4	12.8	14.0	19.0	32.2	41.6	54.5	60.7
grade III									
Brigand	—	—	—	—	—	—	—	4.3	7.0
Hobbit	—	—	—	8.6	20.8	16.9	9.4	3.9	—
Hustler	—	—	—	—	—	—	5.6	3.1	—
Kinsman	—	—	—	—	8.6	3.1	—	—	—
Mardler	—	—	—	—	—	12.5	12.9	10.1	—
Maris Fundin	—	—	3.6	—	—	—	—	—	—
Maris Huntsman	39.6	28.8	34.6	37.9	26.9	18.4	21.6	11.7	5.7
Maris Nimrod	9.0	—	—	—	—	—	—	—	—
Maris Ranger	4.4	—	—	—	—	—	—	—	—
Maris Templar	4.8	4.8	—	—	—	—	—	—	—
Norman	—	—	—	—	—	—	—	—	7.8
Sportsman	—	—	—	—	—	3.1	—	—	—
total grade III	57.8	33.6	38.2	46.5	56.3	54.0	49.5	33.1	20.5
other varieties (< 3%)	12.7	14.1	14.6	12.8	12.9	13.8	8.9	12.4	18.8

alternative but to grow the grain and wait perhaps a year for proof that the contract had not been complied with. Needless to say, most variety specific grain trading activities were conducted, at least until 1976 in the United Kingdom, on the basis of trust.

The identification of wheat varieties by electrophoresis of gliadins

Quite separate from any impetus from the problems of trading grain, analytical techniques were being developed for the identification of the variety of individual grains.

It was known that the gliadin fraction is made up of a heterogeneous mixture of proteins, closely controlled by the genotype of the variety, and an early technique for the fractionation of gliadins by electrophoresis at acid pH in starch gels was developed by Elton & Ewart (1962). An early attempt to apply such a technique directly to variety identification was made by Ellis

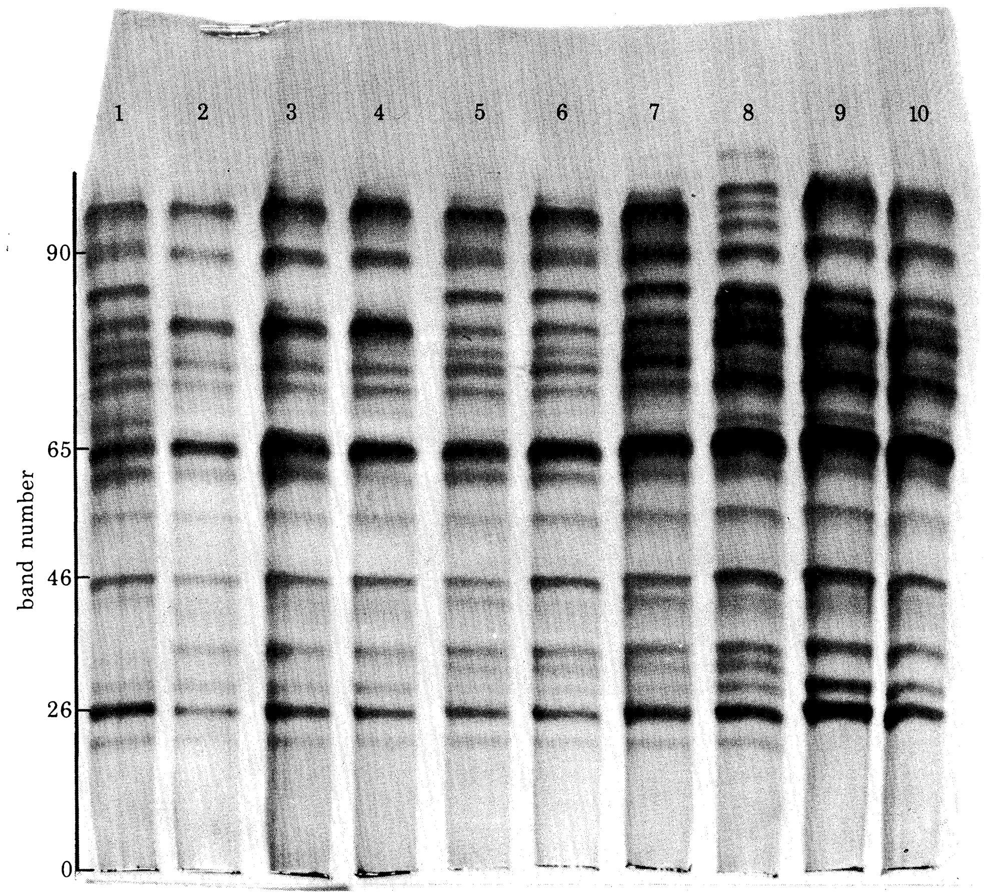

FIGURE 1. Electrophoretograms of four varieties of wheat grown in the United Kingdom. 1, Maris Huntsman; 2, 3, 4, Kador; 5, 6, 7, Kinsman; 8, Maris Freeman (biotype a); 9, 10, Maris Freeman (biotype b).

(*Facing p.* 400)

(1971), who was successful, if he could complement electrophoresis with grain quality tests, such as endosperm hardness, and coleoptile pigmentation. The need to assume varietal purity and the time requirement of several days precluded this approach from practical application.

In the meantime, workers in France (Autran 1973; Autran & Bourdet 1973) and Australia (Wrigley & Shepherd 1974) successfully refined the method of gliadin electrophoresis on starch gels, such that nearly all varieties of wheat, on the French national list (Autran 1975*a*) and commonly grown throughout the E.E.C. (Autran 1975*b*), and in Australia (Wrigley & Baxter 1974) could be distinguished by electrophoresis alone. No complementary grain quality test was required: results could be obtained within a day; and because grains (usually 50) were selected at random from the sample under test, and analysed individually, the composition of a mixture of varieties could be determined to an accuracy of about $\pm 10\%$.

The methodology has been well documented in a recent review (Wrigley *et al.* 1982) and need not be considered in detail in this paper. An example of gliadin electrophoretograms of four varieties that were being grown in the United Kingdom in 1978 is given in plate 1, figure 1, with the band mobility numbers devised by Autran (1975*a*). Several workers have confirmed that the gliadin electrophoretogram identifies the variety of the grain reliably and consistently irrespective of growth environment (Wrigley 1970; Ellis & Beminster 1977; Zillman & Bushuk 1979). Occasionally a variety of wheat is found to give rise to more than one electrophoretic pattern. This occurs when a variety is not entirely homozygous, and individual grains within the population carry alternative alleles for different gliadin species. The resulting alternative electrophoretograms are well documented and cause no impediment to accurate identification. Examples of biotypes of Maris Freeman are shown in figure 1. Several identification procedures have now been developed and are in regular use in other laboratories. All are based on the principle of fractionating the gliadin proteins by electrophoresis in one dimension at acid pH.

Electrophoresis in polyacrylamide gels is, in its various forms, a popular alternative to starch gel electrophoresis, mainly because of the greater control the operator has in preparing gels consistently, as well as savings in cost and time. Bushuk & Zillman (1978) have described a horizontal system which requires up to 5.5 h electrophoresis time, with superior resolution. Redman *et al.* (1980), who used a vertical system reduced the time of electrophoresis to 2 h; and Tkachuk & Metlish (1980) operating at 1000 V in thin vertical gels of 0.75 mm obtained stained electrophoretograms ready for identification in 2.5 h. Wrigley (1980) recommends the use of pre-prepared gradient gels.

The trend in all such developments of procedure is to reduce the time of analysis without losing the means of distinguishing varieties. One exception to this trend was the application by Shewry *et al.* (1978*a*) of sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS p.a.g.e.) to all storage protein extractable with propan-1-ol and reducing agent. This procedure although more labour intensive was found to resolve varieties otherwise indistinguishable by electrophoresis of gliadins alone.

The application of variety identification to grain trading practices

The significance of 1973 to the British milling industry has already been amplified. Just as the problems of regulating varietal specifications in grain trading contracts were becoming acute, several workers demonstrated the means of defining the varietal composition of a consignment of grain. This achievement had an immediate effect on grain trading in the United Kingdom.

The early use of variety identification

The author's company was the first in the United Kingdom to adopt a laboratory method to identify varieties. Of the methods then developed Autran's was preferred to Wrigley's (Ellis 1976) because wheat was then being imported from France, and not Australia.

Indeed it was in the examination of wheat imported from France that the commercial importance of variety identification was established. Wheat was then purchased from one French supplier, on the basis that any combination of varieties would be acceptable, except

TABLE 7. VARIETAL COMPOSITION OF SHIPMENTS OF WHEAT IMPORTED FROM FRANCE

variety	composition of example A %	composition of example B %
Champlein	24	14
Capitole	20	12
Top	18	8
Talent	16	—
Hardi	6	4
Heima Desprez	6	—
Atou	4	—
Joss Cambier	2	2
Maris Huntsman	2	28
Clement	2	32
total	100	100

for two, Maris Huntsman and Clement, that together should not occur at a level of more than 8%. The wheat was shipped from France to England in batches of approximately 2500 tonnes. After automatically sampling when it was discharged into the mill's silos, a range of tests, including variety identification, was performed on a representative sub-sample.

Example A (table 7) is typical of a mixture of French varieties suitable for a breadmaking grist. The occurrence of a small percentage of the excluded varieties was acceptable in a breadmaking grist, as well as being within the minimum specified in the contract. Example B (table 7) is typical of a mixture of French varieties used for animal feed, and clearly a mistake had been made by the suppliers. A total of 60% of the two excluded varieties would have caused considerable bread production problems in the company's bakeries. However, with his electrophoretic proof, the purchaser was able to claim financial compensation that at that time amounted to a difference of about £10 per tonne between wheat of 'milling quality' (example A) and 'feed quality' (example B). Simple calculation determined that in this instance the supplier owed the purchaser about £25,000.

This example of reimbursement on the basis of wrongly supplied varieties of wheat was a watershed: the realization of the commercial and technical significance of variety identification to the millers was matched by the disquiet engendered by the discovery that feed wheat could be entering their mills in the expectation of it being of 'milling quality'. Surveys were implemented with urgency therefore to ascertain the extent of the problem.

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Varietal composition of wheat from France

Wheat imported from France was examined first. The results in table 8 indicate that the majority of shipments complied with the contract (15). Some (five) carried more of the excluded varieties than preferred and, in these circumstances, the supplier was just advised of the results. There remained two instances, further to that of example B, of substantially high levels of the excluded varieties (respectively 34 % and 49 %), and financial compensation was negotiated for each.

Table 8. Proportions of excluded varieties in shipments of imported French wheat

excluded varieties by class	number of shipments
0–8 %	15
9–20 %	5
21–100 %	2
total	22

The survey was conducted on consignments from one supplier, subsequent to the first instance of reimbursement. That supplier was taking all available conventional measures to acquire 'milling quality' wheats from his suppliers, the French cooperatives and farmers. It was therefore surprising that he had failed on two further occasions in 22.

These samples were representative of about one month's trading to just one British miller. To protect himself, the supplier instigated his own facilities for checking the varietal composition of his grain, before it was loaded on board ship. Thereafter his grain supplies were reliable.

Varietal composition of home-grown wheat

A second survey was conducted on home-grown wheat delivered to the author's company's mills after the 1976 harvest. The survey was limited to those deliveries for which a premium payment was made, and that would be required to contain a 'premium' variety. The total number of different varieties discovered, in varying degrees of admixture, was 14, in 44 deliveries tested. Of these 14 varieties, only seven were premium varieties.

In only 12 deliveries out of 44 was no evidence found of admixture. A small amount (up to and including 10 %) of another variety was found in 16 deliveries. The reason for this probably lies in the practice of continuous cultivation. One year's wheat may be contaminated with plants of the previous year's variety, that have grown from grain that escaped harvest. In order to distinguish 'natural' admixing before harvest from artifical admixing after harvest, an amount of another variety of wheat, arbitrarily set at greater than 10 %, was the determinant of an admixed sample.

The results of the survey are shown in table 9. Approximately one third (16) of the deliveries were not of the claimed premium variety, but were admixtures. Often the admixed variety was also eligible for a premium payment, and no action would be necessary. However, in six deliveries (about one in every seven deliveries) the premium variety was admixed with an unacceptably large proportion of a variety ineligible for a premium. As a result of private negotiations between the millers and grain traders, appropriate and expensive reimbursements were agreed.

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The current position

All quality control managers in the author's company responsible for the confirmation of the quality of wheat before permitting its inclusion in a grist, have been trained to identify varieties by electrophoresis. Each quality control laboratory has been supplied with an in-house designed unit capable of the simultaneous electrophoresis on starch gel of 120 gliadin extracts. These days, wheat supplies for breadmaking grists tend to be reliable; the number of current deliveries that require action because of admixing, are only about one in 50.

Table 9. Results of a survey of varietal purity of home-grown wheat

category	number
(1) pure (not more than 10% admixture)	28
(2) admixed (more than 10% admixture)	
2.1. with a premium variety	10
2.2. with a non-premium variety	6
total	44

All the major British millers are skilled in variety identification, and they ensure that their standards are maintained by collaborating in regular joint tests controlled by the Flour, Milling and Baking Research Association. Autran's starch gel procedure is still used widely because, so far, it alone has been accepted by representatives of the milling industry in the E.E.C. as a standard method (van Lonkhuysen & Autran 1981).

The identification of barley varieties

The role of electrophoresis in the identification of cereal varieties is particularly suited to wheat. The identification of barley varieties, by using similar procedures, has had less impact in the trading of barley grain for two main reasons.

Grain morphology

The barley grain, when mature, is enclosed by those flower parts, that the wheat grain loses during harvesting. Thus, the palea, lemma and rachilla, for example, all of which carry distinguishing features, enable the skilled barley grain trader to identify the varieties of grain in question by visual inspection alone. Not all varieties can be distinguished in this way, especially if key morphological characters are damaged during harvesting. Therefore, an electrophoretic approach can be useful.

Hordein electrophoresis

The range of electrophoretic methods, already described for gliadins, has been applied, with minor modifications, to hordein extracts from barley varieties (Autran & Scriban 1977; Gunzel & Fischbeck 1979; McCausland & Wrigley 1977; Shewry *et al.* 1978*b*).

Unlike varieties of wheat, which are nearly always distinguished by a unique gliadin electrophoretogram, varieties of barley are often indistinguishable by hordein electrophoretogram alone. In their comprehensive study of 164 European barley varieties by SDS p.a.g.e., Shewry *et al.* (1979) discovered 32 distinct hordein electrophoretograms. Of these, 16 are unique to individual varieties. At the other extreme the hordein pattern 'group 1A' is common to 35 varieties, and 'group 15A' is common to 38 varieties. The reason for the occurrence of the same hordeins so often in a large number of varieties is because of the linkage of the two loci that specify hordein synthesis, with the *M1a* locus on chromosome 5 (for a review see Shewry & Miflin 1982). The *M1a* locus carries genes that specify resistance to different races of powdery mildew (*Erysiphe graminis*) (Wolfe 1972), that are subject to selection in barley breeding programmes and are associated, therefore, with genes controlling hordein synthesis. In principle, individual grains of barley could be identified uniquely by a combination of electrophoretic separations of hordeins and selected isoenzymes, but the cost to the grain trader would be prohibitive.

The possibility of finding a common electrophoretic characteristic that is correlated with malting quality has been suggested on the basis of examination of a restricted number of varieties (Baxter & Wainwright 1979). This was shown not to be applicable in practice, however, when the range of barley varieties was extended (Shewry *et al.* 1980).

In summary, although maltsters are as concerned about variety as millers, identification through electrophoretic analysis is not so significant as it is in wheat trading, partly because it is sometimes possible to verify a purchase through examination of grain morphological characters, and partly because the alternative of electrophoretic analysis is often impractical.

The consequences of grain trading by variety

It seems to be agreed widely among those who buy and sell wheat that variety identification by electrophoresis has now changed the business of grain trading by introducing a degree of objectivity with respect to varietal composition where little had existed previously. For the reasons already given, barley grain trading has yet to benefit in the same way. In this concluding section, some of the implications of this change for the millers will be considered.

The milling industry would claim to have benefited considerably. After an initial period of adjustment, arable farmers are now accustomed to segregating harvested wheat according to variety, and are aware of the varieties required by the millers. Thus, the quality of raw material supplies is now regulated, and with a consequent improvement in consistency of flour quality for the baker, and other flour users.

However, as is so often the case, solving one problem has generated another. The simplest option for an arable farmer is to grow feed or grade III varieties, that sell at the lowest price, but that compensate by giving high yields. The more difficult and risky option is to grow better quality varieties, that yield less, but give the farmer a premium payment. The refusal of a miller to pay a premium for a quality variety of wheat is a major loss of revenue for the farmer. The number of refusals has tended to increase in recent years, because of the view, which has developed in the milling industry in response to the demands of bakers for a more consistent flour, that 'the better the quality of the wheat, the better the quality of the flour'.

This critically selective attitude may be due for a change. Wheat export data in table 10 are leading some in the milling industry to think that this alternative grain market may cause such a change.

The growth of the wheat export industry has been rapid and inexorable, and the last three years have seen Britain change from a net importer of wheat to a net exporter. It is predicted by eminent commodities dealers (F. T. Rees, personal communication) that the export market will continue to grow for as long as there is the political will to subsidize British wheat for export.

The emergence of an alternative market, in non-member states such as China, Egypt, Saudi

Arabia and Bangladesh, where baking is a less sophisticated process, is partly a reaction to the constraints and risks of growing for the British miller. The implications then are clear: either millers must pay more for their wheat, or the milling and baking industries must adapt to a broader range of quality in their raw materials. The policy of being ever more selective in the purchase of wheat has little prospect of being extended much further.

Table 10. Wheat exports from the United Kingdom

year	wheat exported Mt
1982-83 forecast	3.10
1981-82 provisional	1.94
1980-81	1.15
1979-80	0.30
1978-79	0.14

sources: H.G.C.A. press notice nos. 12/80 and 3/83

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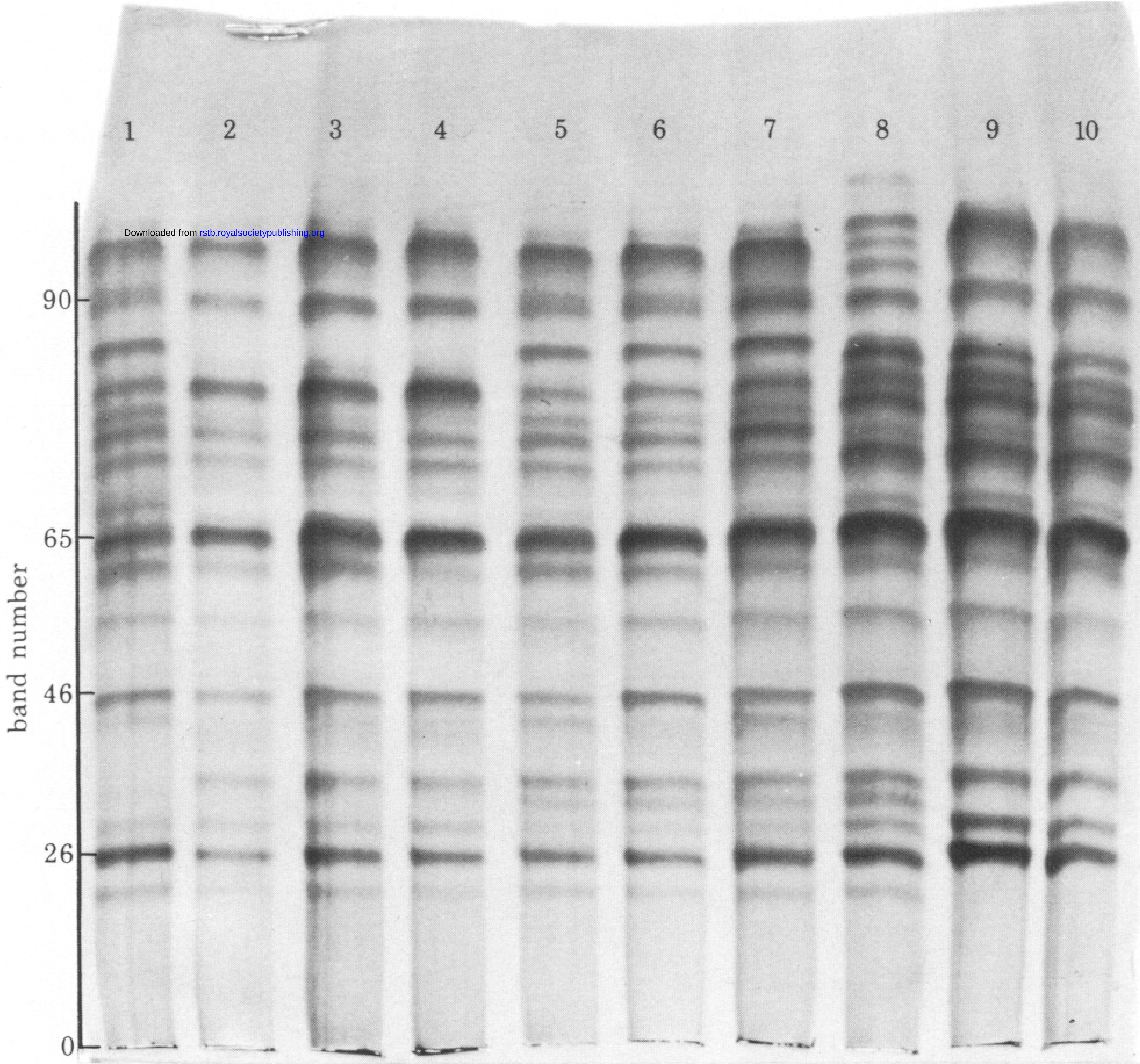
Discussion

A. B. Damania (*Department of Plant Biology, Birmingham University, U.K.*). I have used both the electrophoretic method of Bushuk and Zillman and that of Tkachuk and Metlish and found that the latter method was far superior in all respects including the resolution of banding patterns.

J. R. S. Ellis. Yes, I agree that the method of Tkachuk and Metlish is superior to that of Bushuk and Zillman. When I qualified the slide I showed as being of poorer resolution, I should have added perhaps that this is due to the minimum amount of time we normally allow for the gel to destain. Otherwise, the method of Tkachuk and Metlish in my experience is quite satisfactory.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



GURE 1. Electrophoretograms of four varieties of wheat grown in the United Kingdom. 1, Maris Huntsman; 2, 3, 4, Kador; 5, 6, 7, Kinsman; 8, Maris Freeman (biotype a); 9, 10, Maris Freeman (biotype b).