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Choosing Between Crops: Aspects that Affect the User [and Discussion]

P. W. Russell Eggitt and P. S. Wellington

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Choosing between crops: aspects that affect the user

By P. W. Russell Eggitt
Spillers Limited, Research and Technology Centre, Cambridge

The paper illustrates the need to study the food processor's current requirements and his developing technologies in choosing crops for the United Kingdom or in expressing British views in developing the European common agricultural policy.

Developments in farming, milling and baking are reviewed. These developments have made it possible to increase the proportion of home grown wheat in British bread faster and further than envisaged in the Government's White Paper 'Food from our own resources', up to around 70 %, provided certain feed wheat varieties are rejected and provided there is some selection on protein content. Economic implications of these developments and the desirability of changing the balance between bread wheats and higher yielding feed wheats are discussed and targets suggested for the breeding programme which should make it possible to attain 70 % self-sufficiency both in feed wheats and in wheats for direct human consumption.

The relative merits of growing malting and feeding barleys are examined in the light of changing malting technology and the successful barley breeding programme. There appear to be attractive opportunities for British agriculture in providing more malting barley within the Community, even though we import a compensating amount of E.E.C. feed grain. The development of high yielding, low nitrogen, dual purpose barleys is desirable and probable, although this is counter to attempts to breed high protein, high lysine feeding barleys. The latter are likely to be attractive to the feed compounder only if they can be produced without loss of yield of metabolizable energy. *Triticale*, although of interest to the compounder, is unlikely to be worthwhile in the United Kingdom in the foreseeable future.

Spun and extrusion-cooked textured proteins are already being manufactured from soybean protein in the United Kingdom, on a scale equivalent to at least 45000 t of meat per annum. The new technologies are described briefly. The prospects of field beans, field peas, lupins, soya beans and sunflowers as potential sources of raw material from British farms are discussed. For various reasons, none is likely to succeed in this application in the immediate future. Oilseed rape, however, is a potential source of excellent protein concentrate likely to be exploited within 5 years, in spite of remaining toxicological and technical problems. These are discussed with an indication of the latest developments in manufacturing rapeseed protein concentrates. There is a very strong case for encouraging the newer 'double-low' varieties of rapeseed in the United Kingdom both as oilseeds and as sources of protein.

1. Introduction

The Government White Paper 'Food from our own resources' (1975) is a useful starting point in assessing priorities between crops which compete for land and resources. Their projection into the early 1980s is an attempt to define a framework for deciding future policies and is not a hard and fast programme. Fortunately, this implies an ongoing review of the projection in the light of constraints imposed by membership of the European Economic Community (E.E.C.), the world food situation and current economic problems. It is essential to encourage home production in those areas where we are most competitive within the E.E.C., where import savings are worthwhile and where the return on all inputs is greatest in terms of the nutritional contribution to the human population.

At least 70 % of food consumed in the United Kingdom is processed and the contribution of processing industries to the gross domestic product is similar to that of agriculture as a whole. It is therefore important that developments in food technology in processing, distributing and storing foods are thoroughly assessed in choosing between crops. Cereals, particularly bread-making wheats, provide a good example of this need, as baking technology has progressed faster than envisaged in the White Paper, increasing considerably the direct consumption of home grown wheat in bread. In the United Kingdom, we produce about 16 Mt of cereals of all types on 3.8 million hectares (nearly 20 % of available agricultural land) out of a total requirement of around 23 Mt: a self-sufficiency of 70 %. In 1973/4 we consumed an estimated 7.9 Mt of wheat with a self-sufficiency of 62 % overall, 88 % for feed wheats and only 46 % for all direct food uses. I propose to review briefly the changes in technology which now make it possible to increase the latter to nearer 70 %, provided we maintain a proper balance between milling wheats and higher yielding feed wheats. There are both short term implications in the choice of existing varieties and longer term objectives to be set for the breeding programme.

In a more speculative area, developments in textured vegetable proteins for direct consumption will increase the attractiveness of oilseeds and legumes as break crops in the United Kingdom in the longer term if current work on problems of flavour and toxicity of the protein fractions is successful.

2. Wheat

(a) *Milling grists – the effect of changes in milling and baking technology*

A decade ago most British bread was made from dough which had been fermented in bulk for 3 or 4 hours prior to dividing the dough pieces. Bread flour grists depended heavily on ‘strong’ spring wheats from North America. Home grown wheat was a minor constituent used to the greatest extent in the months following a favourable harvest. Although many options were open to the miller, a typical grist contained 60 % ‘strong’ Canadian spring wheat, 20 % ‘weak’ English wheat and 20 % of a ‘filler’ wheat, possibly Australian.

In 1961 and 1962 Chamberlain, Collins & Elton described the Chorleywood Bread Process (C.B.P.) to members of the British Baking Industries Research Association (now the Flour Milling and Baking Research Association, F.M.B.R.A.). As in earlier continuous mixing processes, bulk fermentation was replaced by greatly increased mechanical development at the mixing stage using special batch machines and a fixed work level of 11 W h/kg of dough (40 kJ/kg). Some recipe adjustment was also necessary, such as doubling the quantity of yeast to ensure adequate leavening with reduced fermentation time, increasing oxidizing improvers, and giving special attention to the nature and quantity of bread fat and additional dough water to allow for the elimination of softening during bulk fermentation. The process gained rapid acceptance in the industry as increasingly effective machines became available, so that today it accounts for around 80 % of British bread of all types.

It was soon apparent that the C.B.P. would produce better bread (as judged by the majority in the U.K.) than the traditional process from a typical flour of the day or alternatively produce equally good bread from a somewhat ‘weaker’ and therefore cheaper flour. In 1963 Chamberlain, Collins & Elton reported that an increase of 20–25 % of all-English flour in a flour blend ‘would not lead to a commercially significant loss of bread quality as compared with bread made by bulk fermentation of the unmodified flour’, and their work indicated that satisfactory bread could be produced from a grist of 50 % Canadian and 50 % English wheats, This was confirmed by trials in plant bakeries (Chamberlain, Collins & Elton 1965*a*, *b*).

The quantity of homegrown wheat in bread grists did not increase during the 1960s to anywhere near the point of exploiting the full potential of the C.B.P. Millers could buy 'at best' from the wheats of the world during a period of wheat surpluses when United Kingdom wheat imports accounted for 12 % of world trade, sufficient to influence price levels. Moreover. in a keenly competitive market, plant bakers were reluctant to use weaker flours which could lead to more rapid firming of bread particularly during cold weather, and also to some loss in bread yield. The Government White Paper noted that the proportion of home grown wheat in all wheats milled for flour rose from about one third in 1969 to 'almost half' by the date of publication, April 1975. It also expressed the view that 'we could not substitute much more without some changes in baking technology or in the kind of bread we eat or without some switch of home production to lower-yielding bread-making wheats'. Events have overtaken this assertion.

By 1971 at least one of the larger milling and baking groups was engaged on research aimed at increasing significantly the usage of home grown and European wheats in response to the constraints of membership of the E.E.C. This work was accelerated by the dramatic changes in world cereal markets in 1972 following Russian intervention, the rapid erosion of surpluses, the escalation of wheat prices and the increase in price differentials between home grown and non-E.E.C. wheats. Developments in the mills included the introduction of rapid methods for wheat selection, separate binning on protein content, flake disrupters for improving sieving and the control of water absorption by adjusting the extent of starch damage. In the bakeries developments in bread-improver technology, using permitted fats, emulsifiers, enzymes and oxidizing agents in combination, improved loaf volume, crumb texture and softness and reduced the rate of firming associated with weaker flours. Raw 'enzyme-active' soya flour at 0.5 % of flour weight or less proved particularly useful as a source of lipoxygenase enzymes. Automatic control of dough consistency at the mixing stage also helped when more variable flours were used, techniques for handling softer doughs improved and greater attention was paid to air-conditioned bread cooling.

Millers do not disclose their grists in a highly competitive situation but it is generally accepted in the industry that it is now possible to use up to 70 % home grown wheat in British bread grists provided certain feed wheat varieties are rejected and provided there is some selection on protein content. The resulting bread is fully competitive. This rapid advance in technology has an important bearing on the choice of crops in the United Kingdom. It would not have been possible to use home grown (or equivalent E.E.C.) wheat as the major component of U.K. bread without concurrent developments on British farms.

(*b*) *Changes on the farm and in the wheats available*

The hectarage under wheat in the U.K. grew from 0.85 million in the period 1946–50 to 1.2 million in 1974 with increases in yield shown in figure 1 reaching a record national average of 4.9 t/ha (39.0 cwt/acre) in 1974, even though some less suitable land had been taken into cultivation.

This increase in yield was due partly to the introduction of new varieties and partly to improved crop husbandry, including the use of new fertilizers and methods of application, improved herbicides, better seed dressings and combine harvesters. The number of combines increased from only 1500 in 1943 to 57000 by 1962, and with the abandonment of stacks (ricks) and shocks (stooks) and the introduction of grain drying facilities, wheat reached the mills in increasingly cleaner and sounder condition. The elimination of white grained varieties, liable to sprouting in the ear, helped to further reduce the dangers of a wet harvest period.

Changes in wheat varieties have, however, generally affected the milling and bread making quality of the crop adversely. Plant breeders and farmers have given higher priority to yield and

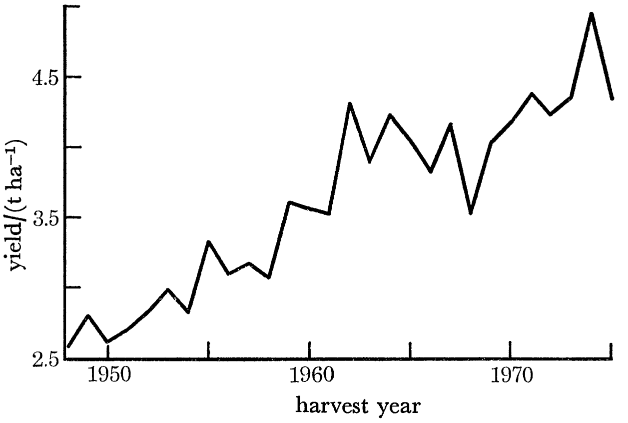

FIGURE 1. Home grown wheat yield.

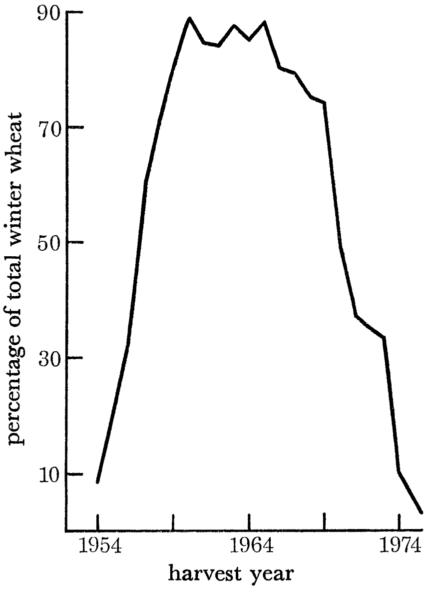

FIGURE 2. Popularity of Cappelle-Desprez.

agronomic factors, such as standing power and resistance to plant diseases, than to milling and baking quality. One third of the wheat harvested in 1948 was potentially of good milling and baking quality (Stewart 1975) even for bulk-fermentation processes.

The high yielding winter wheat Cappelle-Desprez appeared commercially around 1954 and dominated the U.K. crop during the 1960s as shown in figure 2, reaching 88% of the winter wheat crop in 1965. Although a soft variety, its baking quality was acceptable at the percentage used in bread grists at the time, particularly as the less-demanding C.B.P. was introduced.

The advice available to British farmers on the choice of cereal varieties from the National

Institute of Agricultural Botany (N.I.A.B.) and the Agricultural Development Advisory Service (A.D.A.S.), who participate in trials, is second to none. There are nine recommended varieties of winter wheat in the N.I.A.B. 1976 list. Maris Huntsman, from the Plant Breeding Institute, has the highest yield on the farm averaging 20 % more than Cappelle, closely followed by Maris Nimrod. Both share some of the undesirable characteristics of their parent variety, Professor Marchal: high alpha-amylase activities even in the truly dormant state, and very poor and variable bread making qualities, not entirely related to their high enzyme contents. These varieties are usually excluded from bread making grists, particularly when using a high percentage of home grown wheat. Had these wheats gained in popularity on the pattern set by the previous high yielder, Cappelle-Desprez, the effect on the programme for introducing more home grown wheats into U.K. bread grists would have been serious. Millers' and bakers' anxiety on this score was enhanced by the sale of substantial quantities of seed to France. The record yield of Huntsman in a 1974 competition was no less than 10.8 t/ha (4.3 tons/acre).

Table 1. Popularity of wheat varieties

variety	percentage of samples received in national survey: 1975 harvest	1974 harvest
Maris Huntsman	28.8	39.8
Bouquet	13.7	9.9
Flinor	10.0	2.6
Atou	9.1	4.3
Champlein	6.1	7.6
Maris Templar	4.8	3.0
Maris Dove	3.7	2.5
Mega	3.3	1.0
Cappelle-Desprez	3.2	9.9
Maris Freeman	3.2	—
Maris Nimrod	2.9	10.8

Table 1, provided by F.M.B.R.A., shows the popularity of wheat varieties in 1974 and 1975. In 1974 Huntsman and Nimrod accounted for no less than 50.6 % of the crop, justifying the millers' anxiety. There was an improvement in the spread of varieties in 1975 with welcome increases in the area sown to Bouquet, Flinor and Maris Freeman so that, of the varieties listed, one third of the crop was suitable for the new bread grists compared with one quarter in the previous year.

The wet autumn in 1974 led to an increased planting of the spring wheat Maris Dove, which proved useful in 1975 bread grists. Normally winter wheats account for 90 % of the total U.K. wheat acreage.

Two factors caused the shift in the farmers' choice towards acceptable milling wheats:

(1) The Home-Grown Cereals Authority proposed a classification scheme for bread quality varieties as a basis for the payment of premiums, eliminating feed wheats. Two premium categories of named varieties were proposed (A, including Flinor, Maris Freeman and Maris Widgeon, and B, including Cappelle-Desprez, Bouquet and Maris Dove), each subdivided according to protein levels. Millers introduced their own somewhat similar premium schemes.

(2) Farmers generally heeded the advice of N.I.A.B. to spread their choice of varieties as a precaution against yellow rust (*Puccinia striiformis*) following experience with varieties like Joss Cambier which suffered severe attacks in 1972 and quickly disappeared from the charts.

The Cappelle phenomenon is thus unlikely to be repeated in the immediate future. Maris Huntsman accounts for only 21.4 % of the winter wheat acreage in England and Wales in the 1976 seed certification scheme for cereals, an increase of less than 1 % on the previous year.

(*c*) *Economic implications*

Economists argue that self-sufficiency and import saving are less important objectives than increasing national real income, which is the margin of the value of output over the value of all resources used. Thus alternatives tend to be considered as sterling equivalents. The merits of growing high yielding feed wheats or quality milling wheats in the United Kingdom have been compared by determining the additional cost of producing the latter arising from their lower yield on the farm and the need for additional quality testing, provision for occasional failure to meet the milling specification, and additional transportation. Allowance has also been made for variances in the yield of flour and bread in arriving at a figure for extra cost which, in aggregate, is said to come close to the anticipated difference in price in sterling terms between North American and U.K. milling wheats. This has led to support for growing high yielding feed wheats rather than quality wheats and to lower priority for improving bread baking quality in the breeding programme.

This strategy should be scrutinized in the light of developing technology and membership of the E.E.C.

(i) Home grown wheat is now potentially the major component of U.K. bread grists.

(ii) The E.E.C. is now in surplus in feed wheats but not in bread-making wheats. (The 1976 drought may cause an exceptional interruption in the trend.)

(iii) World wheat prices are liable to rapid fluctuation in response to crop failures or other emergencies as long as reserves are low.

(iv) The ultimate output, in terms of human nutrition, is much greater for milling wheats than for feed wheats. Seventy-five per cent of wheat milled for bread is consumed directly, providing the U.K. population with 16 % of its protein and 14 % of its calories. Leach (1975) has calculated that bread contains 1.4 times the non-renewable energy used in bringing it to the point of sale with about one third of the usage consumed in post-farm operations. If wheat is processed agriculturally by feeding to animals, the energy available to humans drops to between one tenth and one third of total input.

Future policy must take into account the wheat growing potential of the E.E.C. as a whole and the probable improvement in facilities for selecting and separate binning of wheats of differing quality on the Continent. Nevertheless, there appears to be a strong case for encouraging a change in the balance between feed wheats and milling wheats grown in the U.K. in favour of quality varieties. A balance which in an average harvest would provide a potential self-sufficiency of 70 % in wheats for direct consumption and 70 % in feed wheats is not inconsistent with the crop projection given in the 1975 Government White Paper, *Food from our own resources*. In the longer term our plant breeders should aim to close the gap in yield between the highest yielding feed wheats and acceptable bread wheats, bearing in mind the wider tolerance provided by the C.B.P. Dual-purpose wheats would improve flexibility. What are the chances of this?

(*d*) *The future*

In the immediate future, in spite of the unsuitability of the highest yielding varieties, U.K. millers should have no problem in obtaining adequate supplies of home grown and E.E.C.

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wheats for current bread grists, because of the range of varieties now selected by farmers as a precaution against foliar disease and in response to quality premiums. Moreover, the E.E.C. proposes a two-tier intervention price for wheat with a price differential of possibly 13 % between breadmaking and non-breadmaking samples (at the time of writing). If implemented, this scheme would encourage the segregation of Continental wheats on a quality basis and adequate test criteria would be essential. Progress has been made in developing a common baking test in spite of the large differences in the breads of the nine countries, although it will be difficult to achieve adequate standardization. The French have taken the lead in devising a 'fingerprint' method for identifying varieties by electrophoresis of the gliadin protein from a single grain (Autran 1975).

In the longer term plant breeders are confident that there will be considerable improvements in the milling and baking quality of high yielding varieties to simplify the choice. Milling texture (or hardness) and α-amylase activity in the dormant grain are strongly inherited characters. The baking quality of protein is also relatively highly inherited, although more complex for the breeder to unravel. Breeders consider that, given time, it is relatively straightforward to achieve quality with high yield but difficult to combine both these requirements with resistance to foliar disease, particularly yellow rust, a problem well illustrated by the break-down of the promising variety Maris Templar.

The selection of the many components of quality is an extra complication which slows down the work of the breeder so that quality varieties lag behind those bred principally for yield and resistance to disease. There is no insuperable problem in raising the yield of U.K. milling wheats to produce dual-purpose varieties, although it takes at least 12 years and a great deal of work to bring a new variety to commercial production.

Protein quantity in wheat is, however, inversely related to yield and is a weakly inherited character (although some genotypes have been found which may be useful in breeding, such as Atlas 66 and Lancota from the U.S.A. and the Indian variety Nap Hal). Higher protein content in future U.K. bread wheats is likely to depend more on improved husbandry practices such as rate and timing of nitrogen application to the crop. The shorter strawed varieties now being developed will permit such applications without lodging.

Bingham (1975), a leading wheat breeder, considered that improvements in yield, grain quality and disease resistance, combined with advances in husbandry, could increase the national average wheat yield to 5.6 t/ha (45 cwt/acre) over the next 10–15 years.

As possibly the ultimate target, within the limitations of the British climate, the miller would like to combine the quality and agronomic merits of Maris Widgeon with the highest farm yield attainable and a protein content about 12 %. A somewhat lower quality, equivalent to the best of the current higher yielding bread wheats, coupled with maximum yield would, however, be acceptable particularly if the wheat were as consistent as possible in our variable agronomic conditions. Technology will also continue to advance and the all-British (or all-E.E.C.) loaf is not an impossibility, although in the foreseeable future 20–30 % North American wheat will be required in our bread. Research must be intensified to discover why such a relatively small proportion of this strong wheat should have such an important effect on loaf quality, particularly on its keeping properties.

3. Barley

(a) *Yield or malting quality?*

Some 6 million tonnes of the U.K. barley crop of 9 million tonnes is sold off the farm, 4 million tonnes for feeding stuffs, with the remainder meeting the U.K. annual malting requirement of 1.9 million tonnes. In spite of price premiums, the maltster has not found it easy to obtain enough of the right sort of barley in recent years in the face of greater yields of feeding barleys on the farm. As with the bread baker, developing technology has modified his requirements. Rising costs and increasing demand for malt have led to reduced steeping, flooring and kilning times, making some established malting barleys less suitable and setting new requirements for barleys which will modify quickly and preferably without additives or mechanical aids. Unmodified β-glucan in malt, for example, is said to cause problems of mash filtration, if not hydrolysed by β-glucanase. This enzyme is reported to become active on the third or fourth day of flooring and may be deficient in malt produced using a shortened process or modified kilning, thus making a low β-glucan content a desirable character in malting barley (Greenberg 1974).

In contrast to milling wheats, the inverse relationship between yield and protein content is an advantage to the breeder of malting barleys because low nitrogen malts are associated with high extract in the brewery and freedom from haze in beer. In practice, this advantage has been counter-balanced by the greater use of nitrogenous fertilizers permitted by the introduction of shorter strawed varieties, like Proctor, which appeared in 1953.

There is no winter malting barley on the 1976 recommended list superior to Maris Otter, which was introduced in 1965, although it yields some 10–13% less than winter feeding varieties. There is a wider choice of spring varieties to suit local environmental conditions. Wing (introduced in 1972) and Hassan (1971) have proven malting quality, and yield on average only some 5% below spring planted feeding varieties. Ark Royal (1976) may prove to be a genuine dual-purpose spring variety, with very high yield and good malting quality, although the latter, and indeed its agronomic merits, must be proved in longer commercial use in view of disappointments in the past.

On the world scale, 13 million tonnes of barley is required this year to make 10 million tonnes of malt. The West Germans alone use 2.4 million tonnes of malt annually, importing up to 800000 tonnes, mainly from France, although in recent years they have imported malt from Australia, Poland, Denmark and even the U.K. The quality of U.K. malting barley is considered to be superior to that of France and, moreover, France is said to be moving previous barley acreage into durum wheat and maize. The E.E.C. is now normally in surplus in feeding grains (the effect of the 1976 drought is uncertain at the time of writing) and there would appear to be an obvious export opportunity for British agriculture and net benefit to this country even though we import a compensating amount of E.E.C. feeding grains.

Maltsters believe that unless we can substantially increase the proportion of the barley crop that is sown with a good malting variety, the future emphasis may be on importing, not exporting, malting barley.

(b) *Feeding value*

Generally the yield of cereal metabolizable energy per hectare is inversely related to yield of protein and, if protein is increased by the application of nitrogenous fertilizer, the yield of the limiting amino acid, lysine, is inversely related to protein content. A genetic variant of

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maize, Opaque-2, found by Mertz in the mid-1960s contains about twice the normal proportion of lysine and in spite of a lower energy yield it will support double the number of human adults per hectare in regions where they depend almost exclusively on eating the whole grain (Young, Scrimshaw & Milner 1976).

About three quarters of the U.K. barley crop is fed to animals, mainly pigs and poultry. Although regarded traditionally as a source of energy, barley can contribute more than half the dietary protein. Thus, the development of Opaque-2 maize has encouraged breeders to look for similar genetic material in barley, capable of breaking the normal inverse correlation between protein content and lysine content, without an unacceptable penalty in loss of yield of metabolizable energy. In 1970 Munck found an Ethiopian variety, Hiproly, with a high lysine/protein ratio stable over a wide range of grain protein contents but with poor yield characteristics under European conditions. Better genetic material has come from the Danish Atomic Energy Research Establishment at Risø, and notably a chemically induced mutant, Risø 1508. The lysine rich fractions, albumin and globulin, form a higher proportion of the protein of Risø 1508, and prolamin a lower proportion, compared with ordinary varieties. It also has the advantage of being a mutant of an adapted European cultivar and possesses simply inherited high lysine characters, providing valuable starting material for the Plant Breeding Institute (Rhodes & Jenkins 1975), where some 80 high lysine selections of crosses with Risø 1508 are undergoing field trials. The work has some way to go before it will affect the choice of crops in the U.K. Feeding trials will be essential to ensure that improved biological value fully reflects the increase in lysine.

The feed compounder is concerned with the overall cost and performance of his completed mixed grist rather than with the cost and nutritional contribution of a raw material in isolation. There is considerable scope for rebalancing, in order to compensate for a deficiency, with the wide choice of ingredients available in the U.K. High lysine barley is likely to be attractive only if this benefit is achieved together with high and reliable yield on the farm and research should continue with this objective. The development would be against the trend towards a dual-purpose malting and feed barley with a high energy yield but low protein.

4. *Triticale*

Triticale, made by crossing wheat (*Triticum*) and rye (*Secale*) is man's attempt to combine the qualities of the former with the hardiness of the latter, particularly the ability to yield in arid, sandy soils. A vast amount of work in many countries, owing much to the discovery of the chromosome doubling properties of colchicine nearly 30 years ago, has led to the creation of a large number of fertile varieties (Tsen 1974). *Triticale* has an important future in dry areas where wheat grows badly or where there is a shortage of fertilizers. In these circumstances it will out-yield wheat and produce more protein with a higher lysine content. Moreover, in countries like Mexico it can be cut for forage several times in a season without significantly reducing grain yield. In North America *Triticale* has been malted commercially for the production of beer and spirits.

Hexaploid varieties developed in the U.K. by the Plant Breeding Institute yielded well compared with spring wheat in 1974 but results were disappointing in 1975, when dry weather should have favoured the crop. The grain is unacceptable for milling or baking but is of interest to the feed compounder, although there are many agronomic problems to be solved including loss of yield due to shrivelled seed, lodging (the straw is long) and susceptibility to ergot. Research should continue but *Triticale* is unlikely to compete with established cereals in this country in the foreseeable future.

5. Vegetable proteins for human nutrition

(*a*) *Technology*

A method for making simulated meat from vegetable protein isolates, using a textile spinning process, was first described by Boyer (1954). Vegetable protein, usually soya, is dispersed in alkali and pumped through a spinneret into a coagulating bath, producing several thousand very fine filaments (each about 20 microns diameter) in a bundle with a diameter around 0.5 cm. The filaments are stretched as they leave the spinneret, orienting the molecules to produce a chewy texture in the final product. Spinnerets are arranged in groups and the resulting 'tow' is combined ingeniously with binders, fat, flavours and colouring depending on the type of meat it is desired to simulate. Spun protein may be used to replace meat entirely, or as an extender, and a wide range of products has been produced, including smoked varieties.

Spun protein is relatively expensive. The simpler and cheaper extrusion-cooking process has made more rapid progress commercially. Solvent-extracted soya bean flour (50 % protein) or a concentrate (70 % protein) or an isolate (90 % protein) is moistened and plasticized in a tubular extruder by means of a screw designed to generate very high pressures, and hence elevated temperatures, as the material moves towards a die at the end of the tube. The plastic mass, with steam entrained at high pressure, emerges through a series of slots in the die and expands as pressure is released to atmosphere. The protein is chopped off in chunks, possibly 2 cm in width, as it emerges and is then dried. The screw and die assembly are designed to combine pressure, heat and mechanical shear to produce an elongated open cell structure in twisted tangential layerings. When rehydrated with three times its weight of water, the textured protein has a chewy, laminar texture suitable for a meat extender, when appropriately flavoured. The high temperatures employed debitter soya and vaporize some of the beany flavours during manufacture as well as destroying growth inhibitors and undesirable enzymes (Smith 1976*a*). A more recent process (Smith 1976*b*) uses double extrusion at lower pressures and produces denser products with even, parallel layers devoid of pockets more closely approaching the mouth-texture of meat.

Although statistics are not yet issued, current manufacture of textured vegetable protein in the United Kingdom probably exceeds 15 kt annually for all purposes (equivalent to 45 kt of meat when hydrated.) The Food Standards Committee (1974) in their *Report on novel protein foods* has made recommendations likely to form the basis of legislation controlling the sale of these products in the U.K., almost all of which are already observed by manufacturers.

The importance of this developing technology in human nutrition is highlighted by the often-quoted calculations of Christensen (1948) who pointed out that one acre† of soybeans in the U.S.A. will provide the protein requirements of a man for 2224 days compared with 77 days for an acre set aside for beef production.

Although some field bean protein has been used for spinning in the U.K., current production of textured protein is almost all from imported soya. Can British farms produce vegetable protein for direct human consumption at home and for possible export?

† Acre = 0.4047 hectare.

(b) *Grain legumes*

The Government report 'Protein feeds for farm livestock in the UK' (1976) recommends that research on field beans (*Vicia faba*) should have the highest priority, largely owing to the low inputs of fertilizer and support energy required and the benefit of soil improvement (table 2).

Table 2. Protein production and efficiency of resource use for selected crops in the U.K., 1973

	area grown	yield/(t/ha)		c.p. produced per kg fertilizer N	c.p. produced per 10^3 MJ support energy input
	$10^3 \times$ ha	d.m.	c.p.	kg	kg
wheat	1146	3.7	0.46	4.8	30
barley	2268	3.4	0.36	4.6	26
oats	281	3.3	0.36	5.5	28
field beans	59	2.7	0.75	30.0	74
oilseed rape	14	2.0	0.38	2.2	19

Spring varieties produce some 30% protein (higher yielding winter beans about 27%) which has been used in spun products although its methionine content is very low. The crop is unpopular and the acreage has dropped in recent years because yields are notoriously unreliable owing to susceptibility to adverse weather conditions, poor seed set, pests and diseases. Yields are said to have increased little more than 20% in the last century. Plant breeders have much to do before field beans are attractive to farmers or to processors for either human or animal nutrition in the U.K. There are similar problems with dried field peas although the 'leafless' varieties (with leaflets converted into stipules) from the John Innes Institute may improve harvesting prospects.

Sweet lupins, bred for low alkaloid content, are mainly a forage crop in Europe and Australia. The seeds of *Lupinus albus* contain 37% protein (low in methionine) and 12–14% oil, which is too little to make them commercially viable as oilseeds. Although experimental work is being undertaken in England, notably at Reading University, lupins are unlikely to become a grain crop here unless yields can be raised appreciably by breeding. Junge (1973) has produced lupin flour with a view to texturing for human consumption using a counter-current leaching stage to remove even the low content of alkaloids found in sweet varieties.

The new European varieties of soybean, although insensitive to day-length, will not withstand the low night temperatures in England. Yields are unreliable and the beans are difficult to harvest. They are unlikely to become a significant British crop in the foreseeable future.

(c) *Sunflowers*

The sunflower is an important oilseed and protein crop in many parts of the world. Thin shelled varieties can contain 45–50% oil which is excellent for margarine. The extracted meal provides 41% protein which is superior to that of soya and there are no toxicological problems. Unfortunately, the newest semi-dwarf varieties do not mature early enough to make them a practical proposition in southern England and it is unlikely that they will be grown there on

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a significant scale in the short or medium term. There is also a snag for the food manufacturer. Sunflower seed protein extracts are light in colour but contain chlorogenic acid, which is difficult to remove and which develops dark colour in foodstuffs.

(*d*) *Oilseed rape*

Two species of rape are cultivated, yielding an average 42 % oil, *Brassica napus* and *Brassica campestris* (turnip rape) both in summer and winter varieties. Summer *B. campestris* is important in Canada and Winter *B. napus* in Europe, excluding the U.K. where winter types are likely to displace summer varieties as breeders introduce cultivars which yield well when planted later after other crops are cleared.

World production in 1973 was 7 Mt, Canada exported 1 Mt, France and Germany 200 kt. The E.E.C. has encouraged production by setting intervention prices and direct subsidies to crushers, achieving over 1 Mt by 1972 (France 720 kt) out of a total of 1.2 Mt used. The U.K. actually had a small export surplus of rapeseed in the 19th century but the crop declined prior to E.E.C. entry. In 1974 the U.K. grew 55 kt of rapeseed, imported 66 kt together with 73 kt of rapeseed meal (Bell 1975). Rape is a valuable break crop and a high yielding oilseed suitable for the British climate although there are rotational problems, as with all brassicas, caused by pests, diseases and late germination of shed seed.

Food from our own resources (1975) forecasts a U.K. crop of 200 kt by 1980. Blaxter (1975) has drawn attention to the importance of fat production in planning greater food self-sufficiency and advocates higher priority for oilseed rape.

Ordinary rapeseed oil contains 40–50 % erucic acid, a C22 fatty acid, which has been associated with fatty lesions in the heart muscle of rats. Fortunately rape's ability to add acetate molecules to oleic acid is amenable to genetic control and low-erucic acid varieties have been bred in many countries (Bunting 1974). Maris Haplona, a diploid produced by colchicine treatment of a selected haploid by the Plant Breeding Institute, has only 0.2 % erucic acid in the oil and is probably the highest yielding European summer variety (Thompson & Betts 1975). Rapeseed oil must now contain less than 15 % erucic acid to qualify for intervention support with a proposed drop to 10 % in July 1977. Rapeseed protein (40 % of the extracted meal) has a very high nutritional value, superior to soya protein owing to a significantly higher content of methionine, approaching the quality of animal protein. Ordinary rapeseed meal is, however, restricted largely to feeding ruminants by the presence of glucosinolates, which are broken down by myrosinase to produce goitrogenic toxins. Breeders are developing varieties low in both erucic acid and glucosinolates. The 'double-zero' variety of *B. napus*, Tower, already accounts for 15 % of the Canadian acreage. Unfortunately 'double-zero' or better 'double-low' varieties have a lower farm yield than either classical or low-erucic acid varieties. Nevertheless, the Canadians have made such progress with a new yellow skinned variety of *B. campestris* that it is realistic to hope that most of their crop will be 'double-low' by 1980. British bred 'double-lows' are in field trials.

The Swedes have taken the lead in developing technology to produce rapeseed protein concentrate (60 % protein) for human nutrition. The main steps are dehulling, myrosinase inactivation by heat, glucosinolate removal by water leaching, drying and oil extraction (Ohlson 1973). This concentrate can be textured by extrusion cooking to produce a bland meat extender, either on its own or in admixture with soya. Toxicologicalpes acts are still under scrutiny but a textured product made from 50 % extracted soya and 50 % Swedish rape protein concentrate has given a protein efficiency ratio of 2.5, equivalent to casein, with figures around 2.8 for an all-rape textured product made from a concentrate from ordinary rapeseed meal. Very low glucosinolate contents are anticipated for concentrates made from 'double-zero' varieties which should be acceptable for human nutrition.

Staron (1974) has described a process for making rapeseed protein isolates said to be detoxified by fermentation.

Toxic symptoms developed by rats late in pregnancy when fed detoxified rape protein have caused anxiety (Eklund 1973) but the problem appears to have been zinc deficiency exacerbated by the high content of phytin in the concentrate (Shah, Jones, McLaughlan & Beare-Rogers 1976) which can also reduce calcium and magnesium levels (Momcilovic & Shah 1976).

Toxicological studies should now be concentrated on protein preparations made from the new varieties, combining the skills of the plant breeder and technologist, including investigation of taints in eggs and fatty liver haemorrhage in poultry fed rapeseed protein. It is probable that a combination of the extraction process and texturing will make this highly nutritive protein available to the human population within 5 years, adding another reason for choosing to grow rapeseed in this country.

6. Conclusion

There are many other examples, with which the author is not directly concerned, illustrating the need to study not only the current needs of the processor but his developing technologies in influencing the choice of crops for British agriculture or, more accurately, in expressing British opinions in developing the European Community's common agricultural policy.

It is hoped that those bodies responsible for advising the Government, including the Agriculture Economic Development Committee and the Nuffield Foundation's Centre for Agricultural Strategy (which is studying self-sufficiency) will give adequate weight to the user's changing requirements in assessing alternative policies and the balance of sponsored research on either side of the farm gate.

References (Russell Eggitt)

Autran, J. C. 1975 Identification des principales variétés communautaires de blé tendre par électrophorese des gliadin du grain. *Bull. anc. Élev. Éc fr. Meun.* **270**, 316–324.

Bell, J-M. J. 1975 *The market for rapeseed and its products in Western Europe with particular reference to the U.K.* London: Tropical Products Institute.

Bingham, J. 1975 Winter wheat breeding and prospects. *Jl R. agric. Soc.* **136**, 65–77.

Blaxter, K. 1975 Can Britain feed herself? *New Scient.* **65**, 697–702.

Boyer, R. A. 1954 U.S. Patent 2682466.

Bunting, E. S. 1974 New arable crops – retrospect and prospects. *Jl R. agric. Soc.* **135**, 107–121.

Chamberlain, N., Collins, T. H. & Elton, G. A. H. 1961 The Chorleywood Bread Process. *Rep. Br. Baking Ind. Res. Ass.* no. 59.

Chamberlain, N., Collins, T. H. & Elton, G. A. H. 1962 The C.B.P.: commercial application. *Rep. Br. Baking Ind., Res. Ass.* no. 62.

Chamberlain, N., Collins, T. H. & Elton, G. A. H. 1963 The C.B.P.: choice of flour. *Rep. Br. Baking Ind. Res. Ass.* no. 66.

Chamberlain, N., Collins, T. H. & Elton, G. A. H. 1965*a* The C.B.P.: the effect of flour strength on the quality of plant bread. *Rep. Br. Baking Ind. Res. Ass.* no. 77.

Chamberlain, N., Collins, T. H. & Elton, G. A. H. 1965*b* The C.B.P.: the effect of flour strength compared with the bulk fermentation process. *Rep. Br. Baking Ind. Res. Ass.* no. 82.

Christensen, R. P. 1948 Efficient use of food resources in the U.S. *Tech. Bull. U.S. Dep. Agric.* 963.

Eklund, A. 1973 Influence of a detoxified rapeseed protein concentrate on reproduction in the female rat. *Nutr. Rep. Int.* **7**, 647–654.

Food from our own resources 1975 London: H.M.S.O.
Food Standards Committee Report on Novel Protein Foods 1974 London: H.M.S.O. FSC/REP/62.
Greenberg, D. C. 1974 Studies on the variations of gum content in barley and its relation to feeding and malting quality. Ph.D. thesis, University of Cambridge.
Junge, I. 1973 Lupine and Quinoa Research and Development. *Rep.* 1 *Bio-engineering Lab.* University of Concepción, Chile.
Leach, G. 1975 The energy costs of food production. In *The man/food equation* (eds F. Steele & A. Bourne), pp. 139–163. London: Academic Press.
Momcilovic, B. & Shah, B. G. 1976 Femur zinc, magnesium and calcium fed Tower rapeseed protein concentrate. *Nutr. Rep. Int.* **13**, 135–142.
Ohlson, R. 1973 Rapeseed protein concentrate for human consumption. *P.A.G. Bulletin* **3** (3), 21–23. United Nations: Protein Advisory Group, New York.
Protein feeds for farm livestock in the U.K. 1976 *Rep.* 2. London: Agricultural Research Council.
Recommended varieties of cereals 1976 Farmers' leaflet 8. Cambridge: National Institute of Agricultural Botany.
Rhodes, A. P. & Jenkins, G. 1975 The effect of varying nitrogen supply on the protein composition of a high lysine mutant of barley. *J. Sci. Fd Agric.* **26**, 705–709.
Shah, B. G., Jones, J. D., McLaughlan, J. M. & Beare-Rogers, J. L. 1976 Beneficial effect of zinc supplementation in young rats fed protein concentrate from rapeseed and mustard. *Nutr. Rep. Int.* **13**, 1–7.
Smith, O. B. 1976*a* Extrusion cooking. In *New protein foods* (ed. A. M. Altschul), vol. 2 (Technology), pp. 86–121. New York: Academic Press.
Smith, O. B. 1976*b* Textured vegetable protein. *Proceedings World Soybean Research Conference*, University of Illinois. (In the press.)
Staron, T. 1974 Méthode d'obtention, propriétés physico-chimiques et valeur nutritionnelle des protéines de colza extraites par voie fermentaire. *Inds Aliment. anim.* **9**, 27–43.
Stewart, B. A. 1975 Home-grown wheat over the past decades. *Flour Milling & Baking Res. Ass. Bull.* 3. Chorleywood.
Thompson, K. F. & Betts, D. M. 1975 *Pl. Breed. Inst. Ann. Rep.*, pp. 95–97. Cambridge.
Tsen, C. C. (ed.) 1974 *Triticale: First man-made cereal.* Symposium Proc. Am. Ass. Cereal. Chem., St Paul, Minnesota.
Young, V. R., Scrimshaw, N. S. & Milner, M. 1976 Food from plants. *Chemy Ind.* 588–598.

Discussion

P. S. Wellington (*National Institute of Agricultural Botany, Huntingdon Road, Cambridge CB*3 0*LE*). The speaker has referred to the first stage in the evaluation of wheat and barley for processing which depends on the genetic quality factors of the available varieties as determined in N.I.A.B. trials. The second stage is to select suitable bulks from within a quality variety by tests for those factors which are determined by the environment. Since the environmental conditions under which both crops are grown in this country are variable and unpredictable the national strategy should be to grow varieties of a quality adequate to meet most of the processor's requirements as widely as possible. This should then ensure that each season there are sufficient bulks available with both genetic and environmental quality from those regions with favourable conditions.

It has already been possible to obtain agreement between plant pathologists and plant breeders on standards for genetic resistance to folial diseases in future varieties. It is hoped that it will be possible soon to obtain agreement between processors and plant breeders on an adequate standard of genetic quality for processing without sacrificing the highest yields which make new varieties profitable for the growers and ensure that they are widely grown. This combination of characters was largely responsible for the predominant position held by Cappelle-Desprez wheat and Proctor barley in the total acreage of each crop for a long period in the 1960s.

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