# Cereals as protein sources

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For at least 5000 years cereals have predominated as the arable crop grown to provide food for man and animals in the temperate climatic zones. They have been regarded as sources of energy and foods such as breads, spaghetti, chapattis, etc., require the addition of other protein sources to provide a satisfactory balanced diet. But cereals do contain significant amounts of protein, especially in diets formulated for animals and their modification in order to provide a 'complete' food would be advantageous, both economically in reducing expensive protein imports and also nutritionally in circumstances such as those obtaining in the developing countries where cereals already form too large a proportion of the diet. The fortification of cereal grains by the addition of supplementary lysine is one attempt at improvement and the arguments for and against this practice have been frequently stated. Selection of cereal strains has been practised from earliest times in order to increase yield. More recently attempts have been made to select for improved disease resistance and desirable characteristics such as strength and length of straw, and the ability to resist the premature shedding of ripe seed. Despite the suggestion that the selection of grains for improved protein quality is not of sufficient economic importance to justify the likely cost in terms of reduced yields (Aitken, 1968), the possibility of selecting for improved amino acid composition has not yet been ruled out. It is the purpose of this paper to examine some other possibilities for making the best use of cereal protein.

## *Supplementation of cereals with protein concentrates*

The cereals currently available have two drawbacks from the point of view of protein composition. Their protein content is too low to sustain optimum growth in non-ruminant livestock, and secondly their proteins are a mixture in which the nutritionally poorer ones predominate. The net result is under-provision of the sulphur-containing amino acids and lysine. In passing it should be noted that, at least as far as lysine is concerned, this objection does not apply to cereal leaf protein; but this aspect of protein production is not peculiar to cereals and will not be considered further here.

That cereals are improved as protein sources by supplementation with animal and plant protein concentrates is of course well understood, as is the fact that maximum benefits are achieved when the supplementary protein sources are rich in those amino acids lacking in the cereals. Fish meals provide lysine and sulphur-containing amino acids. Soya bean is a good source of lysine and sunflower of methionine. Similarly supplementation of cereals with pure amino acids may be beneficial. The addition of one or more of the amino acids lysine, tryptophan and threonine to rice, wheat, maize, millet, barley, sorghum, rye and oats in diets for growing rats yielded protein efficiency ratios comparable to that given by casein (Howe, Jansen & Gilfillan, 1965). These results were quoted as indicating the desirability of judicious supplementation of food grains to improve the world food supply.

Diets for animals rarely consist of cereals and a single supplementary protein source. Frequently two or more concentrates may be included and sometimes pure amino acids as well. This being so, the net effect of the complete mixture must be considered. Bressani & Elias (1968) considered the effects of combining two protein sources and were able to classify the mixtures into three types. In one type the result of combination is predictable from the nutritive value of the individual components and the value of any mixture of the two falls on a straight line joining them. In a second type the protein of poorer quality exerts a sparing action upon the other so that more than the calculated quantity of the poorer ingredient may be incorporated without the value of the mixture falling below that of the better component. The third type is essentially a special case of the second when the particular mixtures may have a higher nutritive value even than that of the better component. The importance of the latter observation stems from the fact that poorer proteins are often cheaper than good ones and there is the clear possibility of achieving considerable economies in diet formulation as well as being able to use the protein sources to best advantage.

Various combinations of cereals with single protein sources have been shown to exhibit this effect: beans and rice (Bressani & Valiente, 1962); beans and maize (Bressani, Valiente & Tejada, 1962); beans and wheat (De Groot & Van Stratum, 1963). Two protein concentrates in the presence of a constant cereal component also exhibit this synergistic effect (Woodham & Deans, 1977). The effect was attributed by Bressani *et al.* to mutual complementation of the two protein sources in that deficiencies in essential amino acids in the one are compensated for by excesses in the other. While this is borne out in some cases, it does not appear to be the whole answer, and the true explanation may rather involve the achievement of a better over-all amino acid balance in the mixture (Woodham, 1976). The deleterious effects of excesses of amino acids, as distinct from effects due to poor amino acid balance involving both excesses and deficiencies, are only now beginning to be appreciated (Waldroup, Mitchell, Payne & Hazen, 1976). The importance of the cereal component of the diet when the other protein-containing constituents are of poor quality has been stressed (Woodham, Savić, Ayyash & Gordon, 1972) and it is in such circumstances that there is scope for making full use of the potential of the cereal protein.

### *The effects of germination*

During germination of cereal seeds starch content falls, sugars increase and there is a transfer of nitrogen from the endosperm to the embryo. This utilization of the stored proteins involves a considerable amount of amino acid interconversion.

Glutamine and proline provide the nitrogen for the synthesis of lysine and other essential amino acids (Folkes & Yemm, 1958). The concentrations of lysine, alanine, leucine, isoleucine, valine and arginine increase to a maximum during the first 4 d of malting and then decline sharply, while glycine, threonine, tyrosine, histidine, tryptophan and methionine rise similarly during the same period but thereafter remain constant (Jones, 1969). The addition of gibberellic acid accelerates the malting process and also accelerates the rate of decline of lysine and the other amino acids associated with it after the fourth day, but the methionine group is not affected. Germination for 5 d at 28° decreased prolamine content and increased lysine and tryptophan contents in maize (Tsai, Dalby & Jones, 1975) and in wheat, barley, triticale, rye and oats (Dalby & Tsai, 1976). These workers reported increases in lysine content from 0·5% of the dry weight of the grain to over 0·8% for wheat, from 0·6 to 0·8% for barley and oats, and from 0·5 to 0·7% for rye.

Such changes in amino acid composition might be expected to improve the nutritive quality of the grain but the results of animal experiments reported in the literature have not been encouraging. The addition of malt to ordinary barley in diets for chicks did not improve growth (Laerdal, Bird, Sunde & Phillips, 1959), nor was egg production or feed conversion affected by the incorporation of barley germinated for three days in diets for laying hens (Müller, 1952). Feed utilization was not improved by the use of germinated barley in pig fattening diets (Schmidt & Kliesch, 1937) and the addition of malt to ordinary barley in diets for pigs was similarly ineffective (Larsen & Oldfield, 1960). Work at the Rowett has confirmed the improvement in amino acid composition resulting from barley germination (Woodham, 1971). Prolonged germination (12 d) yielded a product which supported poorer chick growth than the ungerminated barley. Subsequently it was discovered that the product of 5 d germination gave superior growth in chicks and that 'greening' of the germinated barley gave better results still. The total protein efficiencies (TPE) for the three samples were respectively 1·60, 1·97 and 2·16. The comparatively high quality of the greened sample is clearly associated with its much higher lysine content, and attributable to the known superiority of green leaf protein over seed protein. These results seem reasonable in the light of Jones' (1969) findings and one must conclude that very careful control indeed is needed over the time and conditions for the germination stage. It appears also that germination affects barley varieties differently. Senta, a variety made available to us by the Plant Breeding Institute, Cambridge, was poor in nutritive value when compared to a second variety HB411 and while Senta was much improved by germination, HB411 was not. The TPE for the Senta ungerminated and germinated were 1·03 and 1·86, while for HB411 the corresponding values were 1·62 and 1·53.

## *Nitrogen fertilizers and growth regulators*

Nitrogen fertilizers increase the grain yield and its content of crude protein (Woodham, Savić & Hepburn, 1972) but the quality of the resulting grain as measured by its lysine content may be poorer. Barleys containing 33% more protein may provide 20% less lysine (Jones, Cadenhead & Livingstone, 1968), and while high-protein barleys may indeed provide a greater weight of lysine per ton of grain then low protein samples there is an inverse relationship between crude protein and lysine content for barleys containing from 8 to 11% of crude protein. Within a range of such barleys it was found that one ton of either an 8 or 11% protein barley yielded the same weight of lysine (Woodham, 1973). The additional protein which results from nitrogen fertilization consists largely of the prolamines, hordein (barley), zein (maize), gliadin (wheat), and this accounts for the generally poorer nutritive value.

It has been claimed that spraying growing wheat with growth regulators not only increases the protein content (Lier & Lacroix, 1974), but may also increase the relative proportions of essential amino acids such as lysine. A mixture of 2, 4-dichlorophenoxyacetic acid with 2-methoxy-3,6-dichlorobenzoic acid (10:1 v/v) applied to the growing crop at a rate of 1 l/acre increased grain yield by 66%, grain protein content from 9·80 to 12·85% and resulted in lower levels of aspartic and glutamic acids, glycine, alanine and tyrosine, with increases in valine, leucine, isoleucine, arginine, phenylalanine and lysine. Although the increase in content of lysine was small, the effect would appear to be worth noting (Hegazi, El-Masry & El-Bastawesy, 1974).

*The fractionation of cereal proteins*

The individual proteins of cereals have different physical properties and are not uniformly located throughout the seed. Both of these attributes have been utilized in the development of fractionation procedures designed to separate out the more nutritionally useful proteins from the rest. The germ may contain up to 50% of the total protein of the seed and proportionately more of the better proteins. Accordingly milling procedures which permit separation of the germ offer one possible way of producing a cereal protein concentrate. Normal milling procedures do allow for some fractionation of by-products and it is well known that bran and 'middlings' or 'shorts', which contain a large proportion of the outer layers of the seed, are high in both protein and lysine content relative to the parent grain. At the same time they tend to be more fibrous and less digestible. The ordinary sieving processes do not permit separations below a particle size of around 80 μm. Air-classification, a process involving the opposition of centrifugal force and air drag on particles, is used to divide milled flour into fractions of differing particle size. Because of the tendency for bran particles to concentrate in the coarser fractions, the fine fractions may be high in protein and lysine as well as being acceptably low in fibre content. A hard wheat flour may thus yield a fine fraction (0–17 μm) with 18% protein, a medium fraction (17–35 μm) with 10% protein and a coarse fraction (>35 μm) containing 14% protein (Kent, 1966). Barley flour excluding bran and 'shorts' may be similarly fractionated to give high protein fractions totalling 25% of the original flour (Pomeranz, Ke & Ward, 1971). Triticale flour containing 12·7% protein has been air-classified yielding three fine fractions

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containing respectively 34, 28 and 21% protein, together representing 25% of the total protein of the flour. The three fractions contained respectively 2·7, 2·5 and 2·4 g lysine/16 g N, compared to 2·5 in the original flour (Stringfellow, Wall, Donaldson & Anderson, 1976). So although the air-classification procedure has effected a considerable concentration of protein there is no evidence for a selective concentration of specific protein classes. Air-classification of cooked, defatted, maize germ flakes yielded a fine fraction containing 27% protein, 5% lysine and 3 to 4% fibre (Gardner, Garcia, Stringfellow & Inglett, 1973).

There is clearly a need for more nutritional and analytical studies on the potentialities of air-classification, but it seems possible that a procedure originally developed to provide materials with characteristics suitable for particular bakery products may ultimately be of benefit to the nutritionist concerned with making the best use of cereal protein.

It has been claimed recently that the preparation of protein concentrates by the extraction of ground cereals with dilute alkaline solutions yield products of good amino acid composition and nutritive value. Woerman & Satterlee (1974) have prepared a high lysine–high methionine concentrate from wheat which had a protein efficiency ratio (PER) in rat tests of 2·07 compared to 2·50 for casein. Maize germ protein has been similarly concentrated and it was claimed that the product had a good amino acid balance including 6% of lysine (Nielsen, Inglett, Wall & Donaldson, 1973). Extraction at 24° of rice bran with dilute NaOH at pH 9 yielded products containing 22–31% protein, 33–48% lipid and 15–23% starch in 14–20% yield (Connor, Saunders & Kohler, 1976). The lysine content was increased from 4·4 to 5·1–5·2 g/16 N, the PER from 1·59 to 2·19 and, perhaps most important, the N digestibility was raised from 58 to 84–9. A protein extract identical in amino acid composition, PER and digestibility to the original maize and wheat fermented by yeast after inoculation with fungal and bacterial amylases was extracted at pH 12·2 and a temperature of 80° (Satterlee, Vavak, Abdul-Kadir & Kendrick, 1976). Theoretically extraction with saline solutions which dissolve the globulins, rich in both lysine and sulphur amino acids compared to the other cereal proteins, should yield a better product than alkaline extraction. Although a product of somewhat superior amino acid composition was obtained from barley by extraction with NaCl solution the results of feeding trials were disappointing (Woodham, 1968) and a product obtained by NaOH extraction gave better chick growth. Extraction of oats with NaCl and NaOH yielded concentrates with rather similar amino acid composition.

## *Enzyme additions to cereal diets*

Although the supplementation with amylases of cereal-based diets for animals has been extensively studied much less work has been done on the effects of proteins. Improved protein digestibility for poultry of barley subjected to water treatment or fungal enzyme supplementation has been reported (Potter, Stutz & Matterson, 1965). We have observed small but significant improvements in the growth of chicks on the addition of proteases to diets consisting of cereals with poor meat and fish meals (Woodham, 1974, 1975). The possibility that the improved chick growth found on supplementation of barley diets with mixed enzymes might be caused by the cleavage of complex carbohydrate linkages involving β-glucan, a major part of the endosperm cell wall, was suggested by Petersen & Sauter (1968). They suggested that this might permit the more efficient functioning of the digestive tract enzymes. Although the effects are generally small such improvements in the utilization of cereal protein might be worth while in countries where good quality protein sources are not readily available.

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