GENETICALLY MODIFIED PLANTS FOR POULTRY FEEDS

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Summary

Plant breeding, both conventional and by the production of transgenic plants, has and is developing grains more suited as animal feed, including poultry feed. Past progress has focussed on easily determined feed quality traits. Present progress is using more sophisticated analysis methods. Future development will rely on clearer definitions of the requirements for animal feed and research on the constituents of grains that affect these requirements.

I. INTRODUCTION

The development of crop varieties with targeted qualities that make them more suitable for animal feeding purposes is a relatively recent phenomenon. It has occurred for longest in grain sorghum, where selection for lower tannin content has increased digestibility and palatability (Tsaftaris, 1997). It is much more recent in other grains where the animal feed classification is a lower value grade used for grain not fitting the demanding specifications for human food uses.

This paper reviews some of the history and current state of breeding crop plants for feed quality traits. Only work on grain traits is considered as these are of interest to the poultry industry. Research on forage quality traits and the manipulation of these in grasses and legumes is proceeding, with benefits for grazing animals.

II. CONVENTIONAL PLANT BREEDING

Conventional plant breeding for most major commodity grain crops has now proceeded in the West, with various levels of input, for between seventy to over a hundred years. Considerable increases in commercial yields and reliability of production resulted from the combination of both improved cultivars and agronomic practices, with feedback between the two factors (Duvick, 1984; Evans, 1993). This increased production, other technical and infrastructure advances, and economic pressures contributed to the development of intensive food animal rearing as a major industry.

Conventional plant breeding is also having an influence on feed grain quality by targeting components known or thought to modify grain feed value. The most obvious of these is the strong attachment of the relatively indigestible husk or hull to barley and oat grains. The simple genetic control of the presence versus absence of the husk or hull on the thrashed grain has enabled the development of "naked" cultivars of both barley and oats. Commercial naked barley and oat cultivars are available overseas in the UK, USA and Canada (Mannsell, 2000) as well as in Australia (van Barneveld et al., 1998), and have increased digestible energy per unit volume. Naked oats, in particular, is highly suitable for broilers (Maurice et al., 1994) but they have harvest problems with shedding of grain from the crop (Perry, 1995). In addition, cultivars with thin husks and with higher oil content are available in the UK (Mannsell, 2000).

Another specialty crop developed by conventional plant breeding is “waxy” corn or

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maize. This single gene trait results in the virtual absence of amylose (linear starch) from the endosperm starch, so that the starch is, therefore, composed entirely of the branched polymer, amylopectin (Ferguson, 1994). The difference can be assayed easily by iodine/potassium iodide staining of the grain endosperm. Though initially developed in the 1940s as a tapioca replacement, and largely used for the isolation of “waxy” starch for many food uses, it also finds a good market due to its higher (than non-waxy) feed efficiency for most animals, including poultry (Ferguson, 1994). Waxy barley is also available in commercial cultivars (Blatty, 1997) but these have higher than normal β-glucan levels and are, therefore, not favoured as feed, especially for poultry.

High lysine genotypes of maize and barley are available, based on the opaque-2 and hipoly genes, respectively. In maize, breeding effort in the USA has overcome many of the deleterious effects of the original opaque-2 sources and has resulted in the development of Quality Protein Maize (QPM). Quality protein maize is in quite extensive commercial use in a number of countries with more than a million tons produced in the USA mostly for on-farm animal, mainly pig, feeding (Vasal, 1994).

III. ACCELERATED PLANT BREEDING

Conventional plant breeding is undergoing something of a revolution that is enabling an acceleration of progress. This is coming about by the application of the growing body of knowledge of plant genomics and biochemistry and the availability of molecular tools for selection in plant breeding. In recent times this has resulted in improved “output traits” such as grain quality for animal feeding. It relies on two processes; germplasm screening by high throughput analytical tests for trait identification, and subsequent use of DNA-based molecular markers to incorporate the traits into commercial cultivars (Mazur et al., 1999).

Mazur et al. (1999) have indicated success with this process in two cases, soyabean and maize. In soyabean, screening germplasm and mutated lines found lines with low levels of antinutritional oligosaccharides. Combining these sources led to even lower levels and the lower levels were transferred into commercial high-yielding plants with DNA marker assistance. Feed as well as other uses are envisaged (Mazur et al., 1999).

The development of commercial crops of high-oil corn is a current commercial success in feed grains. This started with the now classic high-oil lines of corn developed by long-term recurrent selection at the University of Illinois (Alexander, 1988). The lines are very poor agronomically but their grain has very high feed value, including for poultry (Lambert et al., 1994). Quantitative genetic studies of the high-oil lines indicated that the trait was controlled by more than 12 genes so that conventional breeding to produce well adapted and high-yielding cultivars would be extremely difficult. To overcome this the TopCross® crop method was developed (Mazur et al., 1999). This involves commercial fields containing a low density of the (agronomically inferior) male-fertile high-oil line with a normal density of an elite F1 hybrid that is male-sterile. The cross-pollination of this later line by the interplanted high-oil line results in high yield of grain with up to a doubling of grain energy content compared with normal hybrid corn. This system has now performed well in a wide area over a number of seasons and is a highly successful product for DuPont Agricultural Products in the USA.

These examples discussed so far partly illustrate an important point concerning plant breeding. Intimate knowledge of the phenotype desired and rapid ways to select for that phenotype, as early in the breeding cycle as possible, are necessary for progress. Other examples will result in products in the next decade.
Mutants of maize and barley with low phytic acid levels in the grain were isolated in the 1990s (Larson and Raboy, 1999). The genetic control of this trait is simple, by one or two lpa loci. This, coupled with the availability of rapid screening tests (Rasmussen and Hatzack, 1998) that rely on the presence of high inorganic phosphate levels in the lpa grains, means that the introgression of this trait into commercial cultivars will be relatively rapid. Low phytate grains will have nutritional value in animal feed, with higher phosphate uptake and higher bioavailability of minerals and proteins, and have environmental advantages as a result of the lower phosphate load in effluent from animals fed such grain (Ertl et al., 1998; Mazur et al., 1999).

The high lysine trait in grains is beginning to be understood better and rapid tests developed. In maize and sorghum the concentration of elongation factor 1A (eEF1A) in the grain is a very good predictor of grain lysine content (Sun et al., 1997). Although eEF1A has a high content of lysine it represents only a small proportion of the grain lysine. ELISA tests of eEF1A levels will enable more rapid breeding progress than could be achieved by conventional lysine determinations as these take longer and are more expensive. Work in wheat suggests that the level of eEF1A is not closely related to grain lysine levels but that the concentration of another lysine-rich protein, aldolase, may be more strongly related to wheat grain lysine levels (Singh et al., 2000).

As consideration moves to less well-defined chemical constituents, and to bioassays such as feeding trials, evidence of the direction to select (if any) becomes less certain (O’Brien, 1999). Two particular interrelated problems of wheat for poultry, soluble non-starch polysaccharides (NSP) and low apparent metabolisable energy (AME) grain, are becoming more clearly defined with the degree of branching of soluble NSP being positively correlated with AME (Austin et al., 1999). Additionally, regions of the wheat genome controlling the viscosity of water extracts of wheat grain are becoming defined by molecular mapping studies (Martinant et al., 1998). These studies suggest that progress in selecting for higher AME in wheat for poultry would be possible.

One way to overcome the limitations of cultivar and environment comparisons in determining grain components important in determining feed quality outlined by O’Brien (1999) is to use precise genetic stocks, such as isogenic lines that differ only at one gene. This approach is being used in wheat to examine poultry feed quality (Anonymous, 1998). These studies indicate that the widespread (especially overseas) wheat-rye translocation chromosome (1BL/1RS) lowers AME while hard grain gives higher starch digestibility than soft grain. Other isogenic line pairs are being investigated (Anonymous, 1998).

Other traits of potential importance for poultry feed quality are under development. Waxy (zero amylose) wheat cultivars are expected in the next few years (Graybosch, 1998; Zhao and Sharp, 1998). It is not yet known if these will have a similar increase in NSP content as waxy barley. Another aspect of wheat starch, the distribution between the large A-granules and the small B-granules is beginning to be investigated (Stoddard, 1999). Any association of this property with feed quality remains to be determined. Quick progress in changing this property can be expected as testing is relatively easy (Stoddard, 1999). Very recently, a mutant sorghum with very high protein digestibility was isolated and the biochemical nature of the trait is being elucidated – one feature is the presence of highly irregular shaped protein bodies, in contrast to the near spherical protein bodies of normal sorghum (Oria et al., 2000). This mutant may be significant to sorghum breeding for feed quality. In addition, the research on the nature of the trait may open up the development of methods to screen for similar changes in other grain crops.
IV. TRANSGENIC PLANTS

The generation of transgenic or genetically modified (GM) grain crops is another possible technology with potential to alter grain feed qualities (Mazur et al., 1999). An initial GM target of significance for animal feeding was increased grain methionine and lysine levels. Two approaches were taken to achieve this; introducing and high expression of a gene encoding a high methionine/lysine seed protein or inserting genes for biosynthetic enzymes of lysine/methionine with altered feed back inhibition.

A well-known example of the first approach is the use of a Brazil nut 2S storage protein. This protein contains 19% methionine (Altenbach and Simpson, 1990). The gene encoding this protein was cloned from Brazil nut (Altenbach et al., 1992), and inserted into canola and soyabean (Altenbach et al., 1992) under the control of seed-specific promoters. This led to significant benefits in nutritional value with increased methionine levels of over 30%. These products have not proceeded to commercialization. This is because the 2S protein is responsible for the sometimes life-threatening human allergenicity of Brazil nuts – a point not known when the work started (Day, 1996).

The incorporation of genes of the lysine biosynthetic pathway insensitive to lysine feedback inhibition has proceeded (Mazur et al., 1999). This has used aspartokinase (AK) and dihydrodipicolinic acid synthase (AHDS) genes from various bacterial species (Falco et al., 1995) or a lysine-insensitive form of a plant AHDS produced by site-directed mutagenesis (Mazur et al., 1999). The results from the incorporation these genes have depended on the host plant species and the tissue-specificity of the promoter controlling the gene. In soyabean and canola lysine levels were more than doubled but the lysine catabolic products, saccharopine and α amino adipic acid, also accumulated in the seed. In contrast, in GM corn these genes gave no lysine accumulation under an endosperm-specific promoter while expression under an embryo-specific promoter gave a 50 to 100% increase in lysine levels with only little accumulation of the catabolism products (Mazur et al., 1999). Commercial release of GM corn and soyabean lines with increased lysine and methionine is due in the next few years in the USA (Mazur et al., 1999).

An early research success in modifying grains for feed use was GM tobacco seeds expressing an Aspergillus niger phytase. This resulted in seed that, when added to chicken feed at about 20g/kg, produced a similar growth response to the use of a commercial feed enzyme supplement (Pen et al., 1993). Clearly, this is not commercially viable but recent work has developed GM wheat expressing the same A. niger phytase (Brinch-Pedersen et al., 2000). Although not yet tested in feeding trials the level of phytase expressed in the wheat grain suggests that only limited amounts of the phytase GM wheat will be required in compound feed to give a beneficial effect. It may be that GM wheat expressing microbial xylanase genes as well would be of additional benefit (Zyla et al., 1999).

V. ECONOMIC AND OTHER ASPECTS

Feed quality enhanced grains will have to bear the cost of “identity preservation” (Mazur et al., 1999) down the production and distribution chains. This is because one is attempting to convert a bulk commodity into a specialized higher-value product (Kidd, 1993). DuPont have such a system organized for their high-oil corn in the USA. Another consideration is how the current controversies concerning GM food will play out. In particular, the public view of GM grains as animal feed and the products from animals fed such grains will be important in their final commercialization.
VI. CONCLUSIONS

Grain cultivars with improved feed quality are in agriculture. Many products are under development. Consequently, we can expect more high-feeding value grain cultivars to come on the market in the next ten years.

REFERENCES


