producing agent or changing the genetics or physiology of the pest.

Integrated pest management. Integrated pest management is a popular concept at the present. It implies a unification of insect, disease and weed control. To some people this means a solution to all our pest problems. To others it is a safeguard to protect the environment from excessive use of pesticides and other pest control practices, so that one practice does not disturb the balance of nature and create another problem. It has been shown, for example, that benomyl used as a foliar fungicide to control disease also kills beneficial insects that normally feed on soybean insect pests.

Carboflurin, a soil insecticide commonly used to control insects and nematodes in corn, increases the damage from Phytophthora root rot in soybeans. Likewise, continual use of certain classes of herbicides has increased the presence of Rhizoctonia root rot. Then there is the more direct cummulative effective of metabuzin on soybeans following corn with atrazine the previous year. To prevent these problems, it is necessary to use a concerted approach in applying the current technology in dealing with pests and pest complexes.

I believe we are in the position at the present that pests should not threaten soybean production. How much we reduce the loss caused by soybean pests will depend upon how well we use the pest management technology we now have and how well we keep abreast of future problems. I would like to emphasize that when introducing a crop into a new area, you must have adapted cultivars that can compete with other local crops in demand and production costs. Much of the basic information and basic production technology is transferable, but the success or failure of the program will depend on local production practices. These are practices in production, including pest management, that must be developed at the local level through applied research to meet the local needs. One must be willing and prepared to meet this challenge of applied research.

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Improving the Quality of the Soybean

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ABSTRACT

Soybeans, once a relatively minor farm commodity, have become the world's most abundant source of vegetable protein and oil. This growth in popularity, much of which has occurred in the last 20 years, has been made possible partly by genetic improvements that have successfully adapted soybeans to a wide variety of environmental conditions. To date, however, soybean breeders have concentrated their research efforts on increasing the quantity rather than the quality of soybeans. This paper summarizes genetic research currently underway to improve the quality of soybeans and/or soybean products. It also examines research efforts to improve the soybean's fatty acid composition, change the amino acid profile and reduce antinutritional factors.

INTRODUCTION

The growth of soybean production is remarkable. Research has played a major role in making this crop the premier of oilseed protein and the dominant vegetable oil, and thus indispensable to our agricultural economy. Research has been responsible for improved soybean yields, for cultural practices that reduce production cost, and for developing a better understanding of plant physiological functions. Today, we know much about soybean production; however, research to improve the quality of the soybean has been limited. This paper will discuss research designed to modify the soybean by maximizing its usefulness and minimizing its shortcomings.

The ideal soybean would be: (a) High in protein. The amino acid profile should compliment cereal grains in meeting nutritional requirements. (b) High in oil. The oil should contain low levels of fatty acids, which cause stability problems. (c) Low in undigestable carbohydrates. (d) Low in antinutritional factors.

TABLE I

Oil and Protein Composition of Soybean Varieties of Different Maturity Groups (1,2)

Maturity group	Number of observations	Oil Range (%)	Oil Mean (%)	Protein Range (%)	Protein Mean (%)	Total oil plus protein (%)
Northern states						
00	13	18.4-19.5	19.0	38.8-40.7	39.6	58.6
0	15	18.2-19.3	18.8	39.9-41.7	40.7	59.5
I	32	18.4-20.4	19.3	39.1-42.4	40.8	60.1
II	19	19.4-20.5	19.9	39.1-43.0	40.5	60.4
III	24	19.2-21.4	20.3	39.4-43.2	41.1	61.4
IV	17	18.8-21.6	20.3	37.9-42.4	40.6	60.9
Southern states						
IV-S	12	19.1-20.4	19.7	39.9-42.6	41.5	61.2
V	12	19.0-20.6	19.9	38.1-41.9	39.9	59.8
VI	12	17.9-20.5	19.3	38.9-42.9	41.2	60.6
VII	12	19.1-20.5	19.8	40.4-42.4	41.4	61.2
VIII	12	19.8-20.9	20.3	39.6-43.0	41.2	61.5

PROTEIN AND OIL

Soybeans have commercial value because they can be processed into a high-quality protein and a versatile edible oil. The amino acid profile of soybeans compliments that of cereal grains. For this reason most poultry and swine diets today are simple corn-soybean diets. Soya oil's market share in 1977 accounted for 80% of the prepared dressings, 78% of the margarines, 75% of the salad and cooking oils and 59% of the shortenings in the United States.

The ideal soybean would be high in protein and oil. Table I provides information on the average percentages of oil and protein in soybeans of different maturity groups. These data were obtained from the 1979 Uniform Soybean Tests (1,2). Ten uniform test groups have been established to evaluate the better strains developed in the soybean breeding programs. Groups 00-IV are adapted for the northern parts of the United States and groups IV-S through VIII are grown in the southern regions. There are only minor differences in average percentages of oil, protein, or total oil and protein. The ranges for protein and oil are not excessive for these agronomically advanced lines. Greater variation was observed in early surveys reported by Piper and Morse (3) and Dies (4) and in the preliminary variety screening evaluations (1,2).

Soybeans are a unique oilseed crop whose value is based on both oil and protein. The well-known inverse relationship of oil and protein is clearly demonstrated in Figure 1, which presents data on oil and protein contents of 144 soybean strains of group V-VII maturities (2). Soybean varieties high in protein have been developed; however, the soybean processor has not enthusiastically encouraged their development due to losses in oil content. Soybeans are a unique oilseed crop—their value is based on both oil and protein.

Several references in the literature conclude that variation in oil and protein contents results from genetic and environmental factors. Several soybean breeders have developed high-protein or high-oil soybean strains (5-9). Figure 2 presents data on 240 strains of soybeans grown in 1979 (2). One can see a wide variation in total oil and protein. The breeding effort is aided by natural variation.

Miller and Fehr (8) reported that direct selection for protein composition causes a significant decrease in both oil and carbohydrate levels, whereas indirect selection (selecting for low-oil cultivars) significantly reduced oil composition without changing the carbohydrate content. They concluded that the greatest progress could be made by direct selection for protein content.

The oil content of soybeans is determined early in the seed development, whereas the protein content continues to be influenced by nutritional conditions until the late stages of maturity (10). Therefore, the environment (moisture, nutrient availability and environmental temperature) has a direct influence on the protein level of soybeans. In an experiment with 9 different varieties, protein content increased and oil decreased from the first to last planting date, thus demonstrating the environmental influence (11).

It is suggested that soybean breeders continue to monitor composition and strive to develop high-yielding soybean varieties with improved total oil and protein contents. Perhaps greater utility could be achieved by indexing oil and protein to their relative economic value and selecting new varieties on the basis of agronomic performance and a composition-economic index. Because traditionally approxi-

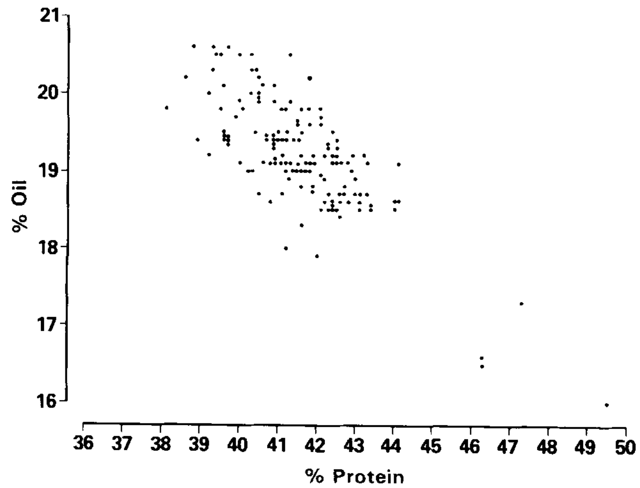

FIG. 1. Oil and protein contents of 144 soybean strains, groups V, VI and VII (1979).

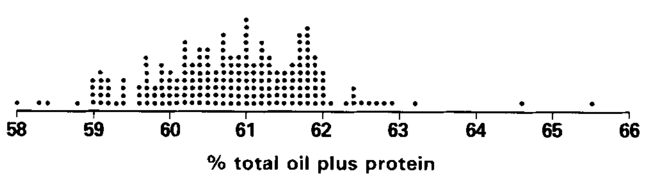

FIG. 2. Total percent oil and protein of 204 soybean strains, groups II-VII (1979).

mately 65% of the value of the soybean is attributed to its protein content and 35% to soy oil, the selection index could be (0.65) plus (0.35). This index would provide breeders another measure of the relative value of various soybean lines in an attempt to maximize both yields (quantity) and quality. An excellent discussion of the factors involved in marketing soybeans on the basis of chemical composition was presented at the World Soybean Research Conference II (12).

Protein Quality (Amino Acid Composition)

Although soybean protein is an excellent source of individual amino acids, the presence of one group of amino acids–the sulfur amino acids–is marginal. The nutritional value of soy protein could be significantly improved if the sulfur amino acid contents of soybeans could be increased. Development of high-protein soybean lines with improved sulfur amino acid levels has been the long-range objective of several soybean breeders.

Improving the methionine content of soybeans has focused on finding soybean cultivars with an improved methionine level. Alders (13) reported a range of 1.28-1.53g/16gN of methionine in 20 soybean cultivars. Krober (14) reported methionine levels of 1.3-1.7g/16gN; however, levels were influenced by location and planting season. Krober and Cartter (15) found a range of 1.0-1.7g/16gN and positively correlated the protein content (0.56-0.58) with the protein content of the seed. Rinne (16) analyzed seed from 34 soybean varieties of 10 maturity groups. In only one comparison did he find a significant difference in methionine levels. Rinne also noted absences of consistent variation in other amino acids among varieties. The results of these researchers, together with those of Schuter and Posselt (11), indicate amino acid levels are not extremely variable in the soybean.

Radford et al. (17) indirectly confirmed these observations in studies developing a rapid method of screening for high methionine/cystine soybean varieties. They reported that methionine and cystine were highly correlated (0.846) to total sulfur in the soybean; however, only small differences were noted in the 12 cultivars studied during 2 seasons.

The ability to genetically improve soybean protein quality seems to be at a new and exciting stage. Most of the protein in soybeans is stored in protein bodies within the calf. The 2 major soybean proteins (7S and 11S glubulins) make up approximately 70% of the total protein. The 11S protein is composed of several polypeptides. These polypeptides have been purified and their amino acid sequence determined (18). The methionine plus cystine values for 8 polypeptides are reported in Table II. Their range is from 0.6-3.0%.

The exciting aspect of this research is that it may now be possible to determine the genetic control of the various polypeptides and ultimately alter the genetic signal that regulates soybean protein synthesis. It may be possible, therefore, to increase the relative proportion of the methionine-rich-polypeptides at the expense of the low-methionine-polypeptides. We are entering a new era of genetic engineering that may produce more results than the research conducted during the past 25 years in trying to locate a super-rich methionine soybean isoline. This makes us more optimistic about the prospects for a soybean with improved protein quality. Nelson (19) has written an excellent review paper on the genetic improvement of protein quality and the quality of plant proteins. This author feels there is much to gain by additional research funding in this area.

TABLE II

Methionine Plus Cysteine Content of Various Glycinin (11S) Polypeptide Subunits (18)

Subunit	Methionine plus cysteine (%)
A_1	2.4
A_2	3.0
A_3	1.6
A_4	0.6
B_1	2.3
B_2	2.4
B_3	0.6
B_4	1.6

Oil Quality (Fatty Acid Composition)

The flavor stability of soy oil has adversely affected its competitiveness with other vegetable oils. Linolenic acid has been blamed for most of soy oil's flavor, stability and odor problems. Genetic research to improve soy oil quality has been underway since the mid-1940s (20,21).

Compared to other agronomic crops (corn, rapeseed), the genetic mechanism of altering fatty acid levels is much more complex in soybeans. In corn, the desaturation of oleic acid at the carbon number 12 position is under simple Mendelian control. Two genes are thought to be involved in lowering the erucic acid level in rapeseed. Linolenic acid levels in soybeans, however, may be controlled by as many as 4 to 5 different genes (22).

Soybean varieties from the world's collection have been surveyed by several investigators (21,23-26). The values for linolenic acid have ranged from 5 to 13% and linoleic acid from 35 to 60% (Table III). *Glycine max* had the lowest linolenic acid level of all of the *Glycine* species studied (27). Low linolenic acid values have been reported for some of the Indian soybean varieties (28). Whether these values are due to genetic or environmental effects is not known.

The relatively narrow range of linolenic acid in diverse genetic materials has made genetic selection progress slow. It is difficult to lower the level of a fatty acid beyond that of either parent.

Some researchers have attempted to increase the genetic variability in soybean plants by artificially exposing the plants to mutogenic treatments (29,30). X-ray or chemical treatment has not resulted in significant improvement in the soybeans' linolenic acid content.

Several interrelationships exist between the fatty acids in soy oil. Linolenic and linoleic acids are highly correlated and there is a significant negative correlation between linolenic and oleic acid (25,31-32). Interestingly, the correlation between linolenic and linoleic acid is greater for plants grown under greenhouse conditions (.96) than plants grown under field conditions (.75) (25).

One Japanese laboratory (33,34) indicated that size was directly correlated with total oil and oleic acid levels and indirectly related to linolenic acid levels. This finding was more prominent in indeterminate-type varieties than in determinate-type varieties.

Based on the fatty acid interrelationships in soy oil, some success has been achieved in selecting soybean lines high in oleic acid to achieve linolenic reductions (35,36). One breeding program (36) that concentrates on selecting for high oleic acid has achieved a 2- to 4-fold increase in oleic acid and a 2-fold decrease in linolenic acid levels.

Research has shown that the maternal genotype has the major control over oil synthesis (37,38). The mechanism may involve control of the components necessary for fatty acid synthesis, regulations of fatty acid synthetase activity and/or internal hormonal control over seed-filling activities.

The pollen parent has little influence over the composition of the seed being developed. F_2 seed analysis would therefore be ineffective in providing information on the plant's genotype.

Environment has a major influence on the fatty acid composition of the seed (39). Linolenic and linoleic acid are negatively correlated with environmental temperatures (23,31). High temperatures during pod filling result in lower levels of these fatty acids.

Other environmental factors influencing fatty acid synthesis are day length (photoperiod), geographical location (where the soybeans are grown) and planting date. Oil composition was not influenced by the quality or intensity of light, nitrogen, phosphorus, potassium, sulfur, trace elements, manure or plant residues, or the chlorophyll content of the leaves (31).

Fatty acids are synthesized by the soybean plant at different rates during pod filling (40,41). The percentage of linolenic acid in seeds decreases rapidly during the first 30 days and then remains constant throughout the period of oil deposition.

Biochemical studies have demonstrated that linolenic acid is formed from linoleic and oleic acids by consecutive desaturation (42,43). Preliminary data indicates selective fatty acid utilization occurs in triglyceride synthesis, therefore, it should be possible to genetically regulate the composition of soy oil through the control of oleic acid desaturation and/or the regulation of triglyceride synthesis.

The American Soybean Association has a major research effort underway to genetically improve soy oil quality. We are optimistic that lower linolenic acid soybean varieties are possible through better understanding of plant metabolism and the genetic control of the individual fatty acids.

CARBOHYDRATES

The oligosaccharides raffinose and stachyose have been implicated as the cause of flatulence and uncomfortable feeling often experienced after consuming soy products (44). If the oligosaccharide content of soybeans could be lowered, it would not only improve the utilization of soy protein, but it could also allow for higher percentages of oil and protein in the soybean.

Hymowitz and others (45) analyzed soybeans from 60 selected lines from maturity groups 00-IV for individual and total sugar contents. The results are presented in Table IV. Sucrose, raffinose and stachyose on the average represent 60%, 4% and 36%, respectively, of the total sugar contents. Total average sugar content was 8 g per 100 g seed. Slightly different ratios were reported by a Japanese laboratory (10). They reported levels of 60%, 10% and 20%, respectively, for sucrose, raffinose and stachyose. Japanese research indicated environmental conditions may significantly effect total carbohydrate levels in soybeans (46).

Hymowitz et al. (45) reported that simple correlation analysis reveals that total sugar content and oil content in soybeans are positively correlated (0.26) and that each was negatively correlated with protein content (-0.63, oil; -0.19, total sugar). Similar correlation for carbohydrates with oil and protein were reported by other laboratories (8,10,46). Sucrose and raffinose contents were positively correlated with oil content (0.42, 0.36, respectively), whereas stachyose content was positively associated with protein (0.41). Even though statistically significant correlations were observed, there were considerable unexplained variations (45). The positive correlation between stachyose and protein content proposes a difficult task for the soybean breeder—to develop higher protein beans with lower oligosaccharide levels.

The genetics of altering the sugar contents of beans are not as Openshaw and Hadley have reported (47). Their results indicate that selection of sugar content among single seeds would be inferior to a program of selecting on individual plant values or by plant progeny means.

Since the oligosaccharides are formed from simple sugars and since they increase late in the maturity process (10), it may be possible, with additional information on the genetic mechanism controlling sugar synthesis, someday to develop genetic materials that would decrease the undigestable carbohydrates which cause digestive disturbances. Research in this area is still needed.

ANTINUTRITIONAL FACTORS

One of the major antinutritional factors in soybeans is the trypsin inhibitor proteins. These proteins will inhibit proteolytic activity of digestive enzymes, stimulate protein synthesis in the pancreas and enhance pancreatic enzyme secretion. These effects lead to an enlargement of the pancreas and to growth inhibition (48).

These proteins are heat-liable, and commercial processing of raw soybeans inactivates these proteolytic enzymes. If, however, soybeans could be produced with fewer trypsin inhibitors, the cost of heat processing would be reduced.

Several different trypsin inhibitors are present in soybeans; however, most of the trypsin inhibitor activity is thought to be due to the protein generally known as the Kunitz inhibitor (49). Orf and Hymowitz (50) found that 2 soybean germplasm lines completely lack the Kunitz trypsin inhibitor. These researchers determined that the Kunitz trypsin inhibitor is genetically controlled by a recessive gene. The homozygous recessive state results in the absence of the Kunitz trypsin inhibitor. They found 30-50% less trypsin inhibitor activity in seeds lacking the Kunitz trypsin inhibitor. This research will help to better understand the physiological and nutritional role of trypsin inhibitor.

Another biologically active protein in soybeans comprises a group of glycoproteins, which cause the agglutination of certain red blood cells. These glycoproteins are

TABLE III

Fatty Acid Composition of Selected Soybean Varieties

Maturity group	Observations	Linolenic acid Range (%)	Linolenic acid Mean (%)	Linoleic acid Range (%)	Linoleic acid Mean (%)	Oleic acid Range (%)	Oleic acid Mean (%)	Saturated acids Range (%)	Saturated acids Mean (%)	Reference
I	9	8.2-9.4	8.7	45.9-51.2	48.2	21.0-26.4	23.6	18.9-20.0	19.4	(24)
II	16	5.4-8.0	6.7	43.9-51.6	48.2					(23)
III	11	7.2-8.7	8.0	46.0-51.4	49.3	21.1-26.7	23.2	18.8-20.7	19.4	(24)
IV	10	7.5-8.7	8.1	45.0-51.2	48.4	21.9-29.3	25.2	15.1-19.7	18.3	(24)
VII	6	6.7-8.5	7.6	49.5-54.9	52.6	18.2-26.6	21.2	18.3-19.8	18.6	(24)

TABLE IV

Total Sugar, Sucrose, Raffinose and Stachyose Content in Selected Soybean Lines, g/100 g seed, dry weight (45)

Maturity group	Total sugar		Sucrose		Raffinose		Stachyose	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
00 & 0	5.6-09.9	7.4	2.5-6.5	4.1	0.1-0.6	0.2	1.9-5.1	3.1
I & II	5.9-10.8	7.9	3.5-7.6	4.8	0.1-0.9	0.5	1.9-3.5	2.6
III & IV	6.2-10.9	8.6	3.8-8.2	5.4	0.1-0.9	0.5	1.4-4.2	2.8

called hemagglutinins or lectins. Their effect on nutritional value of soybeans is unclear.

The major lectin in the seed of most soybeans has a molecular weight of 120,000 and is composed of 4 identical subunits (51). The absence of this lectin was confirmed in 5 soybean varieties (52). In another study, the presence of this lectin was genetically controlled by a single dominant gene; the homozygous recessive gene combination resulted in soybeans without the major soybean lectin (53).

The author has been informed that 2 soybean cultivars have been found without lipoxygenase-1 (54) activity. With the lipoxygenase-free soybeans, we will have another mechanism with which to study the metabolic function and importance of this enzyme system to the quality of soybean products.

Years of research have gone into finding soybean cultivars with genetic variation which can be used to modify the soybean to make it more useful with fewer limitations. We have come a long way, especially when we look at some of the wild soybean species. It is predicted that we will continue to improve the quality of soybeans. Research studies underway are exciting. We are opening new doors to the better understanding of the real potential for this wonder crop. However, the popularity of any variety is based on its profitability. Any genetically improved soybean variety must yield competitively with other commercial soybean varieties in order to gain acceptance by the soybean grower. We are confident that the day will come when quality characteristics are an important part of the soybean breeding program—especially when breeders have the tools to rapidly assess quality differences in genetic materials and the market place provides economic incentives for soybeans with improved nutritional quality.

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