Chapter 6
Genetics
of Grain Quality

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The Genetics of Grain Quality

The most fundamental starting point for efforts to improve the United States' ability to produce, handle, and deliver quality grain is the seed, The role of plant genetics cannot be overstated, Indeed, if the genes for physical and intrinsic quality are not present, little can be done in the rest of the system to improve quality.

Quality is influenced by plant genotype and the environment in which the plant is grown, Genotypes often can be altered using classical plant breeding methods so that changes in quality result, This has not generally been the aim of breeders, however, as their focus on increased yield often means quality factors such as protein or oil content remain the same or even decline unless special incentives are present for the grower. Likewise, some environmental factors can be changed, such as soil fertility through fertilizer application or water status through irrigation. Many others, however, cannot be affected, such as weather and soil type.

Plant breeding can offer a partial solution to problems caused by environmental variation, through consideration of genotype-environment interactions, This chapter considers for wheat, soybeans, and corn:

- the objectives of genetic selection;
- direct genotypic influences on physical and intrinsic quality and the interactions between genotype and environment that affect seed quality;
- the procedures, tests, and criteria for releasing seed varieties; and
- emerging plant breeding technologies to improve quality.

WHEAT

The wheat plant and the grain it bears have evolved over many centuries into the plants grown today. Early humans over thousands of years selected types of wheat with the largest seeds, leading to the wheat grown in crop agriculture in Europe and Asia prior to migration of people to North America in the early 17th century. Early North American immigrants brought wheat seed with them that had been selected from variable native species with different characteristics that were used to make different foods. This led to the different classes of wheat with different end uses now grown in the United States.

Differentiation of end-use characteristics of these different wheats is important. Because the science of wheat breeding has many common points across wheat classes, however, this section is organized by topic area, Any important differences by class will be highlighted in the discussion. '

Objectives of Genetic Selection

Wheat breeders have two major objectives: to raise yield and to increase end-use quality. A secondary objective is to improve resistance to diseases, pest, and environmental stress. Reaching these goals is difficult. High yields are an important attribute that farmers demand in a new variety, On the other hand, millers desire wheat with good end-use characteristics, such as high protein content, Yet an inverse genetic relationship exists between yield and protein content in wheat.

'This section is based on Jack F. Carter et al., "Wheat Breeding Issues Related to Grain Quality, " prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC. 1988.

The primary goal of wheat breeders is usually increased yield, with protein and other end-use quality factors maintained at acceptable levels. Table 6-1 illustrates this point with new Hard Red Spring (HRS) varieties produced in North Dakota and tested from 1981 to 1985. Waldron is the check or control variety, and each new variety exceeded Waldron in yield by 6 to 15 percent. To achieve higher yield, however, protein percentage decreased by as much as 0.5 percent on average. Other selected end-use quality factors stayed about the same or declined compared with the check variety.

This is not to suggest that improvements in certain quality have not been made. In Hard Red Winter (HRW) wheat, traits that have significantly improved include test weight, flour yield, mixing time, loaf volume, and crumb grain. But protein percentage has remained essentially constant (16). In HRS and Durum, the same characteristics have improved.

Genetic Influences on Wheat Quality

Table 6-2 lists important end-use quality traits, the estimated number of genes thought to control a trait, and the degree a trait is influenced by the environment. Environmental variation influences the expression of all heritable traits. Those whose expressions are largely influenced by the environment have low heritabilities, i.e., the majority of the variability for that specific trait is due primarily to the environment and not to the genotype.

Functional quality is the interaction of all the traits in table 6-2 plus others. It is impossible to select one trait individually and interpret end-use quality. Final bread-making quality is the total interaction of all these traits (23). Cereal chemists and wheat breeders use these traits to estimate end use. If all the traits fall into identified accepted categories, the final product is usually satisfactory.

Yield-Quality-Resistance Interactions

Grain yield, grain quality, and disease resistance cannot be separated in a wheat breeding program. Each fits into a package that is released as a new variety. Wheat lines are not developed that feature improvements in some traits and the loss of others. Wheat diseases, lodging, and environmental stress produce shriveled grain that reduces grain yield, lowers test weight, and decreases flour milling yield. However, the best bread-quality wheat is not grown by farmers unless it yields competitively. As noted, yield and quality if evaluated sep-

Table 6-1 .—Grain Yield and End-Use Quality Characteristics of Four Wheat Varieties in North Dakota, 1981.85 Average

	Location						
Cultivar	Dickinson	Williston	Minot	Barrington	Langdon	Fargo	Mean
Grain yield—percent of WALDRON:							
LEN	109	101	104	96	117	108	106
ALEX	109	105	106	105	113	110	108
STOA	124	107	108	107	120	120	115
Wheat protein content—percent (14.0% M.B.):							
WALDRON	15.9	17.7	14.8	16.6	14.8	15.3	15.9
LEN	15.3	17.2	15.0	16.6	14.6	14.8	15.6
ALEX	14.6	17.7	15.2	16.5	14.6	14.8	15.6
STOA	14.4	17.4	14.8	16.6	14.6	14.6	15.4

Cultivar	Test weight (lb/bu)	Vitreous kernels (percent)	Flour extraction (percent)	Wet gluten (percent)	Flour ash (percent)
Quality comparisons:					
WALDRON	58.0	83	67.6	40.2	0.47
LEN	59.1	85	68.5	38.1	0.47
ALEX	60.3	86	66.8	39.9	0.45
STOA	59.2	84	68.0	39.2	0.42

SOURCE: Richard Frohberg, "Wheat Breeding at North Dakota State University," presented at U.S Wheat End-Use Quality Conference, Fargo, ND, 1986

Table 6-2.—Environmental Influence on Important End-Use Quality Traits in Wheat

Trait	No. of genes	Environmental influence
Physical quality:		
Hardness	3 genes	moderate
Color	3 genes	moderate
Kernel size	many	large
Test weight	many	large
Flour yield	many	large
Biochemical quality:		
Protein percentage	few-many	large
Absorption	many	moderate
Mixing tolerance	many	large
Loaf volume	many	large
Crumb grain	many	large
Crumb color	many	moderate
Loaf symmetry	many	moderate
Gluten strength	few	moderate
Pasta quality	many	large

SOURCE: Office of Technology Assessment, 1989

arately as unique entities are usually negatively correlated, primarily due to the negative association between protein percentage and grain yield (35). This negative correlation in soft wheats is extremely beneficial as it allows for concurrent progress in these traits. Low protein percentage is a requirement for producing high-quality end products from soft wheat,

Genotypic Variability

Genotypic variability is generally interpreted as the range of expression for a specific trait, i.e., protein percentage can range from 7 to 30 in wheat, Wheat has not been investigated adequately to determine the range of available genetic variation and to identify the appropriate breeding procedure for each of the characters controlling quality. Wheat germplasm collections have been evaluated primarily for agronomic characters, not for those controlling quality.

Wheat is a hexaploid species and has a large amount of genetic variability. Protein percentage is probably the most frequent quality component measured, and it can be improved by crossing with distant relatives of wheat. A practical limit exists, however, because twice as much energy is required to produce a gram of protein as a gram of carbohydrate (42), In the future, as more is understood about protein quality, it may be more efficient to allow the Hard Red Winter wheat plant produce primarily starch, and then to blend in protein to increase its percentage in wheat flour. The primary use of the genetic variability in wheat in the short term (especially in HRW programs) is to introduce new genes to protect plant health.

Genotype v. Environment

Genetic variations, environment, and the interaction of these components affect the final expression of a trait. Genetic-environmental interaction is produced when different genotypes respond differently to different environments, The HRW variety Newton, for example, produces acceptable quality in western Kansas, but is poorer in eastern Kansas due to disease, in Oklahoma because of late maturity, and in eastern Colorado because of susceptibility to root rot. Environment can be more responsible, in many cases, than the varietal reactions for increased fluctuations in quality (34,41). Genotype-environment interaction is of crucial importance because most HRW wheat varieties are grown across a diversity of environments, and stable quality performance is desired, In addition, more extensive testing programs are required to identify stable genotypes,

Interactions between physical and biochemical characters are frequent, and usually negative, The most noted association involves protein, as discussed earlier. This makes it difficult to improve both traits. However, protein percentage and protein quality are not correlated (23), It is possible to have extremely high protein and very low protein quality. The HRW wheat variety Atlas is a good example. Other interactions that affect progress in a breeding program include kernel size and flour yield, high temperatures at grain filling, and weaker mixing tolerance. Susceptibility to diseases and preharvest sprouting have negative effects on quality. Associations between chromosomes themselves affect quality. For example, attempts to breed resistance for wheat streak mosaic virus have been unsuccessful because the resistant genes for the disease are closely linked to genes that have a negative effect on quality (38).

Role of Public and Private Wheat Breeders

Public and private wheat breeders develop and prepare release of new wheat varieties. One main difference is that public breeders generally work with wheat only for the State or regions within it where they are employed, whereas private breeders develop wheat varieties for one or more States plus foreign countries where the company may have a subsidiary. Another difference is that private breeders can respond more quickly to sudden needs or perceived opportunities for research and development.

One point currently under debate is whether public breeders should only develop basic germplasm and let private breeders use the germplasm to develop the varieties for commercial sale—a system more or less followed in Europe. An argument can be made for such a role differentiation. As the next section points out, however, currently the return on investment in developing new wheat varieties has resulted in many seed firms eliminating wheat breeding from their research activities.

Public funding of wheat plant breeding is derived (in order of importance) from State legislatures, Congress, farm commodity organizations, and foundation seed royalties. Funding is often closely related to the economic health of the State. Overall, funding was relatively stable from 1950 to 1980, but it has declined in real terms since then. State Agricultural Experiment Station (SAES) funding for wheat breeding programs can vary from 35 to 75 percent of the total SAES budget. Some States have begun charging royalties on seed of new varieties in order to help fund plant breeding research as competition increases for use of limited public funds.

Private funding for wheat improvement research is corporate funding to produce a product for sale and, it is hoped, a high return on investment. The financial support and resources may be more generous relative to public funding, but they can be decreased or terminated quickly if return on investment is inadequate. For example, many large and small seed companies initiated breeding programs soon after the passage of the Plant Variety Protection Act in 1970. Wheat breeding did not produce high rates of return for most, however; and today only a few large firms have programs on conventional wheat varieties and/or hybrid wheat. Thus most new wheat varieties are developed by the public sector.

Variety Release Procedures

Public and private wheat breeders attempt to create varieties excelling in both agronomic and end-use characteristics. The public breeder, who produces most of the new varieties, receives guidance on criteria for release from the individual State Agricultural Experiment Stations. In turn, the SAES bases its recommendations on the national policy on release of seed-propagated plants adopted by the Experiment Station Committee on Policy. However, the policy is guidance *only* and States may and do vary from it. Private wheat breeders are influenced by the principles of this policy as well and by the demands or needs of farmers.

The principles used to determine whether to release superior experimental genotypes are based on whether the candidate for release is better in one or more agronomic or quality characteristics as compared with “check” or “control” commercial varieties. But market incentives to farmers and in turn to the wheat breeder signal advancement and release of experimental progenies having unusually high grain yield and not necessarily meeting minimum standards of other agronomic and end-use characteristics. The market seldom rewards farmers who produce wheat varieties with excellent end-use characteristics.

Public Breeder

The general procedures used to select a variety for release are as follows:

- The plant breeder makes crosses of desired parents and progenies and evaluates them over 5 to 8 years for agronomic and end-use characteristics. Those characteristics are compared with a “standard check” or “control” variety, usually a commercial variety under production over a significant acreage in the target geographic area.

- The breeder evaluates and justifies the release and name of the experimental progeny.
- A Variety Release Committee (VRC) of scientists of the wheat breeding team, appropriate extension specialists, representatives from appropriate commodity and regulatory agencies, and the Experiment Station Director recommends release or rejection of the experimental line proposed for release.
- If the VRC cannot agree, the final decision is made by the Director of the Experiment Station.
- The agricultural experiment station is usually considered the “breeder of record” for purpose of Plant Variety Protection and royalties.
- Basic seed stocks of the new variety are increased to Foundation seed by SAES or a quasi-nonprofit agency for the public variety.
- Elite growers increase the new variety to Registered and Certified seed for use by commercial growers.
- The breeder deposits a small amount of breeders’ seed in the Germplasm Bank at the National Seed Storage Laboratory.

Private Breeder

Based on mail inquiries to private breeders, the policies and procedures on variety development and release seem to be as follows:

- The wheat breeder makes hybrids of desired parents and progenies are evaluated for various agronomic and end-use characteristics. Most of the hundreds of progenies from the original “cross” of the two parents are discarded at each testing stage, but a few superior ones are selected and advanced after several generations as worthy of further evaluation.
- A preliminary test is conducted of apparently superior wheat progeny lines at several locations, for 1 year, and each entry is evaluated for agronomic and end-use characteristics. Many wheat lines are discarded as not worthy of further testing,
- An advanced test is conducted at additional locations, again for 1 year, with continued evaluation and further discard of some lines and retention of the most superior ones.
- Elite testing is conducted at even more locations for 2 years with continued agronomic and end-use quality evaluation at the private company quality laboratory and at independent quality laboratories. The latter might include Class end-use quality laboratories, private or public agencies, or a cooperative facility with the milling industry (e.g., flour and bread evaluation by the Spring Wheat Quality Advisory Committee (SWQAC)).
- Wheat progenies (lines) excelling in the elite testing receive Precommercial Nomination based on 2 years of testing and satisfactory end-use quality scores. A Committee or Director of Research, Crop Director, Cereal Chemist, Breeder(s), and Crop Marketing Analyst accepts the variety as *precommercial* if all agronomic, disease, and quality end-use data are satisfactory,
- A third year of elite testing is conducted, including evaluation by an independent agency such as SWQAC, Breeders seed is produced to continue seed increase advancement, if approved.
- The same Committee that considered precommercial status evaluates again and, if approved, Foundation seed is produced and sales divisions are notified. The Plant Breeding Division retains control of the prospective variety. If release is approved, seed is distributed to sales divisions for registered and certified seed production. The Director of Plant Breeding and the Crop Director sign the official release announcement.
- A Commercial Number (equivalent to variety name) is assigned. Seed is conditioned at company plants and allocated to District Sales Managers who establish sales goals

for each sales area. Farmer-dealers sell the seed. The company provides advertising support.

Wheat Breeding Technology

U.S. public and private wheat breeding programs annually release several dozen wheat varieties, each representing 8 to 15 years of research. The principal wheat-producing States have had wheat improvement programs for at least 60 years, and their accomplishments have been impressive. U.S. wheat yields since 1958 rose from 25.1 to 33.1 bushels/acre, a 32-percent increase. Comparisons from regional nurseries indicate a 17-percent genetic gain, accounting for about half the total yield or 0.2 bushels/year genetic gain (46). Production technologies—-including use of fertilizers, herbicides, pesticides, and machinery—accounted for the other half of the yield increases.

This section provides a general perspective of wheat breeding by describing some of the capabilities, methodologies, and limitations of current and future technologies.

The Breeding Program

Generalizing about procedures is difficult because there are as many permutations and combinations of managing the logistics of selection and testing as there are programs. Nevertheless, some primary features of wheat breeding can be described by considering the basic framework of generational advance and testing (table 6-3).

The genetic variation to begin the breeding cycle is obtained through sexual recombination in F_1 plants from 200 to 700 crosses per year. Segregated populations of tens of thousands of F_2 plants, each one a new and distinctive genotype, are grown each year. Genetic segregation continues in the F_3, F_4, and successive self-pollinating generations, diminishing by half each generation as the genotypes of lines become fixed,

In early generations, selection is based on traits that are recognized visually or otherwise evaluated easily, such as plant maturity, plant height, stem and leaf rust resistance, and general plant appearance. Such selection is considered fairly subjective.

Table 6-3.—Generational Advance in a Typical Pedigree Wheat Breeding Program

Season	Generation[a]	Breeding population size	Selection/evaluation activities
1	Initial crosses	200 to 700 new crosses per year	Some selection among F_1s based on additional data or phenotype
2	F_1	200 to 700	
3	F_2	500 to 2,000 plants per F_2 population	Grown as spaced plants, sometimes as bulk populations. Strong selection between populations and for plants within populations, visual selection for easily classified traits
4	F_3	5,000 to 50,000 total plant or head rows	Begin line selection, visual selection, visual selection for easily classified traits, e.g., height, rust resistance
5	F_4	1,000 to 5,000 observation rows or head rows	Continue visual selection with additional traits, possibly begin protein, few quality evaluations
6	F_5	400 to 1,000 lines in preliminary yield trials or observation rows	Testing becomes more quantitative, replicated, multi-location, initial yield data, quality evaluations
7	F_6	150 to 400 lines in yield trials	Similar to F_5
8	F_7	20 to 50 lines in advanced yield trials	Yield trials at several locations, complete quality and disease resistance testing
9-11	F_8	5 to 10 elite lines	Extensive yield testing in State and regional trials, complete disease and quality comparisons to standard varieties, identification of candidate varieties

Finally, seed increase decisions are made during final evaluation stages and at the time of varietal release.

[a] Filial generation

SOURCE Office of Technology Assessment, 1989.

Selection for each trait further depends on the time required to measure the trait, the number of plots that must be evaluated to obtain a reliable estimate of the line's performance, the amount of seed required for the test, and the effect of environment on other traits being selected.

Selection for quality in early generations and during preliminary testing is accomplished mainly by using micro-evaluation procedures. Cereal chemists and breeders have devised an array of such tests that correlate with functional processing quality. Mixograms, cookie tests, and micro-loaves are examples of tests that can be done using small samples of wheat kernels,

Improving the Efficiency of Wheat Breeding

Each breeding program strives to improve the efficiency of its selection and testing procedures and to understand the available genetic variation, The dynamics involve a steady flow of information and data from many sources, Crossing, selection, and testing decisions are revised as agronomic, disease, and quality data from the current season's nurseries, and area wheat crop are evaluated.

Experimental design, statistical analyses of data, and plot and testing equipment are refined continually. Breeding programs collect enormous amounts of data each year. Much of the analysis that formerly was done with mainframe computers now is being done with microcomputers. Also, computer programs are being written that greatly facilitate various organization and data collection activities of the breeding program.

The impact that a new analytical technique can have on selection strategy is shown vividly by the application of near-infrared reflectance spectroscopy (NIRS) to measure protein and moisture percentages. NIRS, developed in the 1970s, is rapid, practical, and inexpensive. Protein percentage can be determined on about 200 wheat or flour samples per day with a single NIRS machine. For a wheat breeding program, this means that early generation selection for protein percentage can become routine, substantially increasing the proportion of later generation lines that have the desired protein level.

Replicated yield trials are expensive to conduct. A breeding program must grow several thousand yield plots each year at several locations. In recent years, small-plot combines have been developed in which one to two yield plots per minute can be harvested while maintaining seed integrity of each plot.

Other Quality Considerations

Wheat breeders encounter several breeding situations in which quality can become a problem. The most common one occurs when selection for one trait causes changes in another trait or traits, The correlated response can be positive or negative, and the degree can vary from slight to very strong. For example, the gene in Durum wheat for white glumes and the gene for strong gluten strength are located near one another on the same chromosome. Durum breeders have used this fortuitous association effectively to identify strong gluten Durum lines. In bread wheats, the negative correlation between grain yield and protein percentage that exists in many breeding populations challenges the breeder to find genes that increase protein percentage or improve the quality of the protein without losing yield potential.

Other situations in which quality can be affected adversely involve the introduction of genes from related species. The best known example is the IB/IR wheat-rye chromosome translocation. The rye chromosome introduced into wheat carries valuable genes for disease resistance, but it also can cause problems with stickiness of bread dough, Problems with test weight, flour color, and other traits have been associated with an alien chromosome segment introduced for disease resistance in several other cases,

Timetable of Wheat Breeding and Varietal Seed Increase

Evaluating past progress in wheat breeding, planning future research, and having some idea about the possible rates of progress of future research requires an appreciation of the time required for varietal development, testing, and seed increase. The breeding and seed increase schedule for Stoa, an HRS wheat variety recently released by the North Dakota Agricultural Experiment Station, provides an example (table 6-4). Greenhouses, off-season winter nurseries, and early, coordinated increases of seed can accelerate this schedule. But it is important to remember that crosses for wheat varieties for the year 2000 are being made now, 12 years before they will be released.

Some future technologies may shorten the period for varietal development far less than intuitively might be expected. Much of the schedule for Stoa is devoted to the initial buildup of seed, to multiyear testing, and to increasing the varietal seed. This process must be done regardless of how a line was produced initially.

Hybrid Wheat

Much progress has been made during the past 25 years to develop germplasm and techniques for commercial production of hybrid wheats. A hybrid advantage for grain yield and other traits similar to those found in corn, sorghum, rice, and other crops is the impetus for hybrid wheat research. Because the farmer must purchase hybrid seed each year—unlike varietal seed, which can be grown from the previous year's seed—the successful development of hybrid wheats also would be the basis for a large commercial seed industry in the United States. Several commercial seed and agricultural chemical companies have hybrid wheat research efforts.

Two technologies are being used for hybrid wheat development:

1. genetic systems that use a cytoplasmic male-sterile female parent and a fertility restorer male parent for hybrid seed production, and
2. chemical systems that use chemical hybridizing agents to treat and sterilize the female parent for production of hybrid seed by cross-pollination with the male parent,

Commercial hybrids have been produced and marketed using both types of systems.

Current hybrid wheat research aims to improve hybrid performance and to reduce the costs of producing hybrid seed commercially. The economic success of hybrid wheat will be determined by the hybrid breeder's and seed producer's success in accomplishing these goals.

Table 6-4.—Breeding and Seed Increase History for Stoa Hard Red Spring Wheat

Year	Season	Generation	Explanation of evaluation state
1973	Fall	Cross	ND527/Coteau sib//Era
1974	Spring	F_1	Grown in greenhouse
1974	Summer	F_2	Space-planted populations
1975	Summer	F_3	Head-row
1976	Summer	F_3	F_2-derived head-row
1977	Summer	F_5	1 row selected, F_4 derived line
1978	Summer	F_6	Preliminary evaluation
1979	Summer	F_7	Preliminary yield trial
1980	Summer	F_8	Elite yield trial
1981-82	Summer		ND HRS variety trial (tested as ND582)
1982-83	Summer		HRS Uniform Regional Nursery
1983	Summer		Spring Wheat Quality Advisory Committee Test
1984			Named and released

Seed ***increase (concurrent):***

1981-82	Purification head rows near Yuma, Arizona
1982	Increase at North Central Station, Minot, North Dakota, 1½ acres
1982-83	Winter increase near Yuma, Arizona
1983	Increased in North Dakota
1984	Released as a variety
1985	26,000 acres certified plus noncertified acres
1986	Estimated acreage, 1 ½ to 2 million acres

SOURCE' Office of Technology Assessment, 1989

Quality standards and questions for hybrids in general are identical to those for conventional varieties. The end-use quality of hybrids has tended to be between their two parents for most traits. Some quality control can be achieved in hybrids by choosing parents that have complementary quality traits.

As wheat hybrids must have a yield advantage to be economical, the breeder must be concerned about grain yield/protein percentage relationships in the wheat classes where high protein is desirable. Also, seed produced on a hybrid (F_1) plant differs from seed produced on a variety. The (F_2) seeds are segregating, each genetically different from another. All seed in conventional varieties is genetically homozygous and is homogeneous. Although these effects have not been examined in detail, generally the maternal F_1 plant of uniform genotype seems to have the predominant effect on endosperm quality and on kernel characteristics.

Future Technologies

Genetic Engineering. -Advances in several technologies for genetic manipulation of plant cells and genes, collectively termed biotechnology, have generated much discussion about their application to important plant breeding problems. The new technology having the greatest potential for expanding the genetic variation available to plant breeders is genetic engineering. This term covers the technology or group of technologies with which scientists can isolate genes from one organism, manipulate them in the laboratory, and then insert them stably into another organism. (This stable insertion is known as transformation.) These complex technologies are the focus of extensive, very active research efforts (15,24,45).

The current capabilities of scientists to use genetic engineering in wheat and most major crop plants are limited. These limitations regarding wheat quality include:

1. insufficient knowledge of which genes affect quality;
2. great difficulty in isolating such genes, even if they are known;
3. inability to insert specific genes stably into the host genome; and
4. and lack of knowledge on how to regulate the expression of inserted genes in the target tissue.

While some of these limitations are likely to have technical solutions in the near future, others could remain barriers to using these techniques in wheat breeding for some time.

Once specific favorable alleles of genes that code for glutenin or gliadin proteins are identified, a process that could require a great deal of research, the isolation of these genes could become fairly routine. Current research indicates that many wheat seed storage proteins actually are “families” of proteins (many similar but slightly different proteins) coded by “families” of genes.

Genetic engineering also can isolate seed storage protein genes from other crops. The potential value of these proteins either to improve wheat quality or to impart additional processing attributes to wheat cannot be assessed until such genes actually are inserted into wheat and expressed in the seed.

Currently, there are no reports that cultivated wheats have been transformed and a plant regenerated (15). Genes have been inserted into the cells of a wild relative of wheat (Triticum monococcum L.), but no plant was regenerated because of an inability to regenerate plants from single cells, which requires an effective tissue culture system. Although Schell (45) has reported that DNA is taken up and is expressed transiently in wheat embryos, he has not determined if this DNA is transmitted to the offspring—i.e., is heritable.

A prudent estimate is that appropriate techniques to engineer wheat genes will be developed within the next 5 years, assuming adequate resources for experimentation, How effective or efficient these systems will be is difficult to predict.

An example of a technology that must be developed when wheat plants are transformed successful y is the regulation of the expression of genes for defined qualities. The genes must be expressed in the seed but not in other tissues. Experience with other crops suggests that the regulatory sequences for wheat seed proteins will have many of the necessary characteristics of regulating the added new genes (45). Genetic engineering allows the addition of relatively few genes, not a gene family. Because gene families for quality characteristics are expressed in the seed, the added genes may need to be strongly expressed, assuming they affect quality positively.

If detrimental proteins (e.g., the secalin proteins of the IB/IR rye translocation) are operative, these families of genes may need to be turned off, requiring techniques not now known. However, germplasm may be found with suitable analytical tools, either through natural variation or through chromosomal manipulation, that lacks the detrimental family of genes.

It must be restated, however, that until useful genes can be successfully identified, isolated, stably integrated into the wheat genome, and sexually transmitted to offspring, genetic engineering of wheat remains a promise and a goal rather than a useful tool.

If procedures that allow routine genetic transformation of wheat should become available within 5 years, how long would it take for the new technologies to have a major effect on wheat quality? Research to improve understanding of wheat proteins and the specific genes that code for them, including methods to isolate these genes, will proceed concurrently with research on genetic transformation. Manipulating gene regulation fully in seeds will take many years. Transformed plants must be grown to maturity to test seed for gene expression. Small-scale baking quality tests to determine if wheat quality has indeed been improved requires 300 grams (0.7 pounds) of seed. Advanced hard wheat quality evaluations can require up to 550 kilograms (1,200 pounds) of seed.

The first U.S. field tests of transformed plants (mainly tomato and tobacco) were allowed in 1987. Hence, little or no previous knowledge and experience exists on which to base speculations about the agronomic and quality performance of transformed wheat. Assuming the new transformed wheat has excellent quality and agronomic performance, another year or two of seed increase would be needed before sufficient foundation seed could be sold to certified growers who, in turn, must grow the seed for 1 year before they can sell certified seed to the wheat grower. The first genetically engineered seed will enter the commercial market after the following growing season (an additional year), when the wheat grower harvests the crop. Commercial acceptance and use of the new, genetically transformed variety then can be determined.

Consequently, at least 7 years will be required, under favorable circumstances, for a seed of a genetically transformed variety to reach the commercial market—plus possibly another 5 years to develop the transformation technology. Although this seems a long time, the total time from identification of beneficial genes to new plant introduction maybe cut by 4 to 6 years.

ELISA and DNA-Probe Screening Assays.—After proteins and genes that enhance or lessen wheat quality have been identified, rapid assays using antibodies or nucleic acids can be used to identify lines having these genes. An example of this technology is the enzyme-linked immunosorbent assay (ELISA), which uses antibodies to identify proteins rapidly. ELISA technology employs a “capture” antibody that is attached to a solid surface and that specifically binds to a single protein from a complex protein mixture. This protein-antibody complex is incubated with an enzyme-coupled antibody that recognizes and binds to the protein. In the presence of a colorless substrate, the enzyme will convert the substrate to a colored product that can be measured spectrophotometrically. The presence of color, therefore, identifies the presence of the (specific) protein that is bound to the capture antibody and to the enzyme-coupled antibody.

ELISA tests are used routinely to identify proteins associated with seed storage proteins and with plant pathogens (as a diagnostic test for diseased plants). Using ELISA techniques to identify specific seed quality proteins is difficult because these occur as families of similar proteins. Isolating specific proteins and obtaining precise antibodies can be difficult. Once the technique is optimized, however, selection to save lines with favorable quality proteins and to discard those with unfavorable ones will be straightforward.

The ELISA technology is not used widely yet because of lack of understanding about which genes affect a given quality. But basic research to study these proteins, using ELISA techniques and developing antibodies, should, if successful, make this technology available to breeding programs.

Biochemical Selection and Doubled Haploid Breeding.—These two new technologies involve tissue culture and the ability to form unorganized tissue (called callus) from organized plant tissue such as immature embryos and anthers on a culture medium and then to reform organized tissue that can be induced to regenerate into plants.

With biochemical selection, the unorganized tissues are challenged (exposed) to a chemical that inhibits normal growth, Cells that have undergone mutations or other genetic changes that make them resistant to the effects of the chemical will grow normally and can be identified. The power of this technique is that approximately 2,25 million cells can be grown in 30 milliliters (about 1 fluid ounce) of medium, Each of these cells potentially can regenerate into a plant. An acre of wheat by comparison, has from 1 million to 2 million plants, depending on seeding rate. For selection purposes, an ounce of cells capable of regenerating into plants is the numerical equivalent of 1 or 2 acres of wheat in a wheat nursery. It cannot be considered the functional equivalent, however.

While selecting directly in tissue culture to improve quality traits that are expressed in the seed may be difficult, selection may be possible for overproduction of essential amino acids that limit nutritional quality (30). Little variation for nutritional quality exists in wheat germplasm, and unconventional selection techniques may become an important objective for improving nutritional quality (e. g., lysine content) (33).

Wheat culture techniques to produce large quantities of regenerable cells routinely have not been refined. Few plant traits, including quality traits, can be selected at the cellular level, New biochemical strategies to improve nutritional quality probably will not be developed until tissue culture systems are developed fully, probably within the next 5 years. Again, as with genetic transformation technology, 7 years of testing and seed increase still will be necessary before the improved line would enter seed trade channels,

Doubled haploid breeding could shorten the time needed to develop inbred lines of wheat that normally are derived by generational advance following crossing. Most commercial wheat varieties are relatively homogeneous inbred lines, as are the two parents of hybrid wheats. The value of this technique is that when the chromosome number is doubled, each of its genes is copied identically.

The major limitation with doubled haploid breeding in wheat is that an efficient system for producing doubled haploids has not been developed. Using a relatively inefficient anther culture system, however, French researchers who developed the wheat variety Florin, released in 1987, believe they saved 4 years by reducing time needed for inbreeding.

SOYBEANS

Several thousand soybean strains were introduced from Asia in the early years of this century (28). Because soybean is photoperiod-sensitive, one of the initial tasks was to identify the potential adaptation areas for these accessions. A maturity group classification system was developed. Those materials adapted to northernmost latitudes were placed in Group 00 and those adapted to southernmost latitudes were placed in Group X. The soybean's potential value as an oilseed was recognized and plant breeding was begun for high oil and for adaptation to North Central States. The cultivars Dunfield and Illini, released in the 1920s, resulted from this breeding effort and their oil content became the standard for succeeding cultivars (9). Soybean was also used as a forage during this time, and prior to 1941 more soybeans were grown for forage in the United States than for grain (28). As soybean gained wider usage as a grain, breeding emphasis on seed yield increased. Early improvements in resistance to plant lodging, seed shattering, and foliar diseases increased soybean adaptability and helped make this a suitable grain crop for a wide geographical area (9).[2]

Objectives of Genetic Selection

Two major objectives of soybean improvement programs are to raise seed yield and to increase seed quality. As with wheat breeding programs, a third objective is the protection of current levels of yield and quality by increasing resistance to diseases, pests, and environmental stress. Because high yield has always been the primary attribute that farmers wanted in a new cultivar, it is the trait that has received the most attention. Comparisons of old and new cultivars have shown that significant improvement in soybean yield potential has occurred. In a test of Group I, II, III, and IV cultivars released between 1933 and 1971, yield increased by 50 percent. In a similar test of Group II and III cultivars released between 1923 and 1974, Wilcox et al. (62) found a total increase of approximately 30 percent. Boerma (7) found that yields of cultivars in Maturity Groups VI, VII, and VIII had increased about 42 percent since 1914.

Resistance to insects has been an objective of some soybean breeding projects. Most research has been conducted in Southeastern States, where insects pose a greater threat to production. Although several insect species are pests, the genetic resistance that has been identified seems to have some effectiveness against many of them (37). Improved insect-resistant breeding lines have been released as germplasm, and one insect-resistant cultivar (Crockett) has been released in Texas.

Many studies aim at characterizing the genetic variation for protein and oil content in soybean and the genetic correlations between oil, protein, and seed yield (11). Yet for most soybean breeding projects, altering protein and oil concentration has been a low or nonexistent priority. Rather, the primary breeding goal has usually been high yield with maintenance of protein and oil at acceptable minimum levels, e.g., 41 percent protein and 20 percent oil. The well-documented negative relationship between protein and oil has meant that selection for either trait alone has resulted in a decline in the one not selected (10,13). Likewise, yield and protein are often negatively correlated and it has been difficult to increase both simultaneously (10). Soybean producers, the primary clientele of breeders, do not receive payment for the beans they produce according to chemical constituency. As a result, they have shown no interest in cultivars with high oil or high protein and this lack of interest has influenced plant breeding objectives.

Three cultivars have been released that are 8 to 12 percent higher in protein concentration. Protana and Provar were developed in Indiana and Iowa, respectively, and released in 1969 (57). Because the yielding ability of these cultivars was below that of other varieties being grown at the time, neither gained much accept-

[2]This section is based on Joe W. Burton, "Soybean Breeding and Seed Quality, " prepared for the Office of Technology\' Assessment, L[T]. S. Congress, Washington, DC, 1988.

ance by farmers. A third cultivar, Tracy, was developed in Mississippi, and because it had good yielding ability and resistance to *Phytophthora* rot and some foliar diseases, it achieved wide usage in Southeastern States, The cultivar Ransom, developed in North Carolina, has a higher than average oil concentration [23 percent). But it achieved wide usage because of its high yielding ability and not because of its high oil content.

While most soybean breeding has been directed toward increasing or protecting productivity, a considerable amount of research has also been aimed at developing germplasm with novel seed traits that would fit particular end uses and markets. These novel types, as usually visualized, would be sold outside the grain trade (probably on a contract basis) and thus have an opportunity to bring a premium price. The development of the cultivar Vance offers a good example of soybean breeding for a special end use. Vance was derived from a cross between the cultivar Essex and a wild soybean (Glycine soja) line. It has tiny seeds (8.8/100 seeds), which makes it very suitable for use in natto, a Japanese food product. Currently this cultivar is being grown in North Carolina and Virginia and is being sold directly to a Japanese importer for more than the soybean grain market price.

Tofu is another soybean food product that could be made from a specialty variety. While tofu can be made from any soybean, high protein seeds with yellow seedcoats and hila are preferred (22), The variety Vinton, which has 44.9 percent protein, was developed for this purpose (5).

Genetic Influences on Soybean Quality

Seed coat and cotyledon color are controlled by a relatively small number of genes. Likewise, small numbers of genes are usually involved in disease resistance. In cases like these where traits are simply inherited, genetic alteration is not difficult, provided the presence or absence of gene expression can be determined. Thus, the seed quality traits related to seed color and disease can be easily manipulated using standard plant breeding methods if genes for disease resistance have been identified in the soybean germplasm collection.

Protein and oil concentration (percentages) in soybean seeds and seed size are quantitative traits known to be under the influence of many genes. These can also be changed by classical plant breeding methods, but the task is usually more difficult. The challenge to plant breeders is mainly that of incorporating the large number of genes affecting the trait into an agronomically acceptable cultivar. This is complicated by the fact that genetic alteration of one trait frequently leads to undesirable changes in other plant characteristics.

When quantitative inheritance (i.e., controlled by many genes) is involved, knowing the heritability of a trait is the key to determining an appropriate plant breeding strategy for changing the trait. The expression of the quantitative trait depends on which genes are present in a given plant. Also, the trait is usually influenced by environmental conditions, which also contribute to the variation in expression. Heritability is a measure that estimates the proportion of the total variation in expression that is due to strictly genetic influences. Thus, as with wheat, a trait with high heritability is subject to less environmental influence, which means that the genetic worth of a particular plant is more easily determined. This usually means that progress in changing the trait through breeding is more rapid.

Johnson and Bernard (32), Brim (8), and Burton (13) have presented heritability estimates for quantitative traits that are usually measured in soybean breeding populations. The estimates were taken from several independent studies of different populations of soybean lines, Heritability estimates for seed protein percentage ranged from 51 to 92 percent. Seed oil estimates of heritability were similar, ranging between 51 and 93 percent, By comparison, seed yield estimates are lower, between O and 73 percent. This suggests that seed composition is less affected than seed yield by environmental factors. Thus, the genetic worth of a soybean line as it pertains to protein and oil composition is easier to determine than its genetic worth relative to seed yield.

Yield-Quality-Resistance Interactions

Breeding a cultivar for disease or pest resistance requires that resistance genes be incorporated into a high-yielding, agronomically acceptable genotype. If the resistance genes are located in a high-yielding adapted cultivar, then the transfer of resistance can usually be accomplished without yield loss. Such would be the case with resistance to soybean mosaic virus (SMV). High-yielding SMV-resistant cultivars are currently available. On the other hand, when resistance genes must be acquired from nonadapted plant introductions, transfer of resistance without some yield loss is difficult.

A major problem in selection for altered seed protein or oil composition in most soybean populations has been, as mentioned, the negative genetic correlations between protein percentage and the two other economically important traits, yield and oil percentage. Thus, selection for increased protein usually results in decreases in percentage oil and commonly in decreased yield (10,61). Similarly, selection for increased seed oil percentage results in decreased protein. Percentage protein and percentage oil were found to be negatively correlated in 12 soybean populations investigated in 5 separate studies (table 6-5). Most of these correlations had absolute values greater than 0.50. Negative correlations between percentage protein and yield, though frequent, were usually not great, with only 2 having absolute values greater than

When considering the problems of genetically increasing the quantity of protein produced by a soybean crop, there must be a recognition of the producer's desire for high yield and the soybean processor's desire for high protein percentage and acceptable oil levels. Thus, breeding methods have been varied depending on the breeding goals. The negative relationship between protein and oil has led some investigators to attempt to increase protein indirectly by selection for low oil. This has some economic advantages in that percentage oil can be measured rapidly and nondestructively in soybean seeds by magnetic resonance imaging spectroscopy.

Increased protein yield can also be accomplished by selection for increased yield, provided percentage protein does not decline significantly. In this respect, recurrent restricted index selection could be used to hold protein constant while increasing yield. In two cycles of selection, using such an index, yield increased from 32.0 to 32.5 bushels/acre while protein and oil remained constant at 45.8 percent and 17.8 percent, respectively (31). It might be possible to select for protein yield directly, although there is the risk that percentage protein would decline.

Genotypic Variability

There is a wide range, approximately 15 percentage points, in seed protein percentage among lines of the U.S. soybean germplasm collection. About 10 percent of these have a protein percentage higher than 44.5 percent. Seed oil percentage for lines in the U.S. germplasm collection acquired before 1970 range between 13.2 and 23.5 percent. Because most currently grown cultivars have between 20 and 23 percent oil, there seems to be more opportunity for increasing protein than oil percentage with the germplasm resources currently available.

With the breeding methods mentioned in the previous section, genetic lines have been developed with higher protein content and similar yielding ability compared to standard cultivars. Three examples of such lines have protein percentages between 44.2 and 45.5 and were recently evaluated in the U.S. Department of Agriculture (USDA) Uniform Soybean Tests (table 6-6). When protein content was higher than the check cultivars, oil content was lower in these three lines.

Genotype v. Environment

As discussed in the section on wheat, variation in the expression of a quantitative trait in any plant population is due to genetic and environmental influences and an interaction be-

Table 6-5.—Genotypic Correlations in Soybeans

		Johnson et al. (1955)		Thorne and Fehr (1970)		Shorter et al. (1976)		Simpson and Wilcc		
Population		1	2	3	4	5	6	7[a]	8[a]	9[
Percent oil	genotypic	−0.48	−0.70	NA[b]	NA	−0.96	−0.35	−0.15	−0.96	−0.
Percent oil	phenotypic ...	−0.48	−0.69	−0.66[c]	−0.58[c]	−0.79[c]	−0.24	NA	NA	N
Percent yield	genotypic	−0.64	−0.12	NA	NA	NA	NA	+0.54	−0.74	−0.
Percent yield	phenotypic ...	−0.33	−0.08	−0.21	−0.27	NA	NA	NA	NA	N

[a]Random F_5 lines from crosses between unadapted high protein lines and adapted average protein lines (UH X AA).
[b]NA = not applicable
[c]Significant at <0.5.

SOURCE: Office of Technology Assessment, 1989.

Table 6-6.—Mean Performance of Check Cultivars and Breeding Lines With Higher Percent Seed Protein

Line	Yield (bu/acre)	Protein (percent)	Oil (percent)
D82-4098[a]	45.8	44.2	18.1
Centennial	43.8	42,9	19.0
N84-1256[b]	37.0	45.5	18.7
Check cultivar[c]	37.5	41.5	21.0
LN82-4049[d]	45.4	44.8	20.2
Sparks	44.0	41.2	21.5

[a]Tested in the Regional Preliminary VI, The Uniform Soybean Tests—Southern Region, 1984
[b]Tested in five North Carolina environments
[c]Braxton, Ransom, or Gasoy 17
[d]Tested in the Regional Preliminary IV A, The Uniform Soybean Tests— Northern States, 1985

SOURCE Office of Technology Assessment, 1989

tween the two. In defining issues related to the interaction of genotype and environment in plant breeding, it is helpful to consider environmental variation in a continuum from predictable to unpredictable. Predictable variation is due to those conditions that can be controlled in some way (e. g., irrigation) or those that have permanent characteristics (e.g., photoperiod and soil type). Weather-related conditions generally contribute most to unpredictable variation,

Most problems in seed quality that arise because of weather have no real genetic solutions. Sometimes, genetics can lessen the impact of a weather-related problem. For instance, the hard-seed coat genotype develops less seed disease when harvest is delayed after maturity. Other genetic sources of resistance to fungal seed pathogens lessen the problem but do not eliminate it. Many seed disease problems are related to cultural practices and harvest. Usually changes in farming, harvesting, and storing practices are much more likely than varietal disease resistance to be effective in controlling seed disease.

Most soybean breeding programs have regional testing efforts to evaluate genotypes across a wide array of environments. A genotype is selected from these tests on the basis of ability to perform well in most environments. Statistical analyses have been developed to determine the relative environmental stability of cultivars. Evaluation and selection of stable cultivars is the most common way that environmental influence is moderated by genetics. The other way is to attempt to tailor a variety for a particular environment. This can be quite successful if the environment can be defined. Breeding for disease resistance fits this category,

Role of Public and Private Soybean Breeders

Private industry investment in soybean breeding has been a relatively recent development. Prior to the passage of the Plant Variety Protection Act in 1970, only six companies (with one plant breeder each) were engaged in soybean breeding because soybean is a self-pollinated crop and, without the act, research investment could not be recovered, Since then, an additional 25 companies and 61 breeders have been added to the private soybean breeding industry (63). Under the act, certificates of plant variety protection can be issued that assure the “developers of novel varieties of sexually reproduced plants . . . exclusive rights to sell, reproduce, import or export such varieties.” It was this guarantee of exclusive rights that enticed private seed companies to invest in soybean research. Thus, the role of the private plant breeder is to develop novel soybean varieties that can be sold at a profit.,

Public soybean breeders have always been involved in varietal development. Yet they have had and continue to have a large role in basic soybean breeding. The roles or responsibilities of public breeders in general have been identified as to teach and train students as future plant breeders, conduct “basic” research, and develop cultivars of minor and regionally adapted crops (52). This latter would obviously not apply to soybean breeders. General agreement exists among those concerned with this issue that training students is an important and appropriate responsibility of public breeders, and most agree that public breeders should conduct basic research.

The changing role of publicly supported plant breeding research was discussed at the 1982 Plant Breeding Research Forum sponsored by Pioneer Hi-Bred International, Inc., which was attended by both public and private plant breeders and administrators. The joint effort between public and private breeders was reported in the conference proceedings as being mutually beneficial. Furthermore, the competition in crops such as soybeans was considered to be healthy because there is no assurance that developing varieties of self-pollinated species will be profitable enough for private companies to justify continued research investment, because it is not possible to draw a line separating basic from applied plant breeding, and because no clear division exists between germplasm enhancement and cultivar development (43).

General agreement exists that increased support for basic research is needed, particularly that involving the collection, assessment, and development of germplasm resources (43,52). This is needed simply to maintain current levels of crop productivity. The average lifetime of a soybean cultivar in the United States is 5 to 9 years, in part because of the dynamic nature of the agroecosystem. The sudden appearance of a disease, changes in climate, water, or soil conditions, or changing cultural practices can necessitate the replacement of a cultivar with one more adapted to the new environment, This situation is not likely to change. The new genetic engineering technologies, such as protoplast fusion, if successful, will be a useful tool in cultivar development but will not eliminate the need for traditional plant breeding research activities.

Rationale for Differentiation

Private plant breeding programs have basically one goal—the development of an improved cultivar that can be marketed and profitably sold to farmers. This permits a concentrated investment of resources for cultivar development that is usually much greater than a similar investment by a public plant breeding program. For example, in 1983 Asgrow Seed Co. made 1,200 crosses combining genetically different material and screened 120,000 lines with a professional staff of five Ph.D. plant breeders (4), By comparison, the public soybean breeding program at North Carolina State University in a typical year makes approximately 6 crosses aimed at cultivar development and screens approximately 1,200 lines for agronomic performance,

Research funds and scientists' time at most public institutions that conduct soybean breeding are spent on a variety of activities not directly related to cultivar development, such as teaching, evaluating germplasm, devising and testing breeding methodologies, and doing inheritance studies. Without a profit motive, publicly funded soybean breeders are usually under less pressure than private soybean breeders to develop and release cultivars. Publicly funded soybean breeders also are freer to conduct long-term research projects that have a low probability of yielding any immediate economic return, The "high risk" nature of basic research means it probably will only be conducted by public institutions (43).

Funding

Soybean breeding by a private company is funded by profits from the sale of seeds of' the varieties the company produces. If soybean varieties are not profitable, then the funds come from some other division of the company that is profitable. Funding decisions are based on company managers' assessment of the market potential for soybean varieties with particular characteristics—e.g., maturity group, resistance to a disease, and so on.

Soybean research has four sources of public funding. These sources and their relative contribution in 1984 were:

- State appropriations (37 percent);
- USDA-Agricultural Research Service (29 percent);
- Hatch Act formula (10 percent); and
- funds to land grant universities and contracts, grants, and cooperative agreements from Federal, State, and farmer check-off sources (24 percent) (3).

Farmer check-off in the 1980s has amounted to between 7.4 and 8.1 percent of the total soybean research funding. Grower funding varies a great deal among soybean-producing States.

Grower funding in 1984 amounted to 25.7 percent of the total soybean research budget in Nebraska, whereas in Ohio there was none.

Even though studies measuring return to investment in agricultural research show rates of at least 15 percent, State and Federal support (in real dollars) for agricultural research has remained nearly constant since 1965 (43). In recent years, as plant breeding positions in public institutions have become vacant, they have been converted to genetic engineering positions so that research in biotechnology can be emphasized. This has meant an overall decrease in funding of traditional plant breeding research. This reduction in public support for plant breeding is generally viewed with great concern.

Alternate means of financing public plant breeding research are being explored. One suggestion is that private industry become more involved. For instance, a private company could support graduate student training and research. It is also suggested that private industry could support research that benefits the industry itself. Some State universities are considering patents on products of their plant breeding research as a means of generating revenue. Increased funding from commodity organizations is another possibility.

All these suggestions have been criticized because funding of this nature is usually unpredictable and tied to particular short-range goals. It does not provide for the long-term, higher risk research that requires a continual resource commitment. A recent suggestion has been the release by State Agricultural Experiment Stations of soybean varieties eligible for royalties, by the brand name Variety Not Stated. This idea has not been viewed favorably by either public or private soybean breeders. It is believed that such a system would tend to shift more resources toward short-term basic research, impede the free flow of germplasm among experiment stations, and limit a farmer's ability to know whether or not two varieties are identical.

Variety Release

Prior to 1946, 194 soybean cultivars were released in the United States and Canada (table 6-7). Nearly all were plant introductions from Asia or plant selections from those introductions. Active soybean breeding increased after 1945. Between 1946 and 1970, 110 cultivars were released from public plant breeding projects. As noted, private soybean breeding increased with the passage of the Plant Variety Protection Act in 1970. Between 1973 and 1987, a total of 363 soybean cultivars were released under plant variety protection (table 6-8). Most of these were developed by private soybean breeding projects. Sixty-four public cultivars in maturity groups 00 to IV were released between 1971 and 1981 (5 I), and in maturity groups V to VIII, 93 public cultivars were released (29).

As the number of public varieties has increased, the number of acres planted with private cultivars also has increased. Currently 57 private cultivars are available to farmers in North Carolina v. 23 public cultivars. The North Carolina acreage planted to public cultivars has decreased from 81.4 to 62.7 percent in the past 4 years (19). The trend toward increased use of private cultivars will probably continue due to the release of improved private cultivars and the ability of private companies to market effectively.

Procedures for Release

Most soybean cultivars are the inbred progeny from matings between two or three inbred lines or cultivars, They are usually "pure" lines, which means they have a high level of genetic homozygosity from having been inbred through at least three generations of self-pollination. A soybean breeder selects the "best" inbred lines from among several populations. These lines are tested in local and regional tests before a decision is made to recommend the line for release as a cultivar. This decision is made based on its yielding ability relative to currently grown

Table 6-7.—Soybean Cultivars Released by Public Institutions in the United States and Canada Prior to 1976

Maturity groups	Prior to 1946	1946-70	1971-76	Total
00-I, ...	35	"29	8	72
II-IV	98	54	12	164
V-VII . .	43	22	6	71
VIII-X	18	5	4	27
Total	194-	110	30	334

SOURCE T Hymowitz C A Newell, and S G Carmer 'Pedigrees of Soybean Cultivars Released in the United States and Canada International Agricultural Publications, IN TSOY Series No 13 University of Illinois Urbana Champaign IL 1977

cultivars in the same maturity grouping. Decision to release is also based on other traits that contribute to agronomic quality and yield stability over a range of environments. In approximate order of importance, these traits include resistance to plant lodging, disease and pest resistance, stress tolerance, rate of emergence, and protein and oil content.

Every State Agricultural Experiment Station or private seed company has a committee that reviews and approves prospective cultivar releases. A soybean breeder who has selected a line that is suitable for release as a cultivar must prepare a report or "defense" of the line. This includes a summary of pertinent test data and a statement of the rationale for release. The latter explains the unique characteristics of the line that would make it an important addition to available cultivars. Productivity and usefulness to growers are the primary criteria in releasing new varieties, For private plant breeding companies, stability is also a critical consideration. Because a company's name and reputation are associated with the cultivars they release, the firm cannot afford to release a cultivar that performs poorly.

Every State has its own cultivar release policies, although these have all been developed within the guidelines of USDA policy (57) and Federal law (Federal Seed Act of 1939 and Plant Variety Protection Act of 1970). As an example, the North Carolina Agricultural Research Service makes the following statement in its

Table 6-8—Soybean Cultivars Released by Private Companies Under Plant Variety Protection Certificates, April 1973-November 1987

Company	Number of PVP cultivars not under Title V	Number of Title V PVP cultivars
Agratech Seeds		1
Agripro, Inc.	7	
Americana Seeds, Inc	1	
Asgrow Seed Co..	48	
B.B. Collier-Barney A. Smith .,		1
Bryco Plant Research Division .	1	1
BSF/Ag Research	1	
Callahan	6	1
Coker's Pedigreed Seed Co. ., .	22	16
Dairyland Seed Co., Inc.	3	8
Delta & Pine Land Co.	7	1
Ferry-Morse Seed Co.	1	
FFR Cooperative	8	1
Funks Seeds		1
Goldkist		1
Growmark, Inc.	1	
Helena Chemical Co.	5	
Identity Seed & Grain Co, ...	1	
Illinois Foundation Seed		1
Jacob Hartz	9	3
Jacques Seed Co, ...	8	
J.M. Schuetz Seed Co.	8	
King Grain U. S. A., Inc.	4	
Land O'Lakes, Inc.	11	
Louis Bellatti		2
Lynnville Seed Co.	4	1
Midwest Oilseeds, Inc.	4	
Milburn Farms		1
Nickerson American Plant Breeders	6	
Nixon Seed Co. & L.		1
North American Plant Breeders	26	
Northrup King Co.	24	15
pioneer Hi-Bred International, Inc.	40	1
Prarie Seed Co., Inc.	1	
Scientific Seed Co., Inc..	1	
Soybean Research Foundation, Inc. . . . .,	13	20
Stanford Seed Co.		1
Syler	1	
Terral-Norris Seed Co., Inc.		7
Teweles Seed Co.	4	
Voris Seeds, Inc.	1	
V.R. Seeds, Inc. ... , ...	8	
Totals	278	85

SOURCE Of fice of Technology Assessment 1989

Plant Patent and Plant Variety Protection Policy and Procedure Statement:

> New plant cultivars and breeding lines may be released for public use if judged to be either unique or superior to currently available germplasm, or equal to presently available cultivars if the genetic base of a crop is broadened so as to reduce disease and other pest hazards (40).

The statement encourages release of new cultivars that enhance yield, but makes no mention of quality.

Length Of Time for Development and Release

In a survey of 64 Plant Variety Protection applications for soybean cultivars, the average time required from cross to application was 9.2 years (4). This development and release time is similar for private and public cultivars. The use of a winter nursery in the inbreeding stages can shorten the time between making a cross and development of a pureline that has variety potential. This has already become common of all soybean breeders, however, so the 9.2-year estimate would include the time savings involved in winter nursery use.

New biotechnologies are unlikely to reduce significantly the time for development and release of a cultivar. They will, however, provide the opportunity for putting a new trait into a plant in a matter of months where now it can take 5 to 7 years to breed into a variety a specific trait through conventional breeding and backcrossing. Field testing and seed manipulation steps are still necessary and will consume most of the development and release time.

Soybean Breeding Technology

Present Technology

Soybean cultivars are typically developed by hybridization of two or more lines followed by self-fertilization to the F_4 or later generation. Homozygous lines (purelines) are isolated and tested to determine those with superior performance and cultivar potential. With this method, the major issue has been how material in the F_2, F_3, and F_4 segregating generations should be handled. The method used depends on the plant breeding objectives and personal preferences of individual soybean breeders. Pedigree selection or modified pedigree selection are the most common methods for systematic inbreeding (22). Backcross breeding is commonly used for transferring a few gene loci from a low-performing line to a high-performing cultivar. Modification of those standard practices include population improvement through early generation testing and recurrent selection, bulk breeding, and mass selection.

The other important issue that has received considerable attention is the most appropriate and efficient way to evaluate lines with respect to a particular trait. Various field plot and laboratory testing techniques have been developed and used (22). The appropriateness of a particular technique depends on the trait being evaluated and the ease with which it is measured. Much of the success or failure of a particular breeding project can be attributed to the quality of the germplasm and the genotypic evaluation program.

These classical methods are adequate for the transfer and recombination of genes within the species and have been successfully used to improve soybean cultivars. Higher yielding cultivars with disease and pest resistance have been developed and released over the past 40 years. Progress, while continuous throughout this period, has been slow. The rate of increase in seed yield has been estimated at between 0.6 and 1.0 percent per year (62). For at least the next 10 years, the classical methods, because they are in place and successful, will likely continue to be those most used to produce improved cultivars.

It is currently not possible to economically produce the seeds for F_1 soybean hybrids. Patents for two F_1 hybrid seed production methods have been issued. However, it remains to be demonstrated that either can be used to produce hybrid seed economically. Strong evidence for significant hybrid vigor in the soybean species is sparse (13). As a result, little research is being conducted on F_1 hybrid seed production for soybeans.

Future Technology

Future technology in the genetic alteration of soybean will undoubtedly include recombinant DNA methods (genetic engineering). Some progress is being made in the regeneration of whole, fertile plants from soybean tissue and cells in culture, But it is impossible to predict how long it will be before regeneration becomes routine. Various methods for transferring genes into plants are being developed, and plant transformations have been successful. For instance, a gene that imparts tolerance to glyphosate herbicide has been introduced into *Petunia* (48),

If methods for foreign gene transfer and regeneration are developed for soybean, the same problems as in wheat will still apply—isolating genes, determining which ones can be beneficially introduced into a plant, and regulating the gene expression once it is introduced. In soybean, the traits most likely to be altered through genetic engineering are seed protein and oil quality, plant stress tolerance, pest and disease resistance, and herbicide tolerance (26). It is expected that desirable changes in these traits can be obtained by manipulating a few genes, As of now, not many soybean genes have been cloned, sequenced, and had the gene product isolated. More basic genetic information is needed about plant traits in order to make significant changes in soybean through genetic engineering (26),

Only the seed quality traits that are related to disease reaction, such as the mottling caused by soybean mosaic virus, are likely to be affected by new genetic engineering technologies in the near future, Percent seed protein and oil and seed size, like seed yield, are polygenic. Many unidentified genes are involved in the determination of these traits. This makes them difficult to evaluate at the cellular level and to work with at a molecular level (27).

The new molecular genetic technologies hold great promise, and much important biological information will be learned from molecular genetic research. This will eventually translate into practical ways to alter plants genetically in a desirable way. In the short term, however, most improvement in soybean seed quality will come through classical plant breeding.

CORN

Corn is the only important cereal crop indigenous to the Americas, and more than twice as much corn is produced in the United States as any other crop. Most modern races of corn are derived from prototypes developed in Mexico and Central and South America. An exception to this is the sole product of North America—the yellow dent corn that dominates the U.S. Corn Belt, Canada, and much of Europe today. The late maturing Virginia Groundseed and the early maturity Northeastern Flints were crossed in the early 1800s, and the superiority of the hybrid was recognized. The cross was repeated many times and out of these mixtures eventually emerged the Corn Belt dents, the most productive race of corn found anywhere in the world. The highly selected cultivars of Corn Belt dents formed the basis of hybrid corn and were the source of the first inbred lines used to produce hybrids, {

Objectives of Genetic Selection

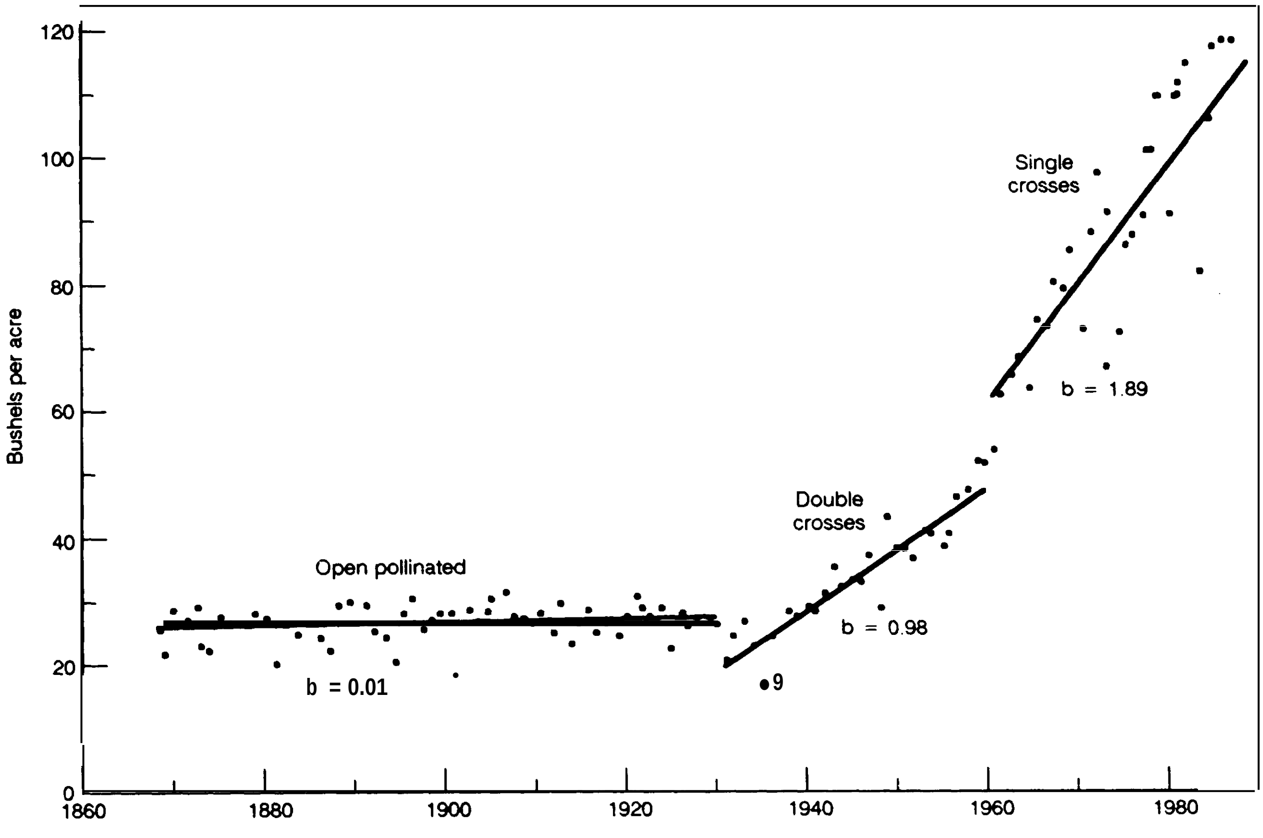
Corn breeding is accomplished by selection for desired plant traits during both inbred development and hybrid evaluation. Breeders have always selected for traits that give higher yield and easier harvest in accordance with current cultural practices, and harvest method has been the most important cultural practice influencing selection traits for corn. Quality factors such as protein or starch content have not been a high priority.

‘This section is based on A, Forrest Troyer, “Grain Quality and Corn Breeding, ” prepared for the Office of Technology\' Assessment, U.S. Congress, Washington, DC, 1988.

Since the introduction of hybrid corn, the U.S. average corn yield has increased steadily, from 16 bushels per acre in 1936 to 110 bushels per acre average for 1981 through 1987. Since single-cross hybrids (circa, 1960), the average yield increase per year is 1.89 bushels (figure 6-l). Most of this yield increase is genetic improvement. Three investigations (14,20,44) compared yields of hybrids from various eras; the gain in hybrid performance due to breeding averaged 64 percent of the total gain in annual corn yields (table 6-9). The other 36 percent has been attributed to improved cultural practices such as fertility, weed control, plant density, planting date, row width, etc. Corn breeders have successfully matched breeding objectives with improved cultural practices steadily and rapidly to increase national average yields of corn and will continue to do so in the future (55).

The other major objective of corn breeding has been to accommodate harvesting methods. Hybrid corn made mechanical pickers possible because of better standability. The corn-picker-harvest period (1940-60) saw many corn production improvements; increased fertilizer use, higher plant densities, more continuous corn, improved herbicides and insecticides, cheaper nitrogen, and earlier planting were some of the more important. Cold tests and other indicators of seed vigor were devised by breeders to develop corns adapted to earlier planting. Plant and ear height were unaffected by use of corn pickers, Most farms were still diversified, and livestock consumed much of the corn on the farm where it was grown. Breeders selected corns that would not shell too easily on snapping rolls and on husking beds of corn pickers, Continuous corn led to root-

Figure 6-1. -U.S. Corn Yields and Kinds of Corn Over Years (b values show average yield increase per year)



SOURCE: A Forrest Troyer, "Corn Breeding and Gram Quality," presented to North American Export Gram Association, May 1986

Table 6-9.—Summary of Studies on Breeding Gain in Corn

Study	Hybrids (number)	Period (years)	Gain (percent)
Duvick, 1977	19	32	57
Duvick, 1977	50	40	60
Russell, 1974	25	48	63
Castleberry et al.,1984	27	60	75
Average	30	45	64

SOURCE Office of Technology Assessment 1989

worm buildup and strains of insecticide-resistant insects, so stronger rooted hybrids were needed. Farmers preferred hybrids that picked cleanly and easily, so breeders selected for smaller shank-to-ear attachment. Use of higher plant densities required selection by breeders of corn genotypes that tolerate stress due to plant crowding. About the same maturity corns were still being grown in a given area (generally full season), and test weight still was not a problem because corn sold off the farm was naturally dried ear corn.

The field-shelling-harvest period (1960 to present) has brought larger farms, higher plant densities and fertilizer rates, even more continuous corn, and more corn marketed off the farm (55). Artificial dryers became commonplace throughout the Corn Belt. For a time, large farms and small equipment increased the need for better standing corns, and newer combines and other equipment steadily increased operational capacity. Corn became shorter and lower eared in this period as farmers shifted to earlier corns in order to start combining sooner. Before the invention of quick-attach heads for combines, stalk quality became extremely important to large operators in cash-grain operations because corn harvest often waited until soybean harvest was finished. Ear retention was also very important to these operators. Harder starch, or flintier types, allowed earlier start of harvest by reducing the number of broken kernels with high moisture shelling. Artificial drying of corn (which lowers test weight), coupled with more direct selling from the field with test weight discounts, further increased the need for harder textured, flintier corns, Hybrids with stronger cobs and easier shelling became an advantage for combine harvest, while those that dried faster in the field and in the dryer became more desirable as fuel costs rose (54). Genetic selection for tolerance to higher plant densities reduced barrenness and increased frequency of two-eared plants. Adoption of minimum tillage to cut costs increased the incidence of diseases and insects (gray leaf spot, corn borer, etc.), leading to more breeding emphasis on these problems.

Genetic Influences on Kernel Quality

Corn kernels can be altered by genetic means to give modifications in starch, protein, oil, and other aspects such as kernel hardness,

Starch Modification

Most genes affecting endosperm composition are recessive. Starch from normal dent or flint corn is composed of 73 percent amylopectin (starch fraction with branched molecules) and 27 percent amylose (the fraction from linear molecules). Corn breeders have been successful in developing waxy corn that has starch with 100 percent amylopectin. However, yields of the waxy hybrids were less than those of their normal dent counterparts. But newer waxy hybrids are comparable to the better dent varieties. It has also been possible to increase the amylose content of starch up to 50 percent. Waxy and high-amylose hybrids are grown under contract for corn wet-milling.

Oil

The oil content of most hybrids ranges from 3.5 to 6.0 percent, with an average of about 4.5 percent. Experiments indicate that oil content can range from a low of 0.1 percent to as high as 19.6 percent (18). High oil hybrids with 6 percent oil content and above are lower in yield than hybrids with less than 6 percent oil. Increasing oil content genetically is not difficult, because variation occurs in existing germplasm and most of it is heritable (2). Oil quality is a function of the relative amounts of unsaturated and saturated fatty acids, the amount of which is under genetic control and can be altered through breeding.

Analyses of hybrid crosses have shown a negative correlation of – 0.49 between yield and percent oil. Data from these experiments suggest that for significant increases in percent oil content, yield would have to be sacrificed.

Protein Quantity

The amount of protein in corn is a function of cultural practices and heredity. The current average protein content of U.S. hybrids ranges between 9 and 11 percent. Through selection, protein can be altered. Experiments covering 70 generations of selection for protein have produced corn with a low of 4.4 percent protein and a high of 26.6 percent (18). But there is a trade-off between higher protein and yield. Genetic correlations between yield and protein range from – 0.41 to +0.34 and average – 0.06 (17). Data from these experiments indicate that within an intermediate range of approximately 14 to 18 percent protein, yield and protein can be increased simultaneously. For higher ranges of protein, yields will decrease. Not much interest exists in developing hybrids with higher protein potential, however, because economically available soybean protein can produce an animal feed ration that is balanced with respect to the essential amino acids.

Kernel integrity

Damage to kernels during harvesting, drying, elevating, and moving grain through commercial channels is of concern. Contributing to the problem is the change from harvesting on the ear to using field picker-shellers. Artificial drying was usually not needed for corn harvested on the ear, because it dried naturally in the corn crib. Combine harvesters allow harvesting corn earlier to reduce field losses; however, grain usually has a high moisture content and requires artificial drying. Most farmers dry grain rapidly at high temperatures because of the small drying capacity of equipment, but this excessively rapid removal of moisture causes cracks to occur in kernels. When grain is moved through market channels, kernels break easily, resulting in fine particles that lower the value of the product.

Methods of determining breakage susceptibility have been developed that indicate many kernel characteristics are related to the breakage problem. These include the ratio of vitreous to nonvitreous endosperm, kernel density and average weight, test weight, and kernel size and shape. Most of these characteristics are heritable, but corn breeders have not given high priority to selection for kernel breakage reduction. Research also indicates that differences exist among genotypes for kernel fracturing caused by fast, high-temperature drying. Selection for resistance to this kind of kernel fracturing should be possible.

Another solution to the problem is to allow corn to dry in the field to a moisture content that would require less artificial drying. Development of fast-drying hybrids is possible.

Genotype v. Environment

The environment greatly influences the quality of grain. Fall seasons with much rain can increase ear rotting. The need for fast drying in the field has caused selection of hybrids with less husk cover. These same hybrids may lack ear protection from heavy rainfalls. The best hybrid for fast drying in a normal autumn may be the worst hybrid for ear rot in a high-rainfall autumn. Early frosts may cause premature death that reduces kernel size and test weight. Dry seasons in general favor insects because insect parasites are inhibited by lack of moisture. Insects reduce grain quality by increasing broken kernels, foreign material, and kernel rot.

Genotype v. Management

Protein content can be increased with nitrogen fertilizer. If the base yield is 75 to 100 bushels **per acre with 8.5 percent protein, and the final yield with extra nitrogen is 100 to 125 bushels, the first 100 pounds of nitrogen will probably raise the protein about 1 percent. The next 100 pounds will raise the protein another 0.5 percent (l). Higher protein contents have been found in corn after drought conditions because a fixed nitrogen amount is distributed** through a smaller crop (25). This is because most nitrogen accumulation precedes endosperm filling. Only one-fourth of the protein in the kernel is in the endosperm. The endosperm increases in size with higher yields and is mostly starch—86 percent starch and 9 percent protein (60). Thus, a negative association occurs between yield and percent protein at high yield levels or at low nitrogen fertilization levels.

Plant density can affect quality when enough stress occurs to cause misshapen ears that may dry slowly or have many small kernels. Grain texture may also be affected by stress. Late planting dates reduce quality by causing flowering during hot weather and an immature crop at harvest with effects similar to early frost.

The chosen drying method is a big factor in corn quality. When corn was harvested on the ear and dried slowly in the crib, test weight and broken kernels were no problem. Field shelling (combining) has changed all that. In the northern and central Corn Belt, harvest at high moisture followed by rapid drying at high temperatures can cause puffing and case-hardening that reduces test weight and increases brittleness, In the southern Corn Belt, ear quality can deteriorate in the field during humid fall conditions.

Ear-corn storage has given way to shelled-corn storage, As mentioned before, these changes in harvest methods have greatly affected corn breeders' selection traits. Stored corn typically has problems with molds and insects that interact with moisture content and temperature of the corn.

Role of Public and Private Corn Breeders

Corn breeding at the Federal, State, and private level greatly increased subsequent to the double-cross-corn formula of hybrid production that made hybrids practical in spite of the weak inbreds and cultural practices of the period. In 1955, the Federal Government spent $300,000 ($80,000 for basic research), State Agricultural Experiment Stations (SAES) no more than $150,000, and private companies at least $2 million on corn breeding and yield testing (59). Estimates for 1987 are Federal Government (USDA) $4 million, State Experiment Stations through the Cooperative State Research Service (CSRS) $8 million, and private companies more than $70 million, For comparison, the 1987 Federal budget contained $35 million (USDA Agricultural Research Service) and $46 million for State Experiment Stations (CSRS) for projects related to biotechnology (6).

Until about 1960, for new inbreds most SAES had delayed-release programs that served to maintain State crop improvement programs by favoring companies that sold State-certified hybrids. Delayed release policies plus the Federal Seed Act of 1939 (58), which prohibits selling the same pedigree under different names, were to exclude new public inbreds from private label seed companies. However, the Federal Seed Act does not prevent this. Public inbreds have been used in crosses and sold under different names (39), This confuses the farmer and prevents the spreading of risk unless the pedigrees of the purchased hybrids are known.

At the beginning of hybrid corn, many small seed corn companies were enticed into the business by promises of new inbreds from the State Agricultural Experiment Stations. Inbred lines from public agencies became the parental lines for SAES commercial hybrids and for development of new inbreds. By the late 1950s, larger seed corn companies had extensive research programs to develop inbreds, and public breeders started doing additional basic research at the expense of inbred development. A total of 156 public lines were released from 1946 to 1955. An American Seed Trade Association survey of the same period showed 52 hybrid corn companies in 12 States were using these lines as 1 or more parents in producing about one-fourth of the hybrid seed used annually. About 500 individual companies produced and sold hybrid seed in Iowa in 1940; only about 100 companies were still in operation in 1957. Observers of these changes concluded that publicly supported corn research was more basic than 10 years earlier and that breeders involved felt even more time should go to basic research.

Variety Release Procedures

The United States places few restrictions on the release of new corn varieties developed by public or private breeders, Release of new varieties takes place at agricultural experiment stations within the land-grant system, Private breeding takes place at research stations operated by private firms around the country, Most States have laws that control labeling of new varieties but these usually deal with seed purity or certification procedures. For example, most State seed laws specify the information required on the tag on each bag of seed, Michigan appears to exert more influence on variety release than other States. According to breeders there, public varieties cannot be released unless they show an "acceptable level of merit."

Public Varieties

As public breeders, agricultural experiment stations around the country follow general guidelines set forth by the seed policy committee or the general executive committee for research, entitled ESCOP (Experiment Station Committee on Policy). ESCOP is organized under the Experiment Station Section of the Division of Agriculture of the National Association of State Universities and Land Grant Colleges in Washington, DC. The seed policy subcommittees under ESCOP represent experiment stations on seed matters, including production and technology, in appropriate agencies and associations. General policies regarding variety release procedures and other breeding issues are established through these committees. A function of ESCOP and its seed policy committee is to maintain consistency in procedures and policies regarding release of public varieties. ESCOP holds no legal power over experiment stations or variety releases,

The variety release decision within each State's experiment station involves a committee within the College of Agriculture. At the University of Illinois, for example, this committee is called the PVRC (Plant Variety Review Committee), and it serves in an advisory capacity to the Dean of the Experiment Station who is appointed by the Chancellor of the University. Each State Agricultural Experiment Station that has an active breeding program has a PVRC similar in function to that at the University of Illinois. Although patenting of germplasm and plant protection of varieties are currently being discussed, the general philosophy of public institutions regarding variety release has been one of information exchange and minimum control.

Private Varieties

Evaluation of new varieties developed by private firms occurs without significant State or Federal intervention. The decision to release a new variety is an internal one arrived at by review committees that vary according to firm size.

Each plant breeding company in the United States has a procedure for determining the usefulness or worthiness of new varieties. These procedures are generally informal in the case of smaller companies, but more formal and structured in the case of larger firms. The decision to release a new variety often evolves during a series of meetings with company administrative personnel, breeders, sales staff, and so on. Large companies (nationals and multinationals) do their own screening and testing of new varieties, and the data are made available at each variety review stage. Recommendations on retesting, rejection, and release are made on the basis of performance data and advice from company personnel. A large firm might start out with several thousand crosses and end up with just a couple that actually meet all necessary criteria. In private firms, the criteria reflect field performance data as well as information on the potential for effective sales, marketing, and advertisement. All of these are related to the firm's profitability.

Michigan is an exception among the Midwest corn-and soybean- producing States in that State law requires public or private certified seed to be subjected to performance trials for at least 1 year before it can be sold as certified seed. This does not preclude selling uncertified seed, nor does it prevent companies from other States selling seed within Michigan that has not been subjected to these tests. It does prevent any dealer in Michigan from labeling seed as certified unless it has been subjected to the performance tests established under authority of the State.

Field Performance Criteria

In a 1981 survey, 454 commercial hybrids were offered for sale; 212 precommercial hybrids were in final testing stages; 7,400 experimental hybrids were in advanced trials; and 61,000 hybrids were in preliminary trials. About 2,800 proven inbreds were on hand and 23,000 inbreds were in preliminary tests (21).

Criteria for judging new varieties in the field are similar for both public and private breeders. Performance criteria for measuring corn varieties are more diverse than those for judging soybeans and wheat. For all grains and soybeans, yield is the number one criteria as breeders try to persuade farmers that their variety is superior to others in the market.

Private and public corn breeders interviewed for this assessment stated that after yield, the ranking of remaining performance criteria differs among firms. This is in part a response to different environmental factors, herbicide developments, or changes in production practices that prompt a change in research emphasis. Variation in the relative importance of field performance criteria may also relate to differences in the ability to measure various performance criteria and differences in terminology among firms, since many performance judgments appear to incorporate some subjective factors.

Several corn breeders indicated that for corn, disease and pest resistance is the second most important performance criterion, with the third being maturity, i.e., length of dry down time required in the field. One firm indicated that standability was the second most important factor, while another ranked standability seventh. Again the difference probably relates to the firm's ability to measure standability and to how directly the firm relates standability to dry down time or disease resistance. Other criteria, ranked loosely in order of importance, are herbicide tolerance, feed value, percent early stand, plant height, percent dropped ears, flowering date, percent barren plants, and test weight.

Corn Breeding Technology

Most U.S. Corn Belt germplasm used today involves only two races, southern dents and northern flints, but more than 100 fairly distinct races of corn exist. From this standpoint the available germplasm base is more than adequate, Considerable genetic variability exists among kinds of corn in terms of adaptation, size, and purpose. It is likely that all traits currently needed to improve corn quality already exist. The problem is to identify exactly what is needed so that seedlots in germplasm banks can be efficiently screened for necessary traits. Certainly a large range of test weight, kernel texture (ratio of hard to soft starch), and kernel size is presently available among materials actively being used by U.S. corn breeders. The hope that an existing, unidentified trait for kernel integrity can be found depends on an accurate and rapid test to identify it.

As noted, present corn breeding technology has worked well. U.S. average yields are increasing almost 2 bushels per acre per year largely due to the highly competitive seed corn industry striving to provide hybrids that give the highest net profit to the farmer. Corn breeders today emphasize high yields, easy harvest, and fast dry down with modern cultural practices. The current system relegates corn quality to fourth rank or lower. Making grain quality or any other desired trait more profitable to the farmer will stimulate more breeding effort for that trait under the present system,

Future corn breeding technology will include more of the present methods plus the **biotechnology approaches discussed in the wheat and soybean sections. Successful breeders are fitting these newer technologies into present methods, Transformation of plants with genes** from other species and with engineered genes may provide the needed trait with less effort and fewer side effects than screening various germplasm storage banks. Ultimately, it may be possible to build a needed DNA sequence and position it into elite lines.

FINDINGS

In examining the objectives of genetic selection, genetic influence on quality, the roles of public and private plant breeders, variety release, and new technologies for wheat, soybeans, and corn, a number of common findings are evident:

- *Yield v. Quality.*—An inverse relationship exists between yield and quality in all three grains considered. In wheat, corn, and soybeans the trade-off is between protein and yield. Increasing the intrinsic factors that improve quality means that yield usually declines.
- *Objectives in Genetic Selection* .—Yield increase and the agronomic characteristics that relate to yield are the major objectives of plant breeders. Quality is not a high priority in genetic selection but this varies by commodity. The objective in wheat and soybeans is to at least maintain quality while improving yields. But this is difficult to attain. In corn, relatively less attention is given to quality factors while striving to increase yield.
- *Genetic Influence on* Quality.—In general, factors affecting quality are more heritable than factors affecting yield. The potential for improving quality through genetics is therefore high. However, many quality factors are quantitative traits known to be under the influence of a number of genes. This makes the task of enhancing quality more difficult relative to altering a plant's trait influenced by only a few genes. This is further complicated by the fact that genetic alteration (especially with many gene sequences) of one trait frequently leads to undesirable changes in other plant traits.
- *Procedures for* Release.—There are no legally binding procedures for controlling the release of new corn, soybean, and wheat varieties in the United States. Each State develops voluntary variety release policies, and the criteria for release differ by commodity and geographic location. Public and private breeders have yield as their primary criterion and seldom include quality of the harvested grain in their performance tests.
- *Time for Development and Release.—New* crop varieties require approximately 9 to 12 years for development and release, If plant breeding program objectives were to change in 1988, such as aim to develop new varieties with enhanced quality factors, it would be the year 2000 before new varieties were commercially available.
- New Plant *Breeding* Technologies.—Genetic engineering will in the future provide the opportunity for putting a new trait into a plant in a matter of months where it now takes 5 to 7 years to breed into a variety a specific trait. Much of the time is taken up in testing cultivars under farm conditions and in seed increase, These steps must be taken regardless of how a cultivar is produced initially, However, total time from identification of beneficial genes to new plant introduction may be reduced by 4 to 6 years.

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