Breaking Yield Barriers in Food Crops by Plant Breeding.

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Varietal improvement is no panacea for increasing per acre yields or total crop production in a subsistence, stagnant agriculture. Unfortunately too often agricultural scientists - and perhaps scientists generally - are overimbued with the importance of their own discipline. The imaginative plant breeder knows that improved varieties with high yield potential may be potent catalysts for provoking revolutionary changes in a traditional agriculture. He does not, however, overemphasize the varietal factor while ignoring the vital role of the other interdependant disciplines such as soils and plant nutrition, management, plant pathology and entomology. Crop yields can be increased greatly only when a sound package of improved practices is introduced simultaneously, drawing on the best knowledge from all disciplines. This principle is often overlooked and is one of the primary defects of many foreign assistance programs. Most scientists sent out on foreign assignments are specialists so imbued with the importance of their own specialty that they either ignore or play down the importance of the other production factors. This is done at the expense of progress in the overall food production program. Literally "they can't see the forest for the trees".

Not only do these scientists become over-imbued with the importance of their own discipline, but they often become over-impressed with current trends in their own discipline. Referring to the accomplishments of modern plant breeding, and the basic underlying science of genetics, what has been its contribution to world food production? How do these achievements compare with those of the prehistoric plant breeder" who established agriculture? Let us examine the record.

The accomplishments of modern scientific man - and specifically the plant breeder- are modest when compared to those of the early prehistoric plant and animal breeders. It was these early, untrained workers who established agriculture and animal husbandry, allowing a sedentary way of life. In all probability the first highly successful plant breeders were not men, for men largely confined their activities to hunting and fishing. More likely it was women of vision, located in different parts of the world, who first cultivated our principal food crops and domesticated the important animals.

Prehistoric Mrs. and Miss America, although taking up the art of plant breeding considerably later than their Asiatic cousins, collected, cultivated and thus saved for posterity, the important cereal - maize (although its wild ancestors have disappeared), as well as beans, squash, potatoes, chili and tomatoes. They domesticated the llama, the turkey and the dog. They bred the escuintle (the Mexican hairless dog) as an improved source of meat. They - or perhaps this was the man's contribution - collected, cultivated and used tobacco for relaxation and ritual.

Lest the "hippies" become over-impressed with their discovery of psycodalic drugs, "peyote" and hallucinatory mushrooms were discovered and used by these prehistoric societies thousands of years ago. And their use apparently was rationally controlled and did not become a cause of national alarm.

The invention and innovation of these early American plant breeders were monumental and dwarf all of our modern achievements. They are surpassed only by their Asian counterparts . Their achievements as animal breeders were limited only by the native fauna. There were few animal species of potential domestic value in North America as compared with Asia. They, however, failed miserably in one potentially valuable invention - the domestication of the bison. This animal was the one species in North America which could have become important as a source of meat, milk and as a powerful beast of burden. Had the bison been domesticated, the wheel and the plow almost certainly would have been invented. By allowing a reliable, abundant source of protein, these inventions would have changed the history and culture of North America. Why didn't it happen? Although we can speculate, we will never know.

After banishment from the Garden of Eden, Eve and her descendants accomplished many impressive feats of plant and animal breeding throughout Asia. They establishe successful cultivation of wheat, rye, barley, oats and rice. They cultivated many important legumes, including chick-pea, lentils and soybeans, and domesticated the goat, the sheep, the cow, the chicken and the donkey. Perhaps theirs weaker half - man - domesticated the horse to carry him on his hunts and on his ceaseless pastime of war. It remained for some unnamed African innovator to cultivate the remaining important cereal - sorghum.

The broad, basic achievements of these unknown primitive plant and animal breeders were monumental during their time and even more so today, when viewed in the light of modern science. Had there been a Nobel prize for service to mankind during their time, they would most certainly have been recipients of such an honor.

The Contributions of Modern Scientific Plant Breeding to Increasing Per Acre Yields and Crop Production

Modern scientific plant breeders have produced many new varieties of all of the major food crop plants in this century. Most of these new varieties have resulted from the successful manipulation of only a few genes to improve pre-existing varieties These new improved varieties have been used to expand the economic range of crop pla plants and have directly increased yields by raising the genetic yield base of the crop. Perhaps the greatest benefits of improved varieties, however, are the indirect ones. They became catalysts for utilizing improved cultural practices, which themselves greatly contribute to increasing yields, e. g. improvements in the use of fertilizers, rotations, cultural practices, improvements in moisture utilization and weed control. They have contributed much to increasing the certainty of harvest by the incorporation of specific genes for resistance to many diseases, insects, drought and cold.

Many varieties have been bred which better lend themselves to more advanced mechanization, thereby reducing production costs. Varietal improvement has also contributed to producing raw materials better adapted to the needs of the food industry and the consumer.

It is not difficult, although sometimes slow, to incorporate any one of the aforementioned characteristics into a single variety. The problems becomes very complex however, when a breeding program is designed to simultaneously combine many of these specific improvements - each of which frequently depends on several genes - into a single variety.

In order to better appreciate the problems that have been encountered in improving several of our important food crop plants, I will illustrate this with wheat, the crop on which I have spent my professional career, Triticales, a new crop with real commercial promise, and with minor references to other food crops.

WHEAT BREEDING DURING THE HISTORICAL PERIOD

Until the time of William Farrer, virtually all new varieties or cultivars of wheat were developed by selecting superior individual plants from indigenous or introduced gene pools. The variability in these gene pools had undoubtedly evolved mainly from natural crossing between earlier existing varieties and species. Such divergent gene pools formed the basis for selecting superior types when moved bymigrating settlers from the centers of origin of wheat into new environments. As wheats spread northwestward into the Eur-Asian steppes from centers of origin in the Near East, winter habit types with cold hardiness were sorted out. Early maturing spring types likewise were selected under warm environments.

This type of gene pool transfer phenomenon was the basis upon which the Soft Red Winter Wheat, Hard Red Winter Wheat, and Hard Red Spring Wheats were established into North America.

Colonists arriving in what is today eastern U.S.A. brought with them mixed types of wheats from Central Europe that gave rise to the Soft Red Winter types.

Later German-Russian pioneers from south eastern Europe brought wheats from the southern Ukraine and Crimean area that could withstand the rigorous winters of the central plains of the United States. From these arose the Hard Red Winter Wheat types. In a similar way the drought resistant spring durum wheats were introduced in Northern U.S.A. From another European introduction a single early maturing spring wheat plant was selected that eatablished the Hard Red Spring Wheat group of Canada and Northern U.S.A. Mr. David Fife, a Canadian, selected this plant from a mixed winter and spring population introduced from Poland via Britain. Similarly mixed introduction from Europe and Asia laid the basis for the Australian wheat production.

Early scientific wheat breeders like William Farrer, Mark Carleton and others greatly refined the methods for exploiting introduced wheat gene pools. They reintroduced additional material, especially from those geographic areas of the Old World, that had proven to be fruitful in earlier introductions made by immigrants. These scientists studied the new introductions under their local environments and from these introductions they made many individual plant selections, some of which subsequently became important commercial varieties, and progenitors for large numbers of wheat breeding (crossing) programs that have functioned in many parts of the world during the past 70 years.

Many improved varieties have been developed by these programs and have contributed in several ways toward increasing world wheat production. They have extended the range of commercial production. They have increased per acre yields. They have reduced crop losses by providing better protection from diseases and insects. They have facilitated the mechanization of the crop, thereby reducing production costs and they have produced superior basic types of grains for specific industrial needs.

Collectively, these benefits have added untold billions of tons of wheat to the world's food larder, while simultaneously adding untold billions of dollars to the income of the farmers.

Nevertheless, there is no time for preening ourselves over past accomplishments. The exploding world population growth confronts us. The food surpluses of the past two decades have largely disappeared, and man is now confronted by a bleak food shortage in many areas of the world. What can be done about this by the plant breeder and his scientific colleagues in related production disciplines?.

MODERN WHEAT BREEDING PROGRAMS AND THEIR CONTRIBUTIONS TO RAISING PER ACRE YIELDS AND WORLD WHEAT PRODUCTION:

I would like to use the Mexican wheat breeding program to illustrate the philosophy, approach and result that is currently contributing far more than I ever dreamed possible, to increasing world wheat production, indirectly influencing progress in the production of other crops in many countries. For it has become evident that a lesson learned by a peasant farmer on one crop is soon adapted by him to other crops.

The Mexican breeding program dates back to 1944, and I am both fortunate and proud to have had the opportunity of being associated with it from its initiation. It has been a pleasure and a stimulating experience to see the benefits that have been derived directly and indirectly from it, first by Mexico, and subsequently, by many other Latin American countries and more recently by an increasing number of Asian and African nations .

1.- PROGRAM PHILOSOPHY:

The breeding program is utilitarian in concept and is crop production orientated. Its staff and trainees, however, can talk the language of the most sophisticated wheat researchers and on the basis of the principle involved agree or disagree with these specialists. They are not hide-bound traditionalists.

The program is based on the concept that varietal improvement is only one factor in crop production. Varieties can be a brake holding back progress, or on the contrary a truly outstanding improved variety can be a catalyst for tremendous change if its potential is properly exploited. We fundamentally believe, and have much evidence to support this statement, that an outstanding new improved variety can be used as the opening shot to trigger off a technical revolution in a stagnant agriculture. To exploit its potential we believe in using an integrated package approach attacking all production factors. Improved seed alone is of little value. We do not, however, accept Dr. Lester Brown's negative concept of "yield take-off". We believe instead in a "yield kick-off" knowing from experience that to acheve the production target it will be a bitter fight every step of the way with government policy makers, bureaucrats, scientists and peasant farmers. We believe that there must be a yield break-through based on biological and psuchological factors, before you can engulf and modernize the enemy - an archaic, stagnant agriculture - by economic planning and manipulation. Change must be made first in the technical factors.

2.- PROGRAM ATTITUDE AND RHYTHM:

The Mexican program has been one of "doing" rather than "theorizing", although it is not opposed to a proper blend of the latter with the former. As "doers" we have never been clock-watchers. We have been coffee drinkers but not advocators or admirers of the international fad of coffee breaks.

We insist on a team approach to wheat breeding. We are not separationists, segregationists, or fragmentationists. We believe that more is accomplished, and that a far superior job of training of young scientists is achieved, when breeders, geneticists, cytologists, pathologists and cereal chemists function as a closely knit team. Even further, we insist that both our staff and trainees learn as much as possible about agronomic research, soils research, and moisture utilization (including irrigation) as they influence wheat production. By so doing the young scientists become better wheat breeders, geneticists, cytologists, plant pathologists, and cereal chemists. Each is thereby in a better position to orient his own research projects as indicated by the advances in other aspects of the general production pattern.

The Mexican program has been time conscious and impatient in its approach to varietal development. It pioneered (23 years ago) the technique of growing two field generations of spring wheat breeding materials per year. This is accomplished by shifting the nursery sites to different latitudes and elevations to find suitable climatic conditions at different times of the year to make the two generations biologically possible. This practice has spread to all closely affiliated programs i.e. Colombia, Chile, Peru, Ecuador, Argentina, India and Pakistan. This practice during the past 11 years, has been adapted by the U.S.A. and Canada who now grow their offseason winter nursery in Sonora, Mexico. This extra cycle per year has also facilitated the rapid seed multiplication and distribution of new varieties.

ORDER OF PRIORITIES IN ORGANIZING A WHEAT BREEDING PROGRAM:

A productive wheat breeding program is dynamic. Conservativism in the choice of progenitors, in the formation of new gene pools and in selecting or discarding in segregating material, leads to stagnation in varietal development.

The success of a breeding program depends upon establishing a sound program of priorities for varietal improvement. It is impossible to simultaneously make improvements in a poor local variety for grain yield, rust resistance, agronomic type, breadth of adaptation and many of the grain quality factors required in a modern variety. The more defects present in the variety chosen as a basic progenator for improvement, the more cycles of breeding will be required to produce the sophisticated variety that is needed for an advanced agriculture. The most limitant defects must be given top priority for corrections in the early cycles of breeding.

1.- BREEDING FOR YIELD:

The primary consideration in the Mexican breeding program has been to increase the grain yield per hectare. This must also become the first consideration in developing breeding programs in all food deficit countries. The Mexican program is not interested in developing new varieties that are

10 or 20 percent better than the commercial varieties when grown at starvation levels of productivity. A new variety that yields 20 percent more than the old variety at the 500 kilo yield base only prolongs the agony of starvation and contributes little to increasing food production. We are instead interested in developing improved varieties which have the genetic potential to effectively utilize an improved environment and under these conditions produce much higher grain yields. This requires that the breeder possess foresight and subjects his segregating populations under this better management and conducts his yield tests under conditions that are likely to become commercially feasible 5 to 10 years in the future. We fertilized our nursery plots when no fertilizer was used on farms in order to develop varieties that would respond to the use of fertilizer. Today when the best Mexican wheat farmers are applying from 120 to 140 kilos of nitrogen per hectare, we apply 200 kilos. Fifteen years ago we applied 4 irrigations to our breeding nurseries; now we apply six, whereas the farmers applied 2 and 4 irrigations, respectively, during the same period. These exaggerated conditions in our breeding nurseries assist in identifying lines which will respond to further improvements in management. The variety Sonora 64, developed in Mexico, illustrates this principle. Under Indian conditions where it is now being grown extensively, it will yield about 1,500 kilos per hectare in the absence of fertilization, whereas the Indian variety C 306 under the same conditions yields slightly more, about 1,700 kilos. When 160 kilos of nitrogen are applied, however, Sonora yields 6,800 kilos per hectare (102 bushels per acre) whereas C 306 yields 4,000 kilos per hectare. The world food problem can not be solved by breeding new varieties adapted only to a low level of productivity. The levels of productivity must be improved or the world will starve. We need new varieties with built

in genetic responsiveness that will exploit these improved environments effectively.

Most breeding programs concentrate on further improvement of the best currently available commercial varieties. This may be a good general practice but flexibility in approach must be excercised for some varieties which are themselves high yielding yet very poor genetic combiners. The value of varieties as parents can only be established by crossing it to a considerable number of superior varieties and lines and observing the progeny.

There is no single guideline that can be used to determine what crosses should be made in order to produce a gene pool capable of increasing grain yields. Some breeders feel that all potential progenitors should be carefully classified on a graded scale for the various yield components, i.e. the number of tillers per plant (or spikes per square meter) number of fertile spikelets per spike and the size and weight of individual kernels. According to this school only those crosses should be made which will bring together parents that complement each other in the various yield components. There is a growing number of breeders who feed vast masses of data into modern computers and hope to come up with the data which indicate what crosses should be made. The results to date have not been impressive.

The most successful wheat breeders are half scientist half artist. There are a few points which characterize their programs. Invariably they know the strengths and shortcomings of the principal commercial varieties, progenitors, and most promising advanced generation lines in their program. They are continiously introducing new parental material into their breeding program from other programs with which they maintain contact. Much of their success results from effectively making and sampling many new gene pools. They make large numbers of new crosses searching for good new combinations. They grow large populations of plants in the early segregating generations, especially the F_2 and F_3. They use many severe simple screening tests to evaluate such characteristics as tillering, the number of fertile florets per spikelets, disease resistance under epidemic conditions, agronomic characteristics such as maturity, plant height, resistance to lodging, resistance to shattering, grain siz e, shape and texture and simple tests of gluten quality. This combination of considerations assist the creative wheat breeder in identifying the outstanding crosses in the F_2 and F3 generation. Many of the crosses are eliminated entirely in these two segregating generations. The dynamic and highly successful breeding program is characterized by the ruthless but judicious discarding of all inferior combinations, and restricting only selections to the truly outstanding combinations.

The Mexican program makes many hundreds of new crosses each year and grows roughly 500 to 700 F_2 populations each cycle (twice yearly), at well chosen sites where a good expression is obtained of as many of the aforementioned characteristics as is possible. Aggressive field selection is practiced followed by severe selection in the laboratory for grain and gluten quality. The laboratory tests eliminate between 40 to 60 percent of the plants actually harvested.

The Mexican program makes many double crosses between superior F_1 crosses, to incorporate greater genetic variability into the program. It also makes a limited number of crosses each generation between the vast promising advanced lines, the best commercial varieties and the outstanding F_3 plants, which showed unusual promise in both field and laboratory evaluations as F_2 plants. This approach helps to inject great genetic variability into the program.

Each generation outstanding new promising lines also are received from the affiliated programs, i.e. Pakistan, India, Chile, Argentina, Ecuador, Colombia, U. S. A. and Canada. Outstanding lines from these new introductions are also crossed into the Mexican material. This constant incorporation of new material into the gene pools as described above keeps the breeding program dynamic and prevents stagnation.

The new gene pools developed by the Mexican programs are generally grown at three locations in Mexico and 15 to 20 locations in 10 other countries. The International Center in Mexico is thus playing a rapidly expanding and increasingly important role in feeding large numbers of new gene pools into wheat breeding programs in many parts of the world.

Another key to the success of dynamic breeding programs is the development of an efficient system for handling the large numbers of selections that are made with a minimum cost and a minimum number of errors. Such a system has been devised and has been taught to more than 60 young wheat scientists who have studied in Mexico during the past six years. These young scientists now back in their own countries, grow and select in the new gene pools that are sent to them each year from Mexico.

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