# CROP BREEDING

## Exploiting Genes for Food and Feed

PROFESSOR DR. GHIZAN SALEH

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# Contents

## ABSTRACT

Crop breeding has contributed significantly to the increase in world food and feed productivity. It has evolved from selection efforts for better plants during early human domestication of crops, to classical breeding, and presently to modern marker assisted breeding. Crop breeding is conducted on the principle of Mendelian genetics, exploiting genes and genetic variations for traits to be improved through manipulation of the available genetic resources or introgression of genes from introduced materials. Significant impact of crop breeding has been seen in the development of food crop varieties including wheat, rice, maize and soybeans. The Green Revolution which was instrumented by Norman Borlaug, the Nobel Laureate for Agriculture, is a classic example of the meaningful contribution of crop breeding in alleviating famine and food shortages in the rapid population growth scenario. Through long years of systematic crop breeding efforts, significant achievements have been made in polyploid breeding, mutation breeding, hybrid breeding, molecular assisted breeding and breeding through genetic engineering. Hybrid breeding has revolutionised the breeding methods of maize, where single cross, double cross as well as three-way cross hybrids have been utilised in the industry, although single crosses are presently almost solely used for production. Food crop breeding efforts in Malaysia have seen the successful development of superior varieties of rice, maize, papaya, pineapple and banana, while breeding successes in oil palm and rubber have also been well realized. Maize breeding work conducted at Universiti Putra Malaysia has focused on grain maize for animal feed, as well as sweet corn for human consumption. The current grain maize breeding programme at UPM was initiated in 1987 with the acquisition of germplasm from foreign countries. These

germplasm materials, together with the locally available varieties, were subjected to a recurrent selection programme employing both half-sib and full-sib selection methods. Concurrently, inbred lines were developed from these populations through continuous self pollinations and tests of combining ability. Selected inbred lines were utilized in diallel crosses, and subsequently, single crosses, double crosses and three-way crosses were developed and then tested for performance in replicated trials. After repeated evaluation at various selected locations and large scale plantings, the $F_1$ hybrid variety *Putra J-58* was released in 1998, with high yield, uniformity and possessing high grain nutritional quality. The locally developed inbred lines were then further involved in crosses with introduced lines from Indonesia and acid soil tolerant lines from CIMMYT, in efforts to develop hybrids that are tolerant to acid soils which make up 72% of the arable lands in Malaysia. SSR molecular markers were also used to assist in the selection of suitable cross combinations, and promising hybrids are expected to be released in the near future. The present sweet corn breeding work at UPM was initiated in 1990, with the application of recurrent selection on the local varieties, Manis Madu and Bakti-1. This led to the development of improved populations which were subsequently utilized in crosses with the modern hybrid varieties introduced from other countries. Subsequently, more cycles of recurrent selection for fresh ear yield, ear length and eating quality were imposed. The resulting improved populations were then utilized in breeding programmes introgressing genes from Ethiopian synthetic varieties, leading to the development and release of the synthetic variety, *Putra GS-2002* in 2003, with superior fresh ear yield and taste quality. Along the way, inbred lines were developed from various local and imported genetic resources, for the purpose of hybrid variety development. Presently, these inbred lines are approaching complete homozygosity and awaiting combining ability analysis for production of hybrid varieties. Molecular assessment utilising SSR markers are also being used to predict performance of the inbred lines in hybrid combinations. As a design science, crop breeding is a long term effort, and therefore requires long term research funding and strategies to increase success in developing new varieties to meet the changing human needs and climatic conditions.

# INTRODUCTION

*"There are two key problems of feeding the world's people. The first is the complex task of producing sufficient quantities of the desired foods to satisfy needs in environmentally and economically sustainable ways. The second task, equally or even more daunting than the first, is to distribute food equitably. Here, poverty is the main impediment to equitable food distribution, which, in turn, is made more severe by rapid population growth".*

*- Norman Borlaug, Nobel Laureate for Agriculture*

Crop breeding is the science and art of changing and modifying the genetic make-up of crops for the benefit of mankind. It requires the combined knowledge of genetics, biology and mathematics. In practice, the application of this knowledge, coupled with the creativity of the researcher as the architect, produces new crop varieties.

Crop breeding has contributed immensely to the advancement of human civilization and increased agriculture productivity in the world, with new crop varieties continuously developed to fulfill the changing needs of humans and the climate, and to solve production problems whenever and wherever they exist, including the effort in finding solutions to poverty and famine. As the world population increases, the importance of crop breeding can only increase (Crosbie *et al.,* 2006).

Over time, varieties produced in certain specific environments need to be replenished with new ones, due to changing human preferences and environmental conditions. It is therefore highly necessary that breeding programmes are continuous to adapt to these changes. It is essential to breed new crops to ensure food security by producing new varieties that possess desirable attributes such as high-yield, resistance to pests and diseases, drought tolerance and adaptation to the growing conditions.

Breeding efforts have been based on the concept that any given phenotype performance (*P*) is the result of the summation of several factors, *viz.* contribution of the genotype (*G*), the environmental effect (*E*), the effect of interaction between the genotype and its environment (*GXE*), with some accumulated measurement of error (*e*). Crop breeders, regardless of the time period during which they exist, have designed various breeding methods to be better able to effect the control of genetic variation and manipulate the variation and analyze the changes made. This is so that improvements made on the phenotypic values of the new genotypes would closely imply the genetic changes made, particularly in enhancing the breeding values of the selected individuals that make up the improved populations established. Conventional breeding methods employ the application of theories on quantitative genetics and selection methods, including the use of parents for hybrid variety development. The search for genetic improvement has not changed but the choice of approach to estimate breeding values and to subsequently achieve genetic gains through selection has widened and will continue to do so, as seen today particularly with the advancements in molecular technology.

Crop breeding is now practiced worldwide at public and private institutions such as universities and research centres in a more organized and structured manner by professional plant breeders, although gardeners and farmers are also involved to some lesser extent for their own personal interest. The major steps in crop breeding activities include the creation of variation, selection, evaluation, release, multiplication and distribution of the new variety (Borojevic, 1990).

## HISTORY OF PLANT DOMESTICATION AND BREEDING

Breeding of plants has been practised since the time of early human civilization some 11,000 years ago, when humans started to domesticate plants (Smith, 1967). Human interference led to the domestication of wild plants, where plant breeding was practiced when humans selected the better plants as sources of seed planting materials for succeeding seasons. Domestication of plants is the artificial selection undertaken by humans to produce plants that are better performing and more desirable than the wild types. This effort contributed to their better survival in the environments and their continued existence, as compared to if they had been left to mercy of forces of natural selection in the wild. Although the term heritability had not been coined at that time, its concept had been understood and indirectly practiced, whereby good parents were thought to produce good progenies. As time passed, human beings were able to apply crop breeding in a more structured and scientific manner. The evolution of crop breeding has seen increased domestication of new plant species and their improvement through artificial selection and subsequent incorporation of other genes through hybridization and introgression of genes from various diverse genetic resources. Today, all our main food crops come from domesticated varieties, although not all domesticated plants used for food and agriculture today were domesticated in their centres of origin. The first attempt of deliberate plant breeding was believed to have been started by the ancient Chinese who tried to improve rice grown at that time. The first planned attempt to create new plants however was believed to have been the breeding of tulips and hyacinths in Holland (Smith, 1966).

Sex in plants was not discovered until 1676, when Millington noted that anthers functioned as male organs and Grew suggested the functions of ovules and pollen. Camerarius, in 1674, was the first to demonstrate sex in plants by being the first to suggest the idea of crossing to get new types and describing the sexual behavior of plants. Mather, in 1716, was however the first to have observed the effects of cross-pollination which he demonstrated in maize, while Fairchild, in 1719, was the first to successfully produce the first plant hybrid (Smith, 1966). Crop breeding principles were only established following the rediscovery of Mendel's Law of Genetics in 1900, following which deliberate breeding programmes were structured. In the early till mid 1900s various theories on population and quantitative genetics were established, including selection theories and methods. With better understanding of statistics, mating designs were later introduced into breeding programmes. It was only in the past 70 years that rigorous crop breeding efforts were undertaken, and since then a tremendous number of crop varieties have been continuously produced. The discovery of the DNA by Watson and Crick in 1953 led to a new dimension in the understanding of the role of genes and DNA as units of inheritance. The conventional breeding methods were subsequently aided by biotechnology tools in the 1990s, when genetic engineering and marker assisted breeding were introduced and which have progressed at a dramatic rate until today.

## GENETIC VARIATION

Every living organism is unique by itself. Organisms differ from each other through the variations they carry. These variations are controlled by the units of heredity called genes. Genes carry the fingerprints of genetic variations and are located on chromosomes. In plants, genetic variation is important in maintaining biodiversity. .Figure 1 illustrates genetic variation revealed by diverse maize varieties.

Crop breeding is dependent upon genetic variability within the crop species. The breeder cannot improve the traits of interest in crop plants without availability of germplasm resources of the genes which need to be incorporated into an adapted cultivar. Before initiating any breeding programme, the breeder, after defining the objectives of the breeding programme, needs to survey the range of genetic variability available to meet those objectives (Poehlman and Quick, 1983). Breeders continually look for genetic variability in traits that give high yield and high quality.

**Figure 1** Picture showing genetic diversity expressed on maize ears

## PRINCIPLES OF CROP BREEDING

Crop breeding applies the Law of Mendelian Genetics laid by Gregor Mendel, the Austrian monk (Figure 2), in 1865, which was rediscovered in 1900. The two governing basic principles are the Principle of Segregation and the Principle of Independent Assortment, which explain the control of variation expressed by seven qualitative traits in peas. Using the principle, scientists were able to explain the genetic basis of variation, which then led to the establishment of selection theories for development of new crop varieties. This principle also led to the establishment of population and quantitative genetic theories. These traits were transmitted from generation to generation in a highly repetitive manner.

Mendel established parents that were true breeding for differing expressions of each character and developed crosses between parents carrying the opposite extremes to form the $F_1$ generation and subsequently plants of the $F_2$ generation were established from self-pollinations of the $F_1$ plants (Welsh, 1981). He explained the segregation of the $F_2$ plants for the traits involving one gene pair and two gene pairs by monohybrid and dihybrid segregations, respectively. For monohybrid segregation, he used the term 'dominant' to describe the expression of the character that appeared in the $F_1$ generation and 'recessive' for the expression that disappeared in the $F_1$ but reappeared in the $F_2$, where the dominant and recessive individuals appeared in a 3 : 1 ratio (Figure 3). For dihybrid segregation, in the $F_2$, all character combinations very closely approached the ratio of 9 double dominant : 3 recessive, dominant : 3 dominant, recessive : 1 double recessive (Figure 4).

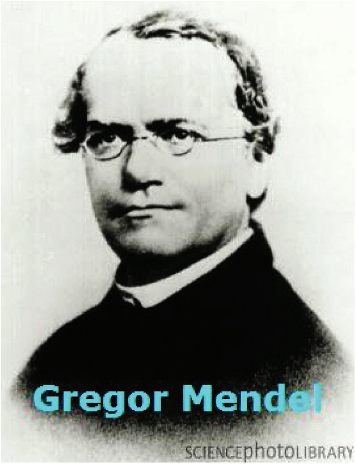



**Figure 2** Picture of Gregor Mendel, founder of Law of Genetics
(Source: Science Photo Library)

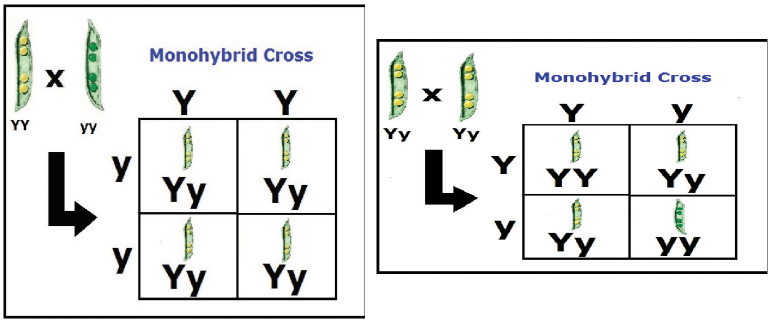



**Figure 3** Diagram illustrating monohybrid segregations in peas

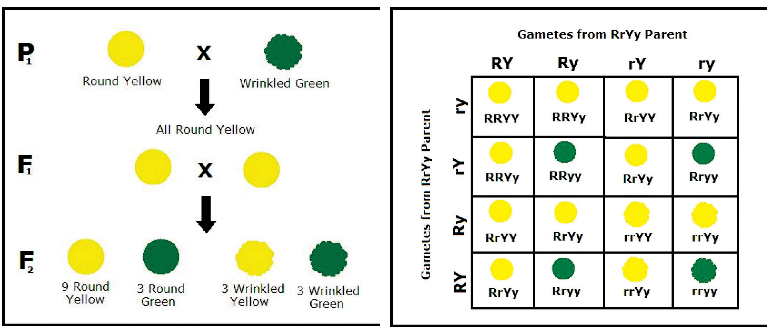



**Figure 4** Diagram illustrating dihybrid segregation in peas

## CONTRIBUTION OF CROP BREEDING TO FOOD PRODUCTION

Strong commitments to crop breeding efforts around the world, particularly in the past 50 over years, have made significant contributions to the development of agriculture (Baenziger *et al.*, 2006). Among the greatest successes of crop breeders include the Green Revolution (Everson and Gollin, 2003) for wheat ( *Triticum aestivum* L.) and rice (*Oryza sativa* L.) and the worldwide acceptance of the $F_1$ hybrid varieties in maize (*Zea mays* L.). These successes are in parallel with successes and developments in other areas of agriculture science including fertilizer technology, plant protection, field mechanization and plant physiology. When humans become more concerned about the quality of the foods they consume, collaborations from the biochemists and the microbiologists become more obvious and important. Further, as aspects of sustainable agriculture become more evident, as in the past 20 years or so, close collaboration with environmental managers is increasingly important. In the 21st century, greater collaboration between the breeders and the molecular biologists has been realized, to ensure appropriate applications of biotechnology tools in crop breeding.

## FOOD PRODUCTION VERSUS POPULATION GROWTH

Food production and productivity has long been a primary concern of humans. In 1798, Thomas Robert Malthus predicted that "the world population will one day suffer hunger, and famine will take its toll unless the population is checked by war or disaster", because human population increases at a geometric rate, while food production only increases at arithmetic rate. The occurrence of his expectation has however been delayed temporarily, due to human's efficiency and creativity in producing food, through the extensive cultivation of new lands and the use of modern agricultural technology in production, more than he had ever anticipated, although it must be acknowledged that poverty and levels of hunger have not been eliminated in many underdeveloped countries in the world. Undoubtedly, among the main contributors to the success of agriculture development in the world, at least till the present time, are the breeders who have creatively produced new crop cultivars, to adapt to various agricultural atmospheres and practices all around the world. The new high yielding wheat varieties were found to be more responsive to nitrogen fertilization compared to the native wheat varieties (Poehlman and Quick, 1983), as was also true for the new rice and maize varieties.

## THE GREEN REVOLUTION

Norman Borlaug, the only Nobel Peace Prize winner for agriculture (received in 1970) highlighted the prominent impact of scientific crop breeding in the 1960s when he used new semi-dwarf wheat varieties that had high yield potential and were responsive to inputs such as fertilizer and irrigation, to help reduce the effects of famine in the Third World. Prior to that, efforts to increase the productivity of existing local varieties had not been successful, as application of too much fertilizer had caused plants to lodge. After years of hard work, Borlaug crossed the local wheat with the Japanese dwarf varieties to produce varieties which could productively utilize greater amounts of fertilizer. The resulting wheat varieties were credited with alleviating the threat of mass starvation that faced the developing world then, particularly in India, Mexico and Pakistan. Meanwhile, scientists extended the principles of crop breeding to other staple crops, such as rice, which became important milestones of the Green Revolution. With new technologies, the science of plant breeding is changing rapidly. The genetic improvement of food crops needs to continue at a pace sufficient to meet the needs of the 8.3 billion world population projected in 2025, and Borlaug believes that both conventional breeding and biotechnology methodologies will be needed (Borlaug, 1999).

## SPECIALISED CROP BREEDING

Besides the successes of the Green Revolution, significant achievements have been carved by breeders as landmark achievements in crop breeding in the world, some of the specialized ones are mentioned below.

## POLYPLOID BREEDING

The Polyploid plant species is one which contains more than two sets of chromosomes in its genome. Polyploidisation in plants occurs naturally in many crop species, mostly those favoured by human beings. Among others, examples of crop plants with varieties produced through natural polyploidation are bananas (triploid), sugarcane (whole range of ploidy levels), wheat (hexaploid), soybeans (tetraploid), and the brassicas (tetraploid). Deliberately induced polyploidisation in crops has been capitalized by human beings to produce more favoured varieties (Peloquin, 1981). This could be done through sexual diplodisation, as in potato through the 2n gametes, or double haploids from anther culture, as in tobacco, or crossing among ploidy levels to obtain intermediate ploidy level, as in watermelon. Polyploids were also created through somatic diploidisation by chromosome doubling using colchicine treatment. Polyploids have the advantages of being larger in size (as in strawberries), or being seedless (as in triploid bananas), or producing progenies that allow fertile crosses which would otherwise be sterile (as in potato).

## MUTATION BREEDING

Mutation breeding in crop plants is chance breeding work. For sexually reproduced crops, success is better for self-pollinated crops than the cross pollinated ones, because self-pollinated crops in their drive towards homozygosity, eliminate rapidly most alleles that do not have high adaptive value (Sigurbjornsson and Micke, 1974). In cross pollinated crops, the random mating system maintains the heterozygosity in the population, resulting in more genetic variability. Mutation breeding work in asexually propagated crops is normally done to produce mutants particularly on fruit and ornamental crops. Useful mutations are usually those from the wild types to the recessive forms. Gustafsson (1969) reported that mutation breeding research was initiated in the early 1900s. Induced mutations can be generated with two principal types of treatments, energy and chemical. The most common mutagens under the category of energy are X-rays, gamma rays, beta rays, slow neutrons, alpha particles and ultra violet light, where X-rays are the most common. The chemical group includes methanesulfonate, ethyleneimine and others. The ethyl form of methanessulfonate (EMS) has been most frequently used.

## HYBRID BREEDING

Hybrid cultivars are derived by mating of unlike genotypes. Hybrid breeding has revolutionized the use of crop varieties from the use of the traditional pure line varieties in the naturally self-pollinated crops and the open-pollinated composites in the cross-pollinated crops to the use of hybrid varieties. The use of hybrid varieties capitalizes on the phenomenon of heterosis or hybrid vigour, as a manifestation of the $F_1$ hybrid progenies are able to perform better than the parents. Hybrid vigour, or heterosis refers to the increase in size or rate of growth of offsprings over the parents. For example, hybrid vigour in crop plants can be manifested as increase in grain yield, dry matter accumulation, or reduction in the number of days to flowering or maturity. Hybrid varieties are not only high yielding but also possess high eating quality and produce uniform plants. Heterosis in plants has been used in large scale production in the world for the past 85 years, as selected and reproduced hybrid cultivars. The most exploited grain crop used for production of hybrid cultivars in the industrialized world is maize. Other crops include sorghum, sunflower and canola. Many vegetable and flower crop varieties produced worldwide now are mainly hybrid varieties.

These include sweet corn, cucumber, carrot, beet and okra, to name a few. All these hybrids are also grown in the developing world. The phenomenon of male sterility in crop have been capitalized for hybrid seed production, which include genic male sterility as in tomato and lima beans, and cytoplasmic genic male sterility as in onion, carrot and rice. Hybrid rice is now grown extensively in China, accounting for more than half the total rice growing area in the country, while increasingly important in India (Varmani, 1999). A yield advantage of 20% over the self-pollinated varieties was reported (Yuan, 1992).

Development and use of hybrid seeds can enhance crop yields and performance. The hybrid seed industry in a multi billion dollar industry and is the backbone of the agriculture production system in developed countries, as high quality seeds that give high return is a prerequisite to a profitable agriculture production system (Figure 5).

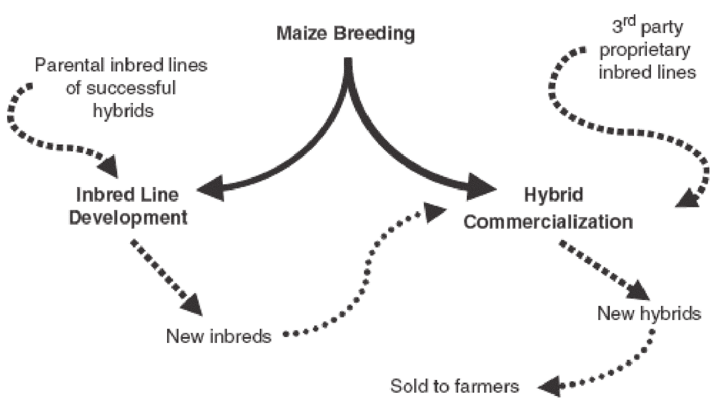



**Figure 5** Overview of a modern commercial maize hybrid seed production. (From: Lee and Tollenaar, 2007)

## Development and Selection of Inbred Lines as Parents of Hybrids

Inbred lines are parents of the hybrid varieties. Crosses among the inbred lines are made to produce the $F_1$ hybrid seeds which are the planting materials for the hybrid varieties. These inbred lines are developed extensively and intensively in breeding programmes through repeated cycles of self pollination. At each cycle of selfing, selection for performance per se and for combining ability are imposed on the inbred lines, while at the later stages, the most promising ones are short-listed as potential parents of promising hybrid varieties. The combination of crosses between two or more inbred lines resulted in the formation of the $F_1$ hybrid.

Combining ability is defined as the ability to produce desirable progenies when inbred lines are entered into a set of crosses. General combining ability (GCA) is expressed in the progenies of an inbred line crossed with many genotypes or genotype with a wide genetic base, and is primarily the result of additive gene action (Welsh, 1981). Specific combining ability (SCA) is the ability of the inbred line to produce a high proportion of productive progenies when combined with other inbred lines or other narrow genetic base stocks, and is considered to include both additive and non-additive types of gene action. SCA is very important in hybrid breeding since financial success depends on identifying the few very superior combinations. SCA estimates are obtained either by crossing all inbreds in a diallel manner or by developing some prediction system to allow estimation without having to actually make all the crosses.

## Categories of Hybrid Varieties

As many inbred lines are available for testing of combining ability, various kinds of hybrid crosses are possible, depending of the nature of hybrids preferred. Hybrid varieties were first introduced in maize. A single cross hybrid is produced as a result of a cross between two inbred lines (first introduced by Shull in 1908), a double cross is a product of a cross between two single crosses (first introduced by Jones in 1918), while a three-way cross is the product of a cross between a single cross and another inbred line. Several methods of estimation of hybrid performance have been summarized by Sprague and Eberhart (1977).

Hybrid maize was first introduced in agricultural production around 1930 and was used in 100% of USA maize plantings by around 1965 (USDA NASS, Agricultural Statistics). When it was first used, the varieties were mainly double crossed hybrids, because seed production for single cross hybrids was costly due to the low productivity of the inbred lines, while double cross hybrids were produced on $F_1$ plants which were more vigorous. At the same time, double crosses were more heterogeneous and therefore more adaptable to various environmental conditions (Duvick, 1999). However, as time progressed, the use of double cross hybrids has been replaced by single crosses. This is due to the substantial improvements in the quality and size of plants of the inbred lines. Therefore, the cost of production of single-cross seeds of inbred lines is no longer a hinderance to commercial seed production, although in developing countries, some three-way crosses are still used for production, as seeds of three-way crosses are produced on $F_1$ plants as the female parent while the pollen parent is the third inbred line. Todate, all maize fields in the US are grown fully with single cross hybrid varieties (Figure 6).

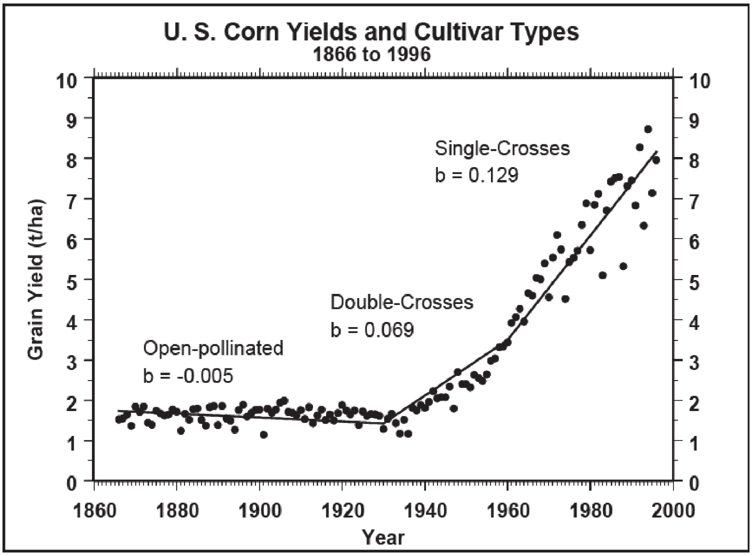



**Figure 6** Average U.S. maize grain yields as affected by the category of hybrid used. Source: Lamkey and Edwards, 1999 (Data from USDA, National Agricultural Statistics Service)

## MARKER ASSISTED BREEDING

After the rediscovery of the Mendelian principles progress in crop breeding has been entirely based on the availability of genetic variation. The task of the plant breeders is to exploit this genetic variability. In conventional breeding schemes, the genetic variation of breeding populations is estimated (and selected) by measuring the phenotypic performance alone. Even though this process has proven to be effective, it is commonly accepted that selection directly at the genotype level would greatly increase the efficiency of breeding efforts. This is due to the environmental influence on the phenotypic measurements, resulting in a biased measure of the true genetic potential of an individual. Prerequisite for the use of selection based on genotype is that the relative value of the different genotypes is well known and predictable. After the discovery of the DNA molecule as the carrier of genetic and heritable information, by Watson and Crick in 1953, the possibility of factually describing the genotype of individuals, and thus using this information through selection, became feasible (Sorensen *et al.,* 2007). The first molecular technique to address this challenge in plants, the RFLP technique, was reviewed (Tanksley *et al.,* 1989). However it was only after the development of PCR based molecular marker technologies such as RAPD (Williams *et al.,* 1990) and AFLP (Vos *et al.,* 1995), that the technologies could be applied at an acceptable cost for marker assisted breeding. Presently, other DNA markers commonly available include SSR, ITS and RAMs, just to name a few. The most widespread use of marker assisted selection todate is to assist in backcrossing of major genes into already proven, elite cultivars. Markers can aid selection of target alleles that are not easily assayed in individual plants, minimize linkage drag around the target gene, and reduce the number of generations required to recover a very high percentage of the recurrent parent genetic background (Holland, 2004).

## GENETIC ENGINEERING

Crop breeding through genetic engineering is also seen as a new non-conventional way of obtaining variations in plants. Through production of transgenics as the new genotypes, new gene or genes could be introduced into a new crop background, with the objective of tackling a specific defect of the particular genotype. New cultivars of maize, soybeans, cotton, etc. have been developed, carrying additional genes conditioning traits as diverse as resistance to insects, viruses and herbicides. These cultivars have been readily adopted by farmers worldwide. However, production of these genetically modified organisms (GMO) has to be handled with care, following various protocols of biosafety regulations being put in place (Gepts, 2002).

## CROP BREEDING SUCCESSES IN MALAYSIA

Malaysia has been highly successful in breeding works on industrial crops, particularly oil palm and rubber. We have been the world leader on genetic improvements involving hybrid (oil palm) and clonal (rubber) variety development of these crops. Oil palm breeding research programmes are mainly handled by MPOB, although FELDA and several plantation companies, particularly Sime Darby, IOI Group and the United Plantations are also devoting great efforts to breeding. Rubber breeding is however mainly confined to the efforts of the Malaysia Rubber Board (LGM).

By far, the most successful food crop breeding programme in Malaysia is rice breeding. Breeding work undertaken by MARDI has continuously produced superior varieties, whereby older varieties have been replaced by the new ones. Breeding has contributed in part to the increase in rice productivity in the country (Figure 7), besides the effects of production technology acquisition, although the rice growing area has not increased (Figure 8). The variety MR220 has gained popularity, where in the year 2007 this variety occupied 38% of the rice fields, compared to just 14.8% in 2004 when it was first introduced for commercial planting (Figure 9). The rice breeding programmes not only focus on improvement of yield, but also on quality traits, like aroma and nutritional status. Recently, breeding efforts to produce varieties that are adaptable to low water input has been given high priority, apart from the early efforts in developing hybrid rice.

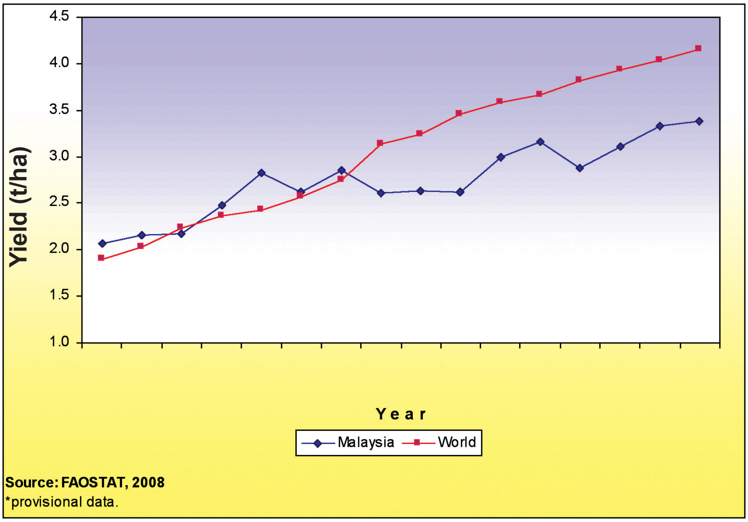



**Figure 7** Rice yield in Malaysia and the world

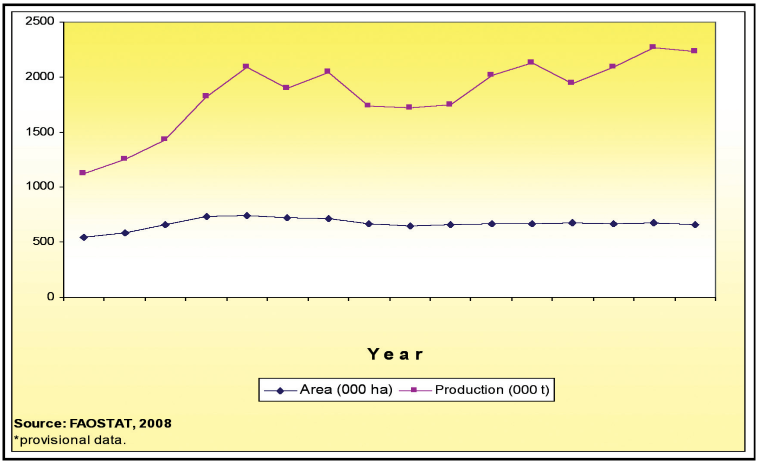



**Figure 8** Rice growing areas and total production in Malaysia

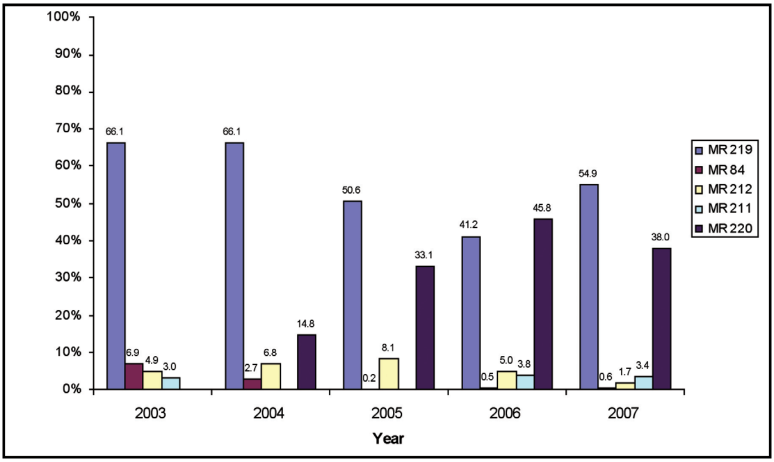



**Figure 9** Utilisation of rice varieties in Peninsula Malaysia, 2003-2007 (Source: DOA, Malaysia, 2008)

Malaysia has also been successful in breeding grain maize and sweet corn varieties, through the production of improved composite varieties and intensive efforts to develop inbred lines for hybrid variety production. These activities were started in MARDI and UPM, but off late, only UPM is still placing emphasis on both grain maize and sweet corn breeding.

The country has also been successful in fruit breeding, particularly with pineapple, papaya and banana. Pineapple and papaya breeding have been much associated with MARDI, and banana breeding with the private plantation company, United Plantations. Fruit varieties from these fruit breeding programmes are in the export market, such as the Josapine pineapple, the Exotica papaya and the Intan banana varieties.

Successes in genetic improvement of other food crops are quite marginal, and mostly limited to adaptation of varieties imported from other countries, to which not much genetic alterations or modifications have been made.

## PLANT BREEDERS' RIGHTS AND VARIETY PROTECTION

Until the 1970s, biodiversity was considered to be part of the "common heritage of humankind." Biological resources were treated as belonging to the public domain and not owned by any individual, group, or state. For long, common heritage has been implicitly used as the principle governing the diffusion of crop and animal genetic resources from the centers of domestication, their exchange among farmers, and their introduction into new continents (Gepts, 2004).

Under the new rules of the General Agreement on Tariffs and Trade (GATT), which took effect on January 1, 1995, all member countries must bring their national IPR laws into conformity with certain provisions of the new agreement on Trade-Related Intellectual Property Rights (TRIPs). This agreement obliges member governments to provide for "the protection of plant varieties either by patents or by an effective sui generis system or by any combination thereof as provided by the UPOV Convention " (sui generis is a Latin phrase meaning "of their own kind.").

The Malaysian Bill for Protection of New Plant Varieties Act, 2004 (PNPVA, 2004) was initially introduced in the Malaysian Parliament in September 2003. It was passed on 25th June 2004, but was only enforced on 1st. January 2007. Prior to PNPVA 2004, there was no formal protection for the rights of crop breeders, though an informal registration of new fruit varieties has been available for certification purposes Although patent law is there to protect registered patented inventions, plant varieties had been excluded from this protection. (Nazura *et al.,* 2007). The issue of lack of protection seems to be remedied by the PNPVA as it allows a breeder of plant variety to apply for grant of protection of plant variety. The only uncertain issue relating to this is whether or not the genetically modified plant varieties can be registered under patent or plant variety protection systems due to the controversies surrounding them.

## MAIZE BOTANY AND HISTORY OF CULTIVATION

Maize (*Zea mays* L.) belongs to the family Poaceae (grass family). The name *Zea (*zeia) was derived from an old Greek name for a food grass. The origin of maize is hypothesised to be derived from teosinte (*Z. mexicana* or *Zea mays* subsp. *parviglumis*), an ancient wild grass growing in Mexico and Guatemala. However, whether its origin is from Asia or the Andean highlands is still uncertain (Galinat, 1988). First indications of domestication of maize originate from around 7.500 years ago. Domestication resulted in the improvement of the maize's agronomical properties, such as increased vigour, yield and uniformity, however, it also caused loss of its ability to survive in the wild without human intervention in planting and harvesting. The chromosomes number of *Zea mays* is 2n=20.

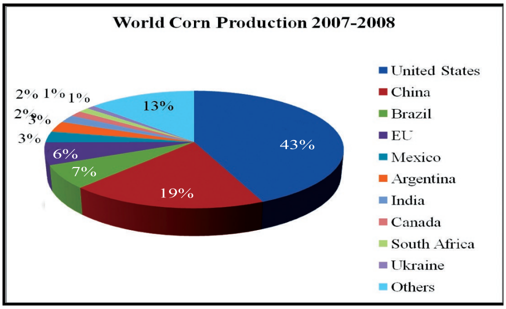
## CLASSIFICATION OF MAIZE

Maize is classified based on the endosperm character of the grain. Kuleshov (1933) grouped races of maize into the following categories: Flint maize (*Zea mays* cover. *vulgaris* Koern) – mainly used for human food in the form of starch and syrup; Dent maize (*Zea mays* cover. *dentiformis* Koern) – mainly used as animal feed and industrial manufacturing of starch, syrup, oil and alcohol; Floury maize (*Zea mays* cover. *amylacea* Koern) – mainly used as starch for human food; Sweet corn (*Zea mays* cover. *saccharata* Koern) – mainly used when tender green for direct fresh comsumption, canned or frozen; and Pop corn (*Zea mays* cover. *microsperma* Koern) – mainly consumed as popular confection when roasted.

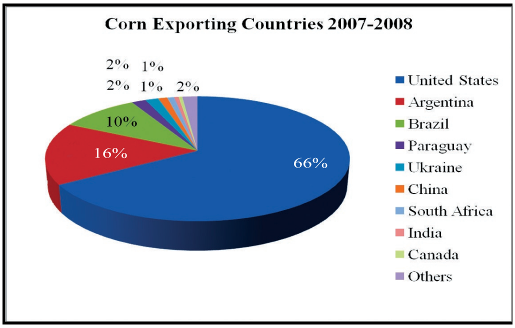
## MAIZE PRODUCTION AND UTILISATION

Maize is the world's third leading cereal crop, behind wheat and rice, and is grown in over 25 countries worldwide. The majority of grain and forage derived from maize is used as animal feed, however maize also has a long history of safe use as food for human consumption. The U.S. is the main producer of grain maize in the world, followed by China and Brazil (Figure 10a). The top exporter is also the US, followed by Argentina and Brazil (Figure 10b). The main uses of grain maize in the world are for animal feed, corn flour, corn syrup, corn oil and most recently for the manufacture of ethanol and biofuel. Due to constraints on local grain maize production, Malaysia remains one of the chief importers of grain maize as animal feed (Figure 10c).

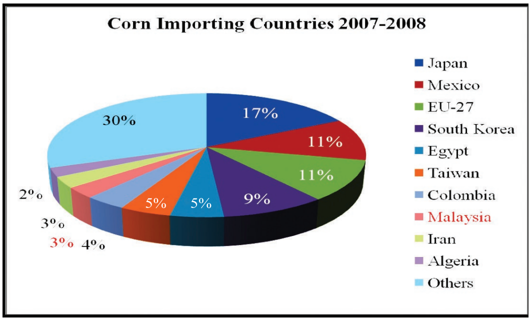
The local poultry and swine feed industries are greatly dependent on imported maize grains for its feed formulation, with an import value amounting to about RM1.2 billion (Figure 11). The maize growing fields in the country are cultivated mainly with sweet corn, while just a small concentration of grain maize is grown in the Sabah state, giving a total production area of about 26,000 hectares (Figure 12). The grain maize cultivation is negligible because of its unfavourable economic feasibility. Growth of Sweet corn is mainly concentrated in the states of Perak, Kelantan, Terengganu and Selangor. However, sweet corn cultivation in Malaysia is almost completely dependent on high quality imported hybrid seeds as planting materials. The local open-pollinated composite varieties, although well adapted to the growing conditions in the country, are less preferred because of their inferior taste and sweetness. It is therefore highly necessary to produce our local sweet corn hybrid varieties to decrease the dependency on seed importation.




(a)




(b)




(c)

**Figure 10** (a) World maize production; (b) World maize exporters; (c) World maize importers, for 2007-2008 production year

Source: USDA/Foreign Agriculture Service, Grain: World Markets and Trade, 2009.

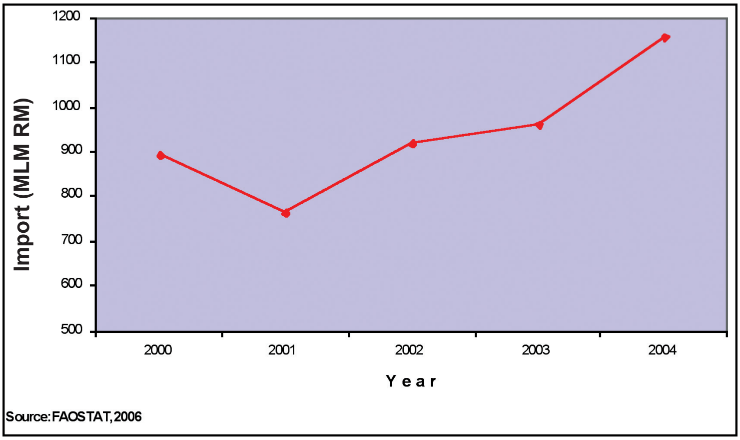



**Figure 11** Annual import values of maize grains in Malaysia

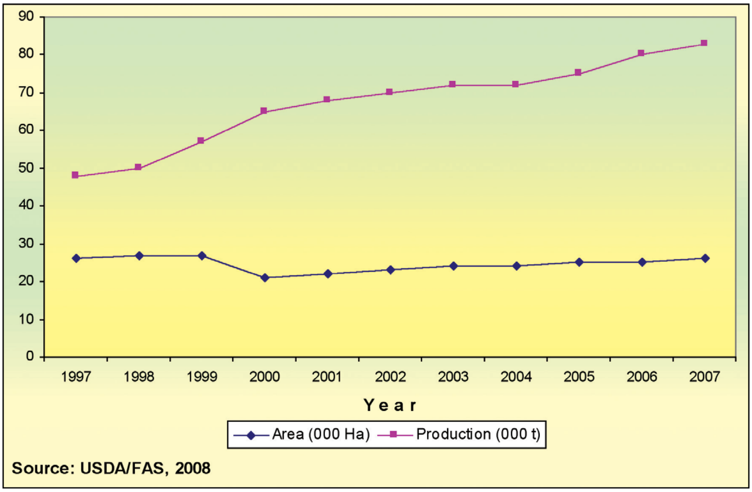



**Figure 12** Annual grain maize and sweet corn growing area and production in Malaysia

# MAIZE BREEDING AT UNIVERSITI PUTRA MALAYSIA

## Grain Maize Breeding

My research efforts on maize breeding started way back in 1987, after returning from the National Maize Workshop in Penang in 1987, during which a resolution was passed, emphasizing that grain maize production for animal feed in this country should be greatly enhanced due to the high dependency on imported maize grains to support the local animal feed industry. This triggered my persistence to continue and strengthen my research on maize breeding, particularly in efforts to produce high yielding superior maize genotypes for local production. The overall road map illustrating grain maize breeding programmes conducted at UPM until today is as illustrated in Figure 13.

### *Recurrent Selection in Grain Maize*

The backbone of UPM's maize breeding programme was recurrent selection for population improvement. It started with recurrent selection conducted to improve the traditional varieties available at that time, i.e. Suwan and Metro. The recurrent selection method employed was half-sib recurrent selection. This led to a steady increase in the yield and productivity of both the Suwan and Metro varieties (Saleh *et al.,* 1988). These recurrent selection efforts resulted in the development of improved populations of these varieties which later became source populations for the extraction of inbred lines.

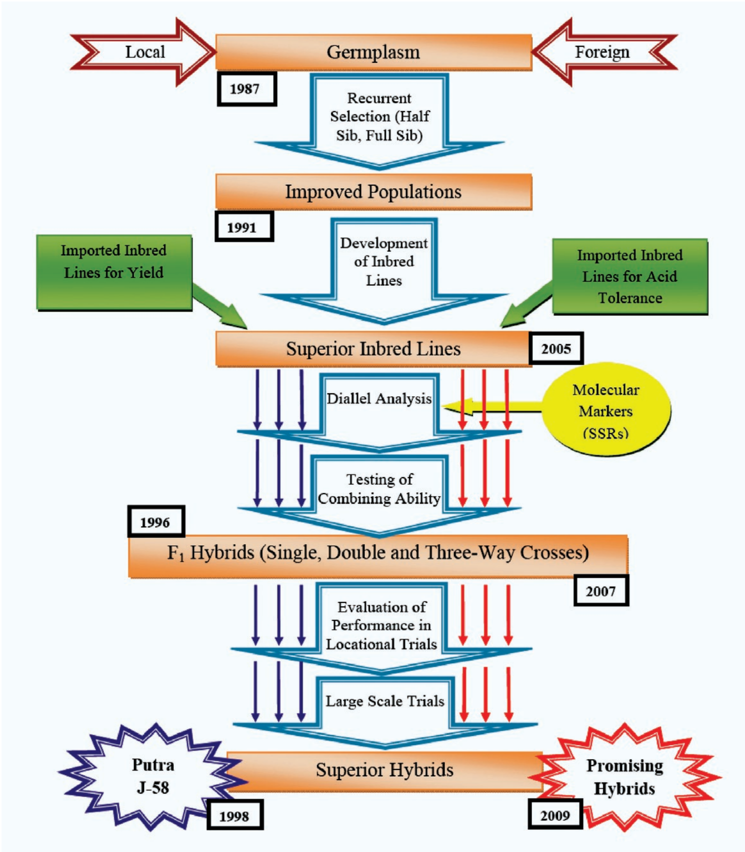



**Figure 13** Road map of grain maize breeding programme at UPM

## *Development of Grain Maize Hybrids for Yield and Quality*

Hybrid breeding starts with the development of inbred lines which serve as the parents to the hybrids. Using Improved Suwan and Improved Metro populations as source populations, inbred line development was started, which was later extended to other source populations obtained from the Southeast Asian region, namely the SMC317, SMC305 and TWC populations. The inbred development programme conducted was as illustrated in Figure 14. Seven generations of self-pollination, each alternately followed by a generation of selection, were employed to the populations. At the early generations of selfing the potential inbred lines were tested and selected for general combining ability (GCA) followed by testing and selection for specific combining ability at the advanced S6 and S7 generations (Table 1). Finally, at homozygosity, the inbred lines were entered into a diallel analysis, and again evaluated for GCA and SCA (Sujiprihati *et al.,* 2001). Table 2 shows the performance of the top yielding hybrids produced from one of the locational trials conducted (Saleh *et al.,* 2002b). The highly potential ones identified as having high GCA and SCA were then entered into replicated trials and subsequently locational trials and large scale trials to determine stability of performance of the hybrids (Saleh *et al.,* 2003a; Min and Saleh, 2003; Min *et al.,* 2008).

Table 3 shows the results of various stability parameter evaluations conducted on single, double and three-way cross hybrids produced (Min *et al.,* 2008). One of the most promising single-cross hybrids was released as the first grain maize hybrid variety in the country, the *Putra J-58* (Figure 15) (Saleh, 1998). This variety, being a hybrid, has the advantage of high yield of 6.2 tons/ha, besides possessing other favourable traits including earliness in maturity and possessing high grain nutritional quality, making it suitable for use as a source of animal feed. In addition, through the breeding efforts undertaken, a series of other potential single crosses, double crosses and three-way crosses were also developed and evaluated (Saleh *et al.,* 2002a; Sujiprihati *et al.,* 2002), some of which have been used in further research involving hybrid varieties in the country.

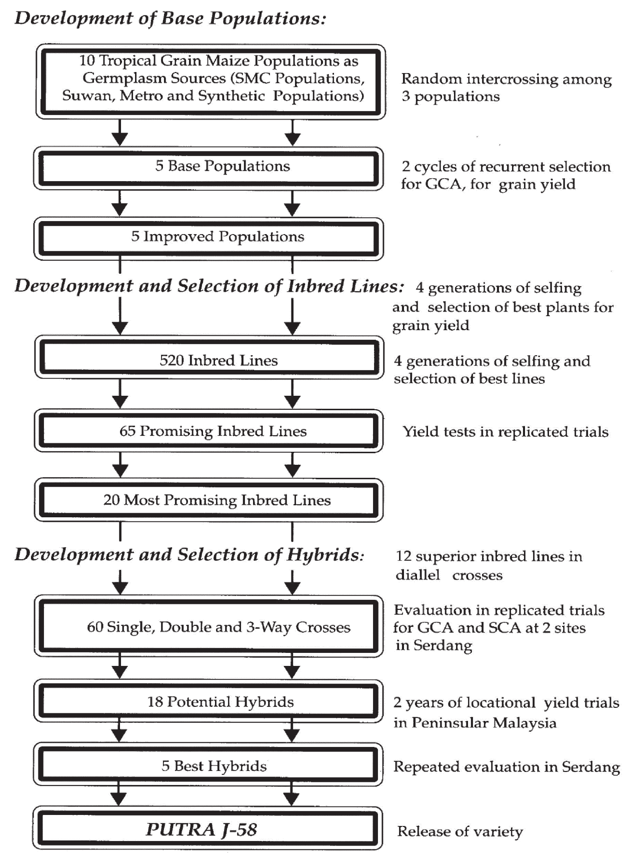



*Diagram showing the breeding procedure to develop **Putra J-58**.*

**Figure 14** Diagram showing the inbred line development steps and formation of variety *Putra J-58*

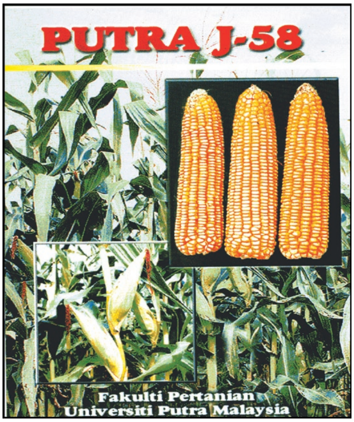



**Figure 15** Document on grain maize hybrid variety, *Putra J-58*

**Table 1** The 12 selected maize inbred lines used in diallel crosses, their source populations and mean performances for grain weight per plant, days to tasselling and days to silking (after Sujiprihati *et al.,* 2001)

| Inbred line | Country of source population | Grain weight per plant (g) | Days to tasselling (days) | Days to silking (days) |
|---|---|---|---|---|
| UPM-TW-12 | Philippines | 36.8 | 52.3 | 57.9 |
| UPM-TW-5 | Philippines | 43.5 | 56.8 | 61.0 |
| UPM-SM5-9 | Philippines | 34.7 | 57.2 | 57.9 |
| UPM-SM5-5 | Philippines | 43.9 | 56.3 | 61.3 |
| UPM-SM5-4 | Philippines | 44.9 | 57.9 | 63.6 |
| UPM-SM7-6 | Philippines | 82.6 | 58.1 | 60.1 |
| UPM-SM7-10 | Philippines | 33.1 | 57.8 | 62.5 |
| UPM-SM7-11 | Philippines | 45.3 | 56.1 | 60.1 |
| UPM-SW-2 | Thailand | 35.8 | 58.9 | 59.6 |
| UPM-SW-9 | Thailand | 29.4 | 60.1 | 63.0 |
| UPM-MT-13 | Indonesia | 39.7 | 56.2 | 59.4 |
| UPM-MT-5 | Indonesia | 54.8 | 55.8 | 59.9 |

**Table 2** Performance of the top yielding maize hybrids from the diallel crosses (after Saleh *et al.,* 2002b).

| **Hybrid/ check variety** | **Grain yield (kg/ha)** | **Plant height (cm)** | **Days to tasselling (days)** | **Days to maturity (days)** |
|---|---|---|---|---|
| *Hybrid:* | | | | |
| UPM-SM5-9 X UPM-TW-5 (Hy-17) | 5015 | 169.0 | 49.0 | 91.7 |
| UPM-SM5-5 X UPM-TW-12 (Hy-18) | 5185 | 170.6 | 50.7 | 92.7 |
| UPM-SW5-4 X UPM-TW-12 (Hy-19) | 5096 | 178.2 | 50.7 | 91.7 |
| UPM-SW-2 X UPM-TW-5 (Hy-33) | 4963 | 183.5 | 48.0 | 90.7 |
| UPM-SW-9 X UPM-SM5-9 (Hy-43) | 5296 | 184.8 | 51.0 | 91.0 |
| UPM-MT-5 X UPM-SM5-9 (Hy-45) | 5511 | 173.2 | 50.0 | 88.3 |
| UPM-MT-5 X UPM-SM5-5 (Hy-53) | 5259 | 194.0 | 52.0 | 90.0 |
| UPM-SW-9 X UPM-SM5-4 (Hy-58) | 5659 | 164.4 | 48.0 | 86.7 |
| UPM-MT-13 X UPM-SM5-4 (Hy-59) | 5726 | 182.4 | 51.0 | 88.7 |
| UPM-MT-5 X UPM-SM5-4 (Hy-60) | 5948 | 183.7 | 51.0 | 89.0 |
| *Check variety:* | | | | |
| Suwan 1 | 5430 | 206.6 | 52.0 | 89.7 |
| Suwan 3 | 4474 | 172.6 | 52.3 | 91.3 |
| Metro | 5104 | 227.0 | 57.3 | 93.0 |
| LSD (0.05) | 131 | 21.1 | 1.2 | 1.6 |
| CV (%) | 28.5 | 7.9 | 1.5 | 1.1 |

**Table 3** Stability parameters for grain maize genotypes evaluated at four locations in two years (from Min *et al.*, 2008)

| Genotype | Mean ($kgha^{-1}$) | $b_i$ | $s^2_d$ | $R^2$ | $s^2$ | $W_i$ | $\sigma^2_i$ | CV (%) |
|---|---|---|---|---|---|---|---|---|
| **SC – 1** | 4855 | 0.81 | 330039 | 0.59 | 60594 | 127796 | 47635 | 11.8 |
| **SC – 2** | 5184 | 0.77 | 248407 | 0.64 | 68131 | 183193 | 69178 | 9.6 |
| **SC – 3** | 4200 | 1.14 | 50501 | 0.95 | 3612 | 23108 | 6923 | 5.4 |
| **SC – 4** | 4621 | 1.07 | 168394 | 0.83 | 34178 | 67750 | 24283 | 8.9 |
| **TWC – 1** | 4797 | 0.93 | 163807 | 0.79 | 35532 | 68605 | 24616 | 8.4 |
| **TWC – 2** | 4574 | 1.24 | 70840 | 0.94 | 4254 | 15105 | 3810 | 5.9 |
| **TWC – 3** | 4724 | 0.72 | 145277 | 0.72 | 14359 | 31484 | 10180 | 8.1 |
| **TWC – 4** | 5130 | 0.87 | 168616 | 0.77 | 41962 | 75811 | 27418 | 8.0 |
| **TWC – 5** | 4612 | 1.47 | 95925 | 0.94 | 37399 | 133848 | 49988 | 6.7 |
| **DC – 1** | 4937 | 1.05 | 33381 | 0.96 | 1472 | 8518 | 1249 | 3.7 |
| **G x A** | 5535 | 0.68 | 293773 | 0.54 | 41307 | 87812 | 32015 | 9.8 |
| **Selected GxA** | 5726 | 0.95 | 24473 | 0.96 | 90 | 8178 | 1116 | 2.7 |
| **Putra J- 58** | 5277 | 1.56 | 79355 | 0.96 | 29988 | 102654 | 37857 | 5.3 |
| **Suwan 1** | 4747 | 0.74 | 34120 | 0.92 | 7021 | 32054 | 10401 | 3.9 |
| **L.S.D. (0.05)** | 429 | | | | | | | |

$b_i$= regression coefficient,
$R^2$= coefficient of determination,
$W_i$= Wricke's ecovalance,
CV=coefficient of variation.

$s^2_d$= mean square of deviations,
$s^2$= environmental variance,
$\sigma^2_i$= Shukla's stability variance, and

### *Breeding of Grain Maize Hybrids for Tolerance to Acid Soils*

Besides breeding for high yield and yield related traits, efforts were also taken to produce hybrids that could adapt well to the acid soil conditions in Malaysia. Approximately 72% of the arable land in Malaysia is acidic in nature. Productivity of maize is low on these highly weathered soils. These soils can be made productive by application of lime, but this is laborious and adds to the cost of production. A series of experiments to screen the inbred lines developed in UPM as well as those introduced from other countries were conducted using three approaches: hematoxylin staining assay, screening in nutrient solution and screening in pot trials (Hayati *et al.,* 2006). CML-5 was found to be acid-soil tolerant, while IPB-19, IPB-14, IPB-12 and SM 7-11 were moderately-tolerant (Table 4) Hybrids derived from them were tested for their performance in acid soils (Hayati *et al.,* 2007). The genetic control of tolerance to acid soils was also investigated. Molecular markers (SSRs) (Figure 16) were used to identify the genetic variability (Figure 17) and also to help in the selection (Hayati *et al.,* 2008). Hybrid H29 which was a cross involving inbred parents that are acid-soil tolerant and of diverse genetic background was identified as a promising hybrid tolerant to acid soils (Table 5). It gave high grain yields on all acid soil conditions tested. Before the completion of the study, this hybrid should be tested further on large scale trials on acid soils in Malaysia, before it can be released as a new hybrid variety.

**Table 4** Selected maize inbred line used in diallel crosses, and their performances on acid soils

| Inbred line | Grain yield Acid soil ($kgha^{-1}$) | Grain yield Relative* (%) | Ear height Acid soil (cm) | Ear height Relative* (%) | Days to silking Acid soil (days) | Days to silking Relative* (%) | Source population |
|---|---|---|---|---|---|---|---|
| MT-13 | 869 | 55 | 33.1 | 66 | 56 | 76 | Metro, Indonesia |
| SM 5-4 | 767 | 43 | 22.5 | 59 | 62 | 76 | SMC 305, Philippines |
| SM 7-11 | 901 | 55 | 30.4 | 61 | 58 | 66 | SMC 317, Philippines |
| SW-2 | 661 | 41 | 30.8 | 62 | 59 | 71 | Suwan 1, Thailand |
| CML-2 | 567 | 46 | 15.6 | 53 | 62 | 74 | CIMMYT Line |
| CML-6 | 60 | 18 | 21.3 | 64 | 72 | 82 | CIMMYT Line |
| IPB-12 | 915 | 49 | 26.2 | 63 | 59 | 73 | IPB Line, Indonesia |
| IPB-14 | 681 | 48 | 27.6 | 72 | 58 | 72 | IPB Line, Indonesia |
| IPB-20 | 479 | 36 | 23.0 | 60 | 59 | 74 | IPB Line, Indonesia |

* Relative performance expressed as a percentage of that on limed soil.

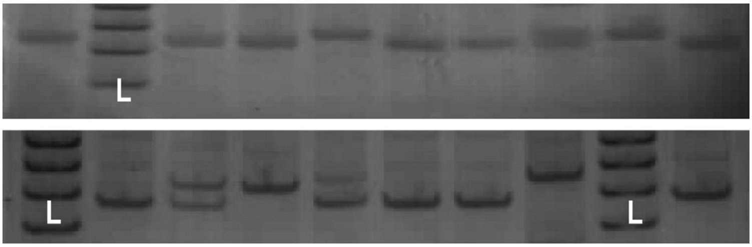



**Figure 16** PCR products of SSR markers, umc1253 (above) and phi034 (below) (L=25 base pair Ladder)

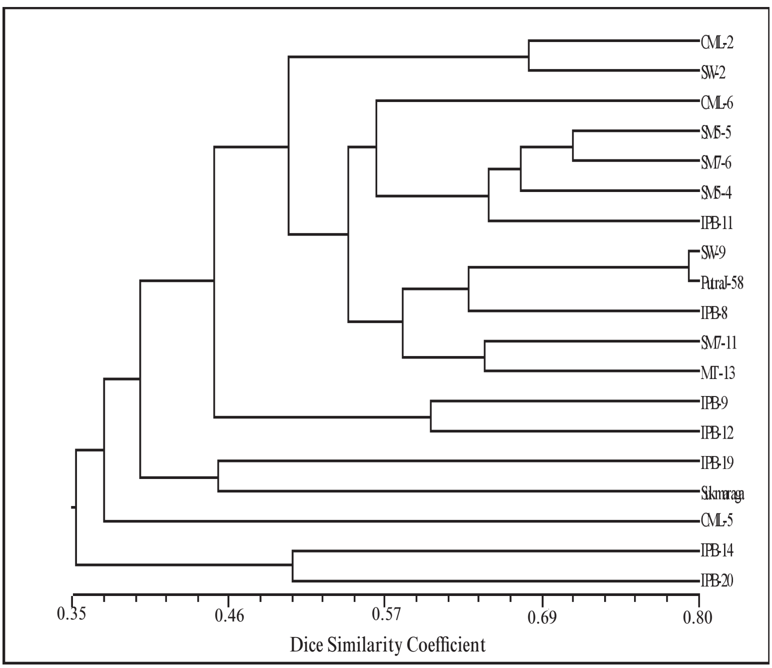



**Figure 17** Dendrogram constructed using UPGMA clustering among 17 tropical maize inbred lines and two check varieties, based on SSR markers

**Table 5** Maize hybrids showing tolerance to acid soils at two locations

| Hybrid | | Grain yield (kgha $^{-1}$) | Hybrid | | Grain yield (kgha $^{-1}$) |
|---|---|---|---|---|---|
| **Unlimed soil** | | | **Limed soil** | | |
| **In Puchong** | | | | | |
| H17 | SM 7-11 X IPB-12 | 2011 | **H21** | SM 7-11 X CML-6 | 5116 |
| **H29** | **IPB-12 X CML-2** | **1996** | H33 | SW-2 X CML-6 | 4918 |
| H30 | IPB-12 X CML-6 | 1890 | H14 | SM 5-4 X CML-2 | 4748 |
| H18 | SM 7-11 X SW-2 | 1654 | **H36** | CML-2 X CML-6 | 4590 |
| H32 | SW-2 X CML-2 | 1606 | **H25** | IPB-14 X CML-2 | 4555 |
| **H23** | IPB-14 X SW-2 | 1594 | H30 | IPB-12 X CML-6 | 4520 |
| H7 | IPB-20 X CML-2 | 1501 | H4 | IPB-20 X IPB-12 | 4441 |
| **H9** | SM 5-4 X SM 7-11 | 1451 | H5 | IPB-20 X SW-2 | 4428 |
| **H24** | IPB-14 X MT-13 | 1432 | **H29** | **IPB-12 X CML-2** | **4394** |
| **H4** | IPB-20 X IPB-12 | 1264 | **H10** | SM 5-4 X IPB-14 | 4377 |
| Putra J-58 | | 906 | Putra J-58 | | 4340 |
| Sukmaraga | | 991 | Sukmaraga | | 4033 |
| Hybrid mean | | 1094 | | | 3806 |
| Al Exchangeable (cmol.kg $^{-1}$) | | 3.05 | | | 0.90 |
| Soil pH | | 4.4 | | | 5.0 |
| **In Serdang** | | | | | |
| **H24** | IPB-14 X MT-13 | 4317 | H8 | IPB-20 X CML-6 | 7426 |
| **H9** | SM 5-4 X SM 7-11 | 4092 | **H36** | CML-2 X CML-6 | 7413 |
| H25 | IPB-14 X CML-2 | 3988 | H34 | MT-13 X CML-2 | 7398 |
| **H4** | IPB-20 X IPB-12 | 3910 | H26 | IPB-14 X CML-6 | 7224 |
| H28 | IPB-12 X MT-13 | 3765 | **H21** | SM 7-11 X CML-6 | 7212 |
| **H29** | **IPB-12 X CML-2** | **3746** | **H25** | IPB-14 X CML-2 | 6775 |
| **H23** | IPB-14 X SW-2 | 3742 | H35 | MT-13 X CML-6 | 6684 |
| H31 | SW-2 X MT-13 | 3739 | H9 | SM 5-4 X SM 7-11 | 6662 |
| H3 | IPB-20 X IPB-14 | 3733 | **H10** | SM 5-4 X IPB-14 | 6431 |
| H11 | SM 5-4 X IPB-12 | 3680 | **H29** | **IPB-12 X CML-2** | **6334** |
| Putra J-58 | | 3451 | Putra J-58 | | 6280 |
| Sukmaraga | | 4135 | Sukmaraga | | 6143 |
| Hybrid mean | | 3350 | | | 6052 |
| Al Exchangeable (cmol.kg $^{-1}$) | | 1.58 | | | 0.52 |
| Soil pH | | 4.6 | | | 5.2 |

Note:

Hybrid H29 (black and bold) is consistently in the list of top ten high yielding hybrids on both acid and limed soils and at each location.

Hybrid H24, H9, H4, H23 and H29 (blue) are consistently within the top ten high yielding hybrids on acid soils.

Hybrid H36, H21, H25, H10 and H29 (purple) are consistently within the top ten high yielding hybrids on limed soils.

## Sweet Corn Breeding

The overall road map describing sweet corn breeding conducted at UPM is shown in Figure 18.

### *Recurrent Selection in Sweet Corn*

My research on sweet corn started in the early 1990s when it was realized that the country had to incur high import bills on hybrid seeds for growing sweet corn. In 1990, a recurrent selection programme was initiated on the open-pollinated sweet corn varieties available at that time, namely Bakti-1 and Manis Madu. Through two cycles of selection, two improved varieties of Bakti-1 and Manis Madu were developed for use in many research programmes (Saleh *et al.,* 1994; Rafii *et al.,* 1994).

In the late 1990s, open-pollinated varieties were no longer the preference of consumers in Malaysia, as hybrid varieties had already been introduced for growing. Seeds of the hybrid varieties used for planting were mainly imported, particularly from the United States and Taiwan. The improved open pollinated varieties previously developed were then utilized in the hybridizing programmes with the imported $F_1$ hybrid variety at that time, Hybrid 240. Through hybridization between the Improved Manis Madu population and Hybrid 240, two cycles of phenotypic mass selection were conducted. The improved M C2 population derived from Manis Madu revealed higher fresh ear yield (10,996 kg $ha^{-1}$) than the base population. The two cycles of phenotypic mass selection for ear length were found to be effective in improving fresh ear yield and ear length (Ali and Saleh, 2003; Ali *et al.,* 2003). The breeding programme was continued by crossing the improved composite population further with two synthetic varieties introduced from Ethiopia followed by alternate cycles of backcrosses to the composite parent (Nigussie and Saleh, 2005). The resulting populations were subjected to two cycles of mass selection (MS) and selfed-progeny selection (SPS). The realized gain obtained differed with selection methods, where in population BC2-10, gain from SPS was twice that from MS, but comparable gains were obtained in population BC1-10xSyn-II (Table 6) (Nigussie and Saleh, 2007). Through the course of evaluation, some superior lines were extracted and intermated to form a synthetic population. This population has been proven to be superior to other available varieties at that time, and was named *Putra GS-2002* (Figure 19) (Saleh *et al.,* 2003b). This new variety was found to have fresh ear yield comparable to Manis Madu but was much sweeter (Nigussie *et al.,* 2005), as it contained genes from the hybrid variety, Hybrid 240 and a synthetic variety from Ethiopia.

### *Development of Sweet Corn Inbred Lines and Hybrids*

Modern varieties grown today are hybrids, which are sweeter and have a more favourable taste. However, for local growing, seeds of these hybrid varieties are all imported, because no local sweet corn hybrids has ever been released. In an effort to produce local $F_1$ sweet corn hybrids, an intensive hybrid development programme has been undertaken at UPM since 1997. The Inbred development programme was initiated on a series of imported hybrids available in the market. Inbred lines were developed, and the most advanced ones are presently at their $S_7$ stage, while others are still at earlier stages of inbred line development (Kashiani *et al.,* 2008). Through the years, the lines have undergone repeated self pollinations and selection to allow accumulation of favourable additive genes. Performance of some of these inbred lines is shown in Table 7. Currently, these lines are being subjected to analysis using SSR markers to help select promising combinations among them for hybrid variety development. The inbred lines will be involved in possible crosses, which would then be subsequently evaluated for performance, before the favourable ones are short-listed and further tested in large scale plantings and finally released as new hybrid varieties.

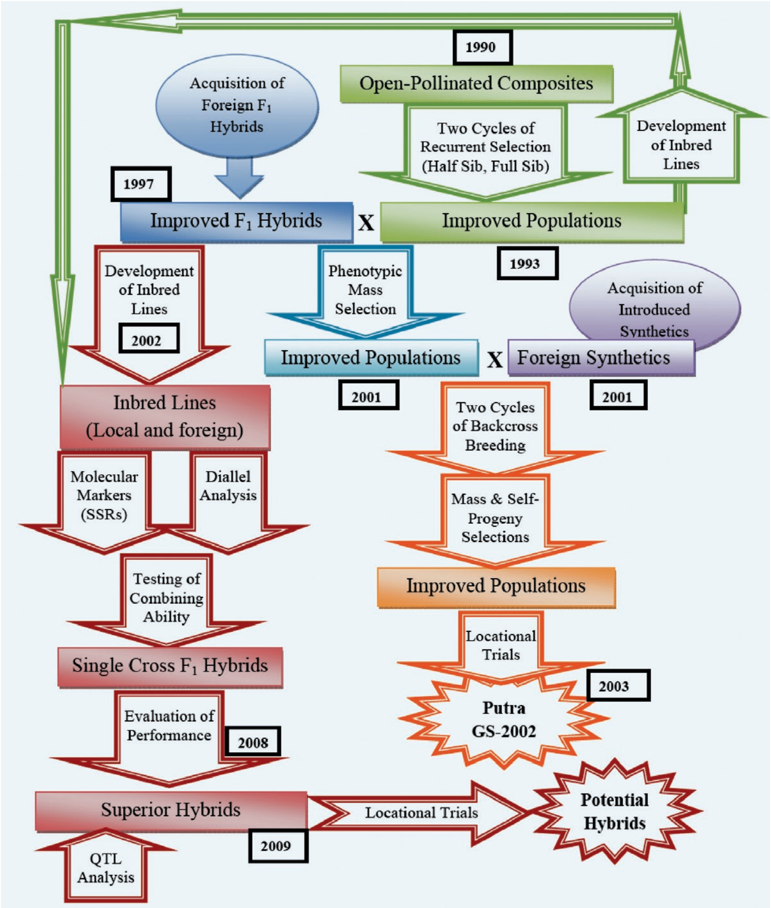



**Figure 18** Road map of sweet corn breeding programme at UPM

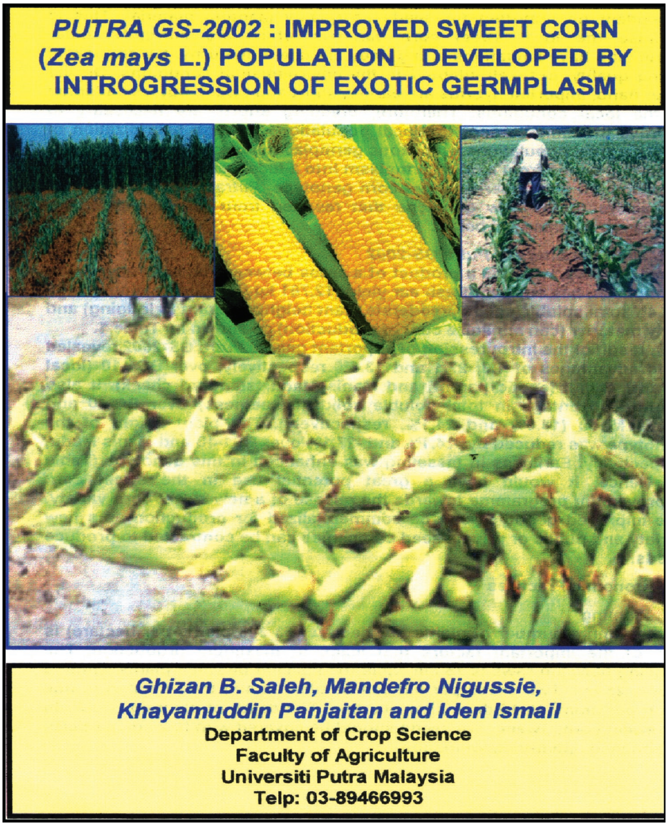



**Figure 19** Document on sweet corn synthetic variety, *Putra GS-2002*

**Table 6** Comparison of response to mass selection (MS) and self-progeny selection (SPS) on two improved populations of sweet corn

| **Population** | **Predicted Response (%)** | | | **Realised Response (%)** | | |
|---|---|---|---|---|---|---|
| | **MS** | **SPS** | **$X^2$** | **MS** | **SPS** | **$X^2$** |
| **BC2-10** | | | | | | |
| C1 | 24.7 | 13.2 | 5.35* | 5.1 | 10.1 | 4.90** |
| C2 | 18.8 | 9.8 | 4.31* | 4.8 | 1.7 | 2.00 |
| Cumulative | 47.2 | 21.7 | 13.78** | 10.1 | 12.0 | 0.36 |
| **BC1-10 x Syn-II** | | | | | | |
| C1 | 22.3 | 9.9 | 6.90** | 5.5 | 5.6 | 0.01 |
| C2 | 16.0 | 8.3 | 3.70 | 2.9 | 2.9 | 0.00 |
| Cumulative | 41.6 | 18.7 | 12.60** | 8.5 | 8.7 | 0.01 |

**, * Significant at $p \leq 0.01$ and 0.05, respectively

**Table 7** Performance of potential inbred lines developed from the programme (from Kashiani *et al.*, 2008)

| **Inbred line** | **Mean** | | | | |
|---|---|---|---|---|---|
| | **Husked ear yield (kg/ha)** | **No. of ears/ ha** | **Plant height (cm)** | **Husked ear length (cm)** | **TSS (%)** |
| Bakti-1-$S_7$ | 8043 a | 35556 abc | 175.1 a | 16.9 a | 15.7 a |
| Manis Madu-$S_7$ | 5298 abcd | 35556 abc | 126.4 b | 15.9 a | 15.8 a |
| TSS Tin-$S_7$ | 2651 d | 25185 c | 88.6 c | 13.9 a | 16.9 a |
| Mas Madu-$S_6$ | 3012 cd | 32593 abc | 123.5 b | 13.9 a | 16.7 a |
| Thailand-$S_6$ | 6053 ab | 44444 a | 135.9 b | 15.4 a | 15.3 a |
| Indonesia-$S_6$ | 4555 bcd | 28148 bc | 97.5 c | 12.1 a | 16.9 a |
| TSS Melaka-$S_5$ | 7532 a | 41481 ab | 145.4 b | 14.3 a | 15.4 a |
| MM x Ind-$S_4$ | 5638 abc | 32593 abc | 143 b | 14.5 a | 13.3 b |
| SBY-$S_2$ | 3883 bcd | 22222 c | 88.1 c | 12.4 a | 15.3 a |

Means followed by the same letter in the same column are not significantly different at $p<0.05$ based on DNMRT

## CONCLUSION

Crop breeding has contributed greatly to the development of world agriculture, despite the challenges faced. However, it involves very tedious efforts and demands for patience from the breeders, strong financial support, time commitments and sufficient trained human resources. The ultimate aim of a crop breeding programme is to produce new crop varieties. A crop breeding programme is therefore, considered incomplete if it does not successfully end with the release of new varieties. One of the main constraints of crop breeding programmes is that funding is very short term, in most cases between two to three years. This has hindered long term planning of breeding research which impedes efforts in developing superior varieties. Realizing these constraints, more often than not, research workers prefer to be content with running research programmes that are just ‘adopt and adapt’ in nature after introducing varieties from outside, without having comprehensive breeding plans and significant genetic alterations of the original variety. It is therefore necessary that some nationally prioritised breeding programmes are supported with long term funding to produce varieties that are mature enough before they are released. In recent developments in crop breeding, where applications of molecular biology are used as tools, knowledge in genetics is crucial to allow creativity of the breeders. This is even more obvious now in the era of biotechnology, when researchers tend to be more competent on just the techniques of doing things rather than mastering the science of genetics behind the breeding procedures.  Today there is a lack of plant breeders and plant geneticists for almost all crops. Hence, the country should be prepared to train more breeders with sound theoretical knowledge in applied genetics and breeding as a scientific foundation. Further, collaborations between applied breeders and molecular biologists should be strengthened, to ensure the execution of convincing crop breeding research, with proper laboratory techniques and field applications. Bigger achievements are even more possible with stronger collaborations between researchers in the public universities and research institutions, and the private sector and practitioners in the industry.

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## BIOGRAPHY

G**hizan Saleh** was born on 4th June 1958 in Jementah, Segamat, Johor. He received his early education at the Primary English School Segamat and subsequently at High School Segamat, before continuing at Sekolah Menengah Sains Johor, Kluang, for his secondary education. His father is a retired primary school teacher, while his mother still serves as a loyal housewife.

He pursued his tertiary education at Universiti Pertanian Malaysia (now known as Universiti Putra Malaysia) where he received the Bachelor of Agricultural Science degree in 1981. As a multitalented graduate, he was awarded the university's Chancellor's Gold Medal, besides garnering three other awards, i.e. the Faculty of Agriculture Gold Medal for best in academic standing, the Agriculture Institute of Malaysia (AIM) Gold Medal for best all-round graduate of the faculty and the C. Melchers Award for best Agronomy graduate.

Ghizan's profession as an academician began when he took up the position as Tutor at the Department of Agronomy and Horticulture (now known as Department of Crop Science) in 1981. Under the sponsorship of Universiti Putra Malaysia and the Malaysian Government he continued his postgraduate studies at the University of Wisconsin-Madison, USA, where he obtained his M.S. and PhD degrees in 1983 and 1986 respectively, in the area of Plant Breeding and Genetics, under the supervision of Professor Dr. Earl T. Gritton. His breakthrough graduate research pioneered the complex work of investigating the inheritance of the pea plant root system. Papers published on his findings which revealed the importance of its applications in breeding and selecting favourable root traits in crops received overwhelming requests for reprints from researchers all over the world.

After completion of his postgraduate studies in 1986, he began serving as a lecturer at UPM at the Department of Crop Science.

Since then, he has been involved with and contributed his efforts to teaching, research, administration, and extension services, not only limited to UPM academia, but also to the country as a whole. He was appointed as Associate Professor in 1995 and later promoted to full Professor in 2003.

Chronologically, his administrative experience started in 1989 when he took office as Principal of Chancellor's College, running for three terms. He was also appointed Deputy Director of the University Research Park (now University Agriculture Park) in July 1999 (was acting Director from February until April 2001). In October 2001, he was asked to serve the Faculty of Agriculture as Deputy Dean (Research and Graduate Studies), and later as Deputy Dean (Academic and Student Affairs) from 2004 to 2006. He was appointed as Dean, Faculty of Agriculture in August 2006, a position he holds until today. He is also very active professionally, where he is the current President of the Genetics Society of Malaysia, a position he has held since 2003, as well as the President of the International Society for Southeast Asian Agricultural Science (Malaysian Chapter) since 2006. He was Deputy President of both societies in the preceding term.

Ghizan's area of specialisation is Plant Breeding and Genetics, mainly focussing on Quantitative Genetics, looking into heritability assessment, gene effects, genetic analysis and selection methods for population improvement, using the conventional approach of crop breeding, and to some extent, the molecular approach as well. He has taught at both undergraduate and well as postgraduate levels, courses including Plant Breeding, Quantitative Genetics, Biometry and Advanced Statistical Methods. He has devoted his long years of research in UPM mainly to grain maize and sweet corn breeding research, although he has to some lesser extent executed research on groundnuts, soybeans, passionfruit, and recently, kenaf, banana and lemba breeding. Through his long years of research, he has secured a total of 16 research funds, mainly through the mechanisms of IRPA and Science Fund under the administration of MOSTI, and FRGS (including Top-Down) and RUGS under the administration of MOHE and UPM, out of which four are still on-going. His greatest milestone research achievement was the release of the first grain maize hybrid variety in the country, *Putra J-58* in 1998, which was launched by the then Minister of Agriculture. This innovation has been awarded the Gold Medal during the Malaysian Science and Technology Expo 2002. In the following year, another invention from his breeding work, the new sweet corn synthetic variety, *Putra GS-2002* was also awarded a Gold Medal at the same expo. He has also developed numerous grain maize and sweet corn inbred lines.

In 1996, Ghizan won the prestigious Association of Commonwealth Universities (ACU) Fellowship Award, administered by the Commonwealth Commission, to spend a year sabbatical at the School of Biological Sciences, University of Birmingham, UK. He took this opportunity to conduct research and learn new techniques on applications of molecular markers to crop breeding and selection.

To his credit, todate, he has authored and co-authored more than 50 papers in local and international journals, and more than 110 research papers in conference, congress, symposium and seminar proceedings and abstracts. Adding to his academic credentials and experiences, through the years of his academic career, he has attended numerous international and local congresses, conferences, symposia and seminars. Thus far in his career, Ghizan has supervised a total of 15 PhD, 24 Masters and 82 undergraduate students in their research work.

Recognising his research and professional capabilities, Ghizan was appointed as Editorial Board Member of *Pertanika Journal of Tropical Agricultural Science*, the Advisory Board Member of *Pakistan Journal of Agronomy* and *Jurnal Penelitian Universitas Islam Sumatera Utara* and also as the Malaysian representative as Scientific Consultant for Plant Breeding and Genetics for the *Journal of International Islamic Academy of Science,* Turkey. He is also a regular reviewer for manuscripts submitted to *Pertanika Journal of Tropical Agricultural Science, Journal of Oil Palm Research, Malaysian Applied Biology Journal* and *Journal of Tropical Agriculture and Food Science*. He has also reviewed manuscripts submitted to international and local journals including *Euphytica Journal of Plant Breeding*, *SABRAO Journal of Breeding and Genetics, Journal of International Islamic Academy of Science, Journal of Molecular Biology and Biotechnology, and Journal of Bioscience*. In addition, he has also served as an independent external examiner for numerous PhD and M.S. theses of students working in related areas from other local universities. He is also a regular independent assessor on promotion exercises to professor and associate professor positions at local universities.

With his significant expertise and vast experience, Ghizan has contributed to the nation and UPM by serving on numerous committees, participating in local and international exhibitions as well as building local and international linkages. Presently, he sits on the National Technical Evaluation Committee for Science Fund Agriculture Sector, Ministry of Agriculture, and also on the Technical Advisory Committee of the Ministry of Agriculture and Agro-based Industry. He is also a Board Member of Kolej Risda. His vast experience in consultancy work on maize has earned him recognition as a key reference person on matters involving improvement, production and cultivation of maize and sweet corn in the country.

Digressing from his professional routines, Ghizan had the opportunity to serve the local community as Chairman of the Parents and Teachers Association (PIBG) of two primary schools, Sekolah Kebangsaan Taming Jaya (2002-2003) and Sekolah Kebangsaan Jenderam Hilir (2007-2009).

In recognition of his successes and contributions, Ghizan Saleh is one those featured in *75 Jewels of UPM*, a commemorative book published by the Alumni Association of UPM in conjunction with UPM's 75 Year Celebrations.

Ghizan and his wife, Mazli, a secondary school physics teacher, are blessed with three wonderful children, Harrith, Hazwan and Nurina. He loves badminton, and during his active years in the past has played the game at competitive levels.

## ACKNOWLEDGEMENTS

First and foremost, syukur Alhamdulillah, praise be to the Al-Mighty for His blessings in making all paths possible for my life endeavours and a wonderful career.

I would like to thank Universiti Putra Malaysia and all officers concerned, past and present, for providing me this strong platform to serve the nation and society in various forms as an academic. Thanks also to the Government of Malaysia, particularly MOSTI and MOHE for providing research funds throughout the course of my research projects under various funding mechanisms, namely the MPKSN Trust Fund, IRPA, Science Fund, FRGS (including Top-down Fund), and RUGS.

My gratitude also goes to the Association of Commonwealth Universities (ACU) for providing me funds at one point of my career development to explore new areas of research, and officers of the International Maize and Wheat Improvement Center (CIMMYT) for their continuous support in furnishing genetic materials for my research programmes.

To all my teachers in all facets of my search for knowledge, I would like to express my sincere appreciation for their help and sincerity in sharing all formulae towards understanding the wisdom in knowledge seeking. I would also like to express my thanks to all friends, colleagues and staff members who have been associated with me at one time or another through the years in making things possible. To colleagues who have together added colour and diversity to the Genetics Society of Malaysia, thank you all. All my successes wouldn't have been possible without the strong commitment and devotion of all my post-graduate and undergraduate students, and research assistants, past and present, going through thick and thin together, making research more interesting. My thanks also go to

Pedram and Dewi for helping me in putting the bits and pieces together in the preparation of this inaugural lecture.

My deepest gratitude to my loving parents for having me and for their understanding in giving me the freedom to choose my study path. Last but not least, deep from my heart, thanks to my beloved wife, Mazli, and children Harrith, Hazwan and Nurina for their love, support and sacrifices, and for understanding my commitments and role as an academic. May Allah bless all of you!

## LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   *The Challenge to Communication Research in Extension*
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   *Indigenous Materials and Technology for Low Cost Housing*
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   *Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops*
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   *Numerical Solution of Ordinary Differential Equations: A Historical Perspective*
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   *Changing Roles of Agricultural Economics*
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   *Marketing Management: Prospects and Challenges for Agriculture*
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   *The Changing Demand for Livestock Products*
   20 April 1994

8. Prof. Dr. Ruth Kiew
   *Plant Taxonomy, Biodiversity and Conservation*
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   *Engineering Technological Developments Propelling Agriculture into the 21st Century*
   28 May 1994

10. Prof. Dr. Shamsuddin Jusop
    *Rock, Mineral and Soil*
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
    *Natural Toxicants Affecting Animal Health and Production*
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    *Pest Control: A Challenge in Applied Ecology*
    9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
    *Managing Challenges in Fisheries Development through Science and Technology*
    23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
    *Sejarah Keagungan Bahasa Melayu*
    6 Ogos 1994

15. Prof. Dr. Law Ah Theem
    *Oil Pollution in the Malaysian Seas*
    24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
    *Fine Chemicals from Biological Resources: The Wealth from Nature*
    21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
    *Health, Disease and Death in Creatures Great and Small*
    25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
    *Fish Health: An Odyssey through the Asia - Pacific Region*
    25 March 1995

19. Prof. Dr. Tengku Azmi Tengku Ibrahim
    *Chromosome Distribution and Production Performance of Water Buffaloes*
    6 May 1995

20. Prof. Dr. Abdul Hamid Mahmood
    *Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan*
    10 Jun 1995

21. Prof. Dr. Rahim Md. Sail
*Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues*
22 July 1995

22. Prof. Dr. Nik Muhammad Nik Abd. Majid
*The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure*
19 August 1995

23. Prof. Dr. Ang Kok Jee
*The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century*
14 October 1995

24. Prof. Dr. Sharifuddin Haji Abdul Hamid
*Management of Highly Weathered Acid Soils for Sustainable Crop Production*
28 October 1995

25. Prof. Dr. Yu Swee Yean
*Fish Processing and Preservation: Recent Advances and Future Directions*
9 December 1995

26. Prof. Dr. Rosli Mohamad
*Pesticide Usage: Concern and Options*
10 February 1996

27. Prof. Dr. Mohamed Ismail Abdul Karim
*Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia*
2 March 1996

28. Prof. Dr. Wan Sulaiman Wan Harun
*Soil Physics: From Glass Beads to Precision Agriculture*
16 March 1996

29. Prof. Dr. Abdul Aziz Abdul Rahman
*Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia*
13 April 1996

30. Prof. Dr. Chew Tek Ann
*Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms*
27 April 1996

31. Prof. Dr. Mohd. Yusuf Sulaiman
*Back to the Future with the Sun*
18 May 1996

32. Prof. Dr. Abu Bakar Salleh
*Enzyme Technology: The Basis for Biotechnological Development*
8 June 1996

33. Prof. Dr. Kamel Ariffin Mohd. Atan
*The Fascinating Numbers*
29 June 1996

34. Prof. Dr. Ho Yin Wan
*Fungi: Friends or Foes*
27 July 1996

35. Prof. Dr. Tan Soon Guan
*Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too*
10 August 1996

36. Prof. Dr. Nazaruddin Mohd. Jali
*Will Rural Sociology Remain Relevant in the 21st Century?*
21 September 1996

37. Prof. Dr. Abdul Rani Bahaman
*Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases*
16 November 1996

38. Prof. Dr. Marziah Mahmood
*Plant Biotechnology - Strategies for Commercialization*
21 December 1996

39. Prof. Dr. Ishak Hj. Omar
*Market Relationships in the Malaysian Fish Trade: Theory and Application*
22 March 1997

40. Prof. Dr. Suhaila Mohamad
*Food and Its Healing Power*
12 April 1997

41. Prof. Dr. Malay Raj Mukerjee
*A Distributed Collaborative Environment for Distance Learning Applications*
17 June 1998

42. Prof. Dr. Wong Kai Choo
*Advancing the Fruit Industry in Malaysia: A Need to Shift Research Emphasis*
15 May 1999

43. Prof. Dr. Aini Ideris
*Avian Respiratory and Immunosuppressive Diseases- A Fatal Attraction*
10 July 1999

44. Prof. Dr. Sariah Meon
*Biological Control of Plant Pathogens: Harnessing the Richness of Microbial Diversity*
14 August 1999

45. Prof. Dr. Azizah Hashim
*The Endomycorrhiza: A Futile Investment?*
23 Oktober 1999

46. Prof. Dr. Noraini Abdul Samad
*Molecular Plant Virology: The Way Forward*
2 February 2000

47. Prof. Dr. Muhamad Awang
*Do We Have Enough Clean Air to Breathe?*
7 April 2000

48. Prof. Dr. Lee Chnoong Kheng
*Green Environment, Clean Power*
24 June 2000

49. Prof. Dr. Mohd. Ghazali Mohayidin
*Managing Change in the Agriculture Sector: The Need for Innovative Educational Initiatives*
12 January 2002

50. Prof. Dr. Fatimah Mohd. Arshad
*Analisis Pemasaran Pertanian di Malaysia: Keperluan Agenda Pembaharuan*
26 Januari 2002

51. Prof. Dr. Nik Mustapha R. Abdullah
*Fisheries Co-Management: An Institutional Innovation Towards Sustainable Fisheries Industry*
28 February 2002

52. Prof. Dr. Gulam Rusul Rahmat Ali
*Food Safety: Perspectives and Challenges*
23 March 2002

53. Prof. Dr. Zaharah A. Rahman
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