HISTORY, DEVELOPMENT AND MARKET OF MAIZE CULTIVARS WITH LOW SEED COST IN BRAZIL

Abstract – Maize is one of the cereal crops most produced on the planet. It constitutes one of the species of greatest economic interest and provides multiple products, with applications in diverse sectors, from animal feed to industrial products and even human food. More and more companies that represent this segment release genetically modified maize hybrids as a manner of ensuring return on investment, decreasing the supply of conventional (non-transgenic) cultivars available on the market. Seed is one of the main components of the cost of maize production. Thus, farmers that obtain lower yield are not able to afford to pay the relatively high costs of the high technology hybrid seeds or to improve their production system, but it is possible to obtain satisfactory results through lower seed investments. Intervarietal hybrids may represent an alternative for meeting the needs of small and medium-sized farmers, with fewer resources for investments in inputs and seeds, and for supplying varieties that meet the needs of the small maize grower. This review presents a history of conventional maize breeding in Brazil and describes the main maize cultivars with low-cost seeds developed by public R&D companies, mainly focusing on the Instituto Agronômico (IAC) as an option for small and medium-sized maize growers in Brazil.

Keywords: intervarietal hybrids, small growers, varieties, Zea mays

HISTÓRICO, DESENVOLVIMENTO E MERCADO DE CULTIVARES DE MILHO DE BAIXO CUSTO DE SEMENTES NO BRASIL

Resumo - O milho é um dos cereais mais produzidos do planeta. Constitui uma das espécies de maior interesse econômico e fornece múltiplos produtos com aplicações em diversos setores, desde rações, produtos industriais até alimentação humana. Cada vez mais as empresas representantes desse segmento lançam híbridos de milho geneticamente modificados como forma de garantia de retorno aos investimentos, diminuindo a oferta de cultivares convencionais (não transgênicas) disponíveis no mercado. A semente é um dos principais componentes do custo de produção de milho. Assim, a falta de condições dos agricultores que obtêm menor produtividade é fator limitante para pagar os custos relativamente altos das sementes de híbridos de alta tecnologia, bem como de aprimorar o seu sistema de produção, mas é possível obter resultados satisfatórios com investimentos menores em sementes. O híbrido intervarietal pode representar uma alternativa para o atendimento de pequenos e médios agricultores, com menos recursos para investimentos em insumos e sementes, bem como as variedades, que atendem às necessidades do pequeno produtor de milho. A presente revisão apresenta um histórico do melhoramento convencional de milho no Brasil e descreve as principais cultivares de baixo custo de sementes de milho desenvolvidos por empresas públicas de P&D, com maior enfoque no Instituto Agronômico (IAC), como opção para os pequenos e médios produtores de milho no país.

Palavras-chave: híbridos intervarietais, variedades, Zea mays, pequenos produtores.

How to cite

Maize is one of the cereal crops most produced on the planet. In the 2019/2020 crop year, Brazil achieved total production of 1.11 billion metric tons, with 35% directed to export, 9.5% to industrial consumption, and 1.1% to human consumption (Paterniani and Fachini, 2020).

*Zea mays* L. is a monoecious species with open pollination and has broad natural genetic variability, with approximately 300 races identified. Its favorable cycle and reproduction traits make it a model for genetic studies of allogamous species (Paterniani et al., 2000a). Intervarietal hybridization plays an important role in maize breeding. In evolutionary terms, many of the currently established maize varieties were synthesized from intervarietal crosses.

From the perspective of plant breeding, maize is the greatest example of successful use of heterosis, and breeding programs of private companies in general focus on the development of transgenic single hybrids. There are very few conventional (non-transgenic) maize cultivars on the market and for human consumption, and this represents a promising niche for public research and development companies.

The high cost of seeds is one of the determining factors in the choice of the type of cultivar adopted in low-investment and subsistence agriculture, which leads to use of one’s own seeds and of advanced generations of hybrids (Pacheco et al., 2010). Expenditures on this input can represent around 20% of the value of financing the crop, but it is possible to obtain satisfactory results with smaller investments in seeds.

Due to the immense volume that the maize seed industry represents and, in spite of high competition in the sector, the maize seed market mainly focuses on serving the main niche of current production, the feed production market. More and more, the companies representing this segment release genetically modified maize hybrids as a manner of ensuring return on related R&D investments and to ensure marketshare, which reduces the supply of conventional (non-transgenic) cultivars available on the market. In the 2019/2020 crop year, only 10% of all the maize planted was of conventional seeds (Abimilho, 2020).

Considering the domination of the seed market by multinational companies, the public institutions of Brazil, such as Embrapa, the Universidade Estadual de Maringá (UEM) and the Instituto Agronômico do Paraná (IAPAR) in the state of Paraná, and, in the state of São Paulo, the Instituto Agronômico in Campinas (IAC) (Sawazaki and Paterniani, 2004) and the Coordenadoria de Desenvolvimento Rural Sustentável (CDRS), formerly known as the Coordenadoria de Assistência Técnica Integral (CATI), of the Department of Agriculture of the state, diversified their plant breeding programs and focused on meeting specific demands and market niches. An alternative adopted by IAC was to direct breeding to the markets of intervarietal hybrids and of special maizes for human consumption (popcorn and green corn).
This review presents a history of conventional maize breeding in Brazil and describes the main maize cultivars with low-cost seeds developed by public R&D companies, mainly focusing on the Instituto Agronômico (IAC) as an option for small and medium-sized maize growers in Brazil.

**Low-cost cultivars: Intervarietal Hybrids and Maize Varieties**

**History**

The first hybrid maize breeding program in Brazil, after that of the USA, began in the Instituto Agronômico (IAC) in 1932 by Krug and associates, who released the first double-cross maize hybrid in 1939. The method of exploiting hybrid vigor, which revolutionized maize breeding and has allowed high yields to be achieved up to today, has thus been at work for around 90 years in Brazil.

Intervarietal maize crosses have been of great importance in maize breeding programs. Beal (1877) was the first to report hybrid vigor in crosses between maize varieties. From then until the beginning of this century, various studies were performed. Beal (1880) reported results of intervarietal hybrids, such that the hybrids proved to have 10% to 50% higher yields than the parents. Rychey (1922) summarized results from 244 intervarietal hybrids and observed that 82.4% exceeded the mean of the parents and 55.7% exceeded the highest-yielding parent. Griffee (1922) mentioned data from various authors in the period from 1892 to 1919, where, in 157 intervarietal hybrids, heterosis in yield ranged from 11.9% to 81.0% in relation to the mean of the parents and from -3.0% to 43.7% in relation to the highest-yielding parent.

As Jugenheimer (1958) reported in an extensive review on that time period, although intervarietal hybridization proved to be promising, it did not come to be used commercially, due to the difficulty of obtaining seeds. In that same period, hybrid vigor in crossing lines was also studied, where Shull (1908; 1909) and East (1909) found that crossing inbred maize lines resulted in an extremely high vigor and high yielding F₁ generation. In 1918, Jones (1918) suggested the use of double-cross hybrids, which are the result of crossing two single-cross hybrids. Since double-cross hybrid seeds were easily and economically produced, the interest of researchers returned to the method of hybrids from lines, and intervarietal hybridization was practically forgotten. In 1940, when the programs of obtaining double-cross hybrids reached a high point and stagnated, not providing return on the effort made, interest returned to the intervarietal crosses (Paterniani, 1967).

Conceptually, there are basically the following types of hybrids: single-cross (obtained through crossing two inbred lines); three-way-cross (obtained by crossing a single-cross hybrid with a third line); double-cross (resulting from crossing two single-cross hybrids, that is, coming from the cross between four lines); top cross (cross of a line with a variety); and intervarietal
cross, which is the result of crossing two varieties (Sawazaki and Paterniani, 2004).

Intervarietal hybrids are obtained in a direct way by crosses between two or more parent varieties. They have a genetic base that is intermediate between single-cross hybrids and varieties. Their advantage over varieties is the opportunity of taking advantage of / exploiting heterosis and, consequently, higher yield.

In IAC, from 1939 to 1942, diverse intervarietal hybrids were developed with the aim of taking advantage of traits of economic value of some varieties that had been introduced at that time in the germplasm bank of the institution. A yield increase in the hybrids was found, especially from the crosses between Brazilian varieties with Mexican and American varieties, indicating that heterosis depends on the degree of genetic divergence of the material that is crossed (Krug et al., 1943).

According to the reports of the former cereal crop section of IAC from 1936 to 1949, the varieties yielded from 2500 to 3000 kg ha\(^{-1}\). The origin of these varieties is unknown, with many coming from introductions or from selection of types practiced by farmers, collected from local maize growers, receiving names of the region or of the municipality of collection, such as Cateto Vermelho, Cristal, Amparo, Armour, and Itaiici.

After obtaining the first hybrids through IAC and then through Sementes Agroceres, there was a significant increase in yield. The double-cross hybrid H 4624 began to be produced in 1953. It was a semi-dent hybrid, released by IAC, which was 43% higher yielding than the Armour variety. In this same period, the Azteca variety was under testing, one of the most important contributions of IAC to breeding of varieties, obtained from maize samples from Mexico. This exotic variety – compared with the hybrids in 27 trials from 1955 to 1957 – yielded 56% more, matching the semi-dent hybrid H 4624 (Sawazaki and Paterniani, 2004).

H 7974 was the most successful hybrid produced by the Department of Agriculture of the State of São Paulo, and it remained on the market from 1966 to the middle of the 1980s. It was used as a check cultivar in the National Maize Trials up to 1986/87, when it was replaced by the hybrid H 8214 (Sawazaki and Paterniani, 2004).

Studies carried out by the Rockefeller Foundation (1963, 1965) in Mexico showed that a Michoacán maize line drastically reduced its growth under dry conditions. When water was once more provided, its growth was quickly reestablished. This trait was called “latent”. In IAC in the 1960s, the work began in breeding populations that aimed at the synthesis of the highest-yielding intervarietal hybrids and, at the same time, introduction of “supergenes” in the parent populations to obtain hybrids more resistant to unfavorable environmental factors. In 1966, the IAC Maya variety was released, which has maintained characteristics of drought tolerance and cold tolerance until now.

With refinement of the ear-to-row methods (Lonquist, 1968), the selection method
among and within half-sib families was developed (Paterniani, 1967), and at that time there was an increase in the breeding programs of varieties at Escola Superior de Agricultura Luiz de Queiroz (ESALQ) and at IAC.

The varieties developed by the IAC program in the past are as follows:

- **IAC Azteca**: originating from maize samples from Mexico, from San Louis de Potossi, of the Tuxpeno race. This variety showed the same yield capacity as the hybrid H 4624.

- **IAC Maya**: obtained from the combination of a variety and 19 lines, coming from Tuxpeno, Tuxpan, and Azteca. The Maya variety produced around 11% more than Azteca.

- **IAC 1**: obtained from chain crosses of the lines IP 48-5-3, IP 365, IP 365-4-1, IP 398, Linea 1 from Colombia, IP 701-1, SPP 103-3, TX 303, and PD (MS)6. It yielded 24% more than HMD 6999B (Miranda et al. 1978).

- **IAC Taiúba**: obtained from intercrossing 13 populations – twelve hybrids and a variety; it has a normal cycle, dent-type orangish yellow kernels, and tolerance to aluminum toxicity in the soil, allowing growing in acid soils.

The following varieties were obtained at ESALQ:

- **Piramex**: developed in 1969 from the Tuxpeno germplasm. It had yield capacity near that of H 6999-B, a double-cross hybrid, and was quite widely disseminated among farmers in the South region of Brazil and also in the North and Northeast.

- **Piranão**: in 1971, from the cross between Piramex and a Tuxpeno material homozygous for the recessive gene br2, which conditions reduced size of plants. In generations subsequent to crossing, the material was selected for yield and standardization of height, as well as other traits. It was well received in the market.

According to Guimarães (2020), up to the 1970s, the maize crop in Brazil was based on tropical cultivars, with late cycle and tall size. The germplasm at that time had few materials for traits such as low plant and ear height, resistance to lodging and breakage, an earlier cycle, and suitability for growing at greater densities and for mechanized harvest. Because of the very late cycle, second crop maize was not sown, and there were greater risks of frustration of the first crop seasons in the constant dry periods that occur at the time of flowering, called *veranicos* (unseasonal hot summer conditions). The large area of acid soils in Central Brazil, which at this time is responsible for a considerable part of Brazilian maize production, practically was not used at that time for growing maize, both because of the low use of suitable systems of soil correction, such as liming and fertilization, and because of the lack of maize genotypes adapted to these environments. The use of varieties and hybrids that had much lower yield potential predominated.

The few breeding programs at that time
had a much lower testing capacity, with manual planting and harvest of experimental plots, and crop trial networks with few locations. There were also no cultivars tolerant to temporary flooding; consequently, no suitable cultivars were available for planting in systemized floodplains. In the states in the North region of Brazil, subsistence agriculture had practically no improved variety that could be used by small local farmers.

At EMBRAPA, many populations have been developed and improved, mainly aiming to adapt them to Brazilian environmental conditions. In studies developed in network throughout the country, crucial information was also obtained regarding the potential of these new populations for development of hybrids and varieties. This great collective effort resulted in the dissemination of new populations (such as BR 106, BR 107, BR 105, BR 111, BR 112, CMS 04, CMS 28, and CMS 50) and information that impacted the basis of all maize cultivar development programs, whether public or private.

**Intervarietal Hybrids and Varieties in the 21st Century**

Currently, the genetic base available for diverse breeding programs in Brazil is much better and broader. New cultivars have had a positive impact on the production and yield of the maize crop in Brazil, allowed the occupation of marginal areas (Cerrado, systematized floodplains) and seasons (second crop seasons), reduced the risk of possible veranicos affecting all the maize cultivars of a determined region in the critical phase of development, and allowed the generation of new maize-based products.

The current seed market is dominated by the oligopoly of seed companies, by the production of transgenic seeds (after they were released for use in Brazil), and by the small share of conventional (non-transgenic) cultivars in the market.

This market has shown a consistent percentage of transgenic crops over the years. In the 2017/2018 crop year, the percentage of transgenic seeds that went to the market came to 65.43%, and 34.56% were seeds from conventional maize cultivars (ISAAA, 2020).

Pereira Filho and Borghi (2020) show the evolution in the number of maize cultivars available as of the 2000/2001 crop year. Reduction in the number of maize cultivars as of the 2016/2017 crop year was due to changes that occurred through mergers and acquisitions of multinational groups. Since then, the number of cultivars has grown very little, and, with new events being introgressed in materials already available on the market, there may be the misunderstanding that new materials were not available. However, data collection shows that there have been replacements, and those that have been released as new items have occupied the space of conventional cultivars.

In the 2009/2010 crop year, the proportion of transgenic crops grew exponentially, and since the 2014/2015 crop year, this proportion has been greater than 60%, except for the 2015/2016 crop.
For the 2019/2020 crop year, the proportion of cultivars with a transgene event represents 67% of the total of maize materials available on the market (Pereira Filho and Borghi, 2020, Figure 1).

The demand for conventional cultivars, however, has continued, especially among small and medium-sized growers and to serve niche markets, such as maize as a direct human food (popcorn, fresh corn, and white corn). Cultivars with low seed cost also continue in demand for areas of refuge within transgenic crop areas, and they are practically not found in the Brazilian seed market.

The intervarietal hybrid was especially developed to meet the demand of small or medium-sized rural growers that use lower-yielding production systems and that lack higher-yielding seeds, though at prices that do not make their production unfeasible. These hybrids, also called hybrids from F₂ populations, double-cross hybrids from F₂ generations, synthetic hybrids, or simplified double-cross hybrids, originate from crossing F₂ generations of single-cross hybrids or from crossing two synthetic hybrids.

Souza Sobrinho et al. (2002) compared the performance of double-cross hybrids derived from the F₁ and F₂ generations of commercial single-cross hybrids and observed that the performance of the double-cross hybrids of F₂ was similar to the performance of hybrids derived from the F₁ generation of single-cross hybrids. Furthermore, according to these authors, the use of the F₂ generation of populations derived

![Image](image.png)

**Figure 1.** Evolution in the number of cultivars with transgenic events and their percentage in relation to the total number of cultivars, from data collection made by Embrapa Milho e Sorgo from crop years 2008/2009 to 2019/2020.

Source: EMBRAPA, Pereira Filho and Borghi (2020).
from single-cross $F_1$ hybrids to generate double-cross hybrids is one of the best alternatives for reducing costs.

The double-cross hybrids produced by crossing the $F_2$ or $F_3$ generation derived from single-cross hybrids should respond like the double-cross hybrids produced with $F_1$ single-cross hybrids, as long as there is no selection that can cause changes in the gene frequencies. Kiesselback, in 1930, found that this occurs (Allard, 1971). According to the Hardy-Weinberg law, the allele and gene frequencies of a sufficiently large allogamous population will always be the same in the absence of migration, mutation, and selection (Hallauer & Miranda Filho, 1988; Pugh & Layrisse, 2005).

The cost of producing seeds from $F_2$ or intervarietal hybrids is reduced because the steps of obtaining and multiplying lines are eliminated, with only the need for maintenance and production from the fields of the parent populations. The intervarietal hybrids allow the use of heterosis without the need for obtaining lines (Sawazaki and Paterniani, 2004).

The relevant point of the process of obtaining a hybrid from $F_2$ populations is the simplification of seed production, which reduces costs. To better understand how this occurs, we make the following review: In production of hybrids from lines, the plants of a population are inbred, generally through successive self-fertilizations from six to eight generations, until obtaining homozygotic or pure lines. This process of maintaining lines and obtaining hybrids from lines is expensive and is performed every year. Currently, the techniques of obtaining lines through doubled haploids is an efficient alternative, but it does not apply to growers of a low or medium technological level, due to the high cost.

$F_2$ parent populations are used in production of a hybrid from $F_2$ populations. These parent populations could be maintained in isolated lots and used every year to obtain the hybrid from $F_2$ populations (Pugh & Layrisse, 2005).

With this same philosophy, Amorim & Souza (2005) evaluated the viability of producing hybrids from $F_2$ populations of commercial single-cross hybrids. For that purpose, crosses to obtain hybrids were carried out in a paired interpopulational and intrapopulational arrangement, without replication of plants; and $F_2$ interpopulational hybrids superior to the mean of the commercial hybrids were identified.

The study developed by Doná et al. (2009) showed promising $F_2$ populations regarding per se performance; and the yield potential of hybrids from $F_2$ populations as an alternative for commercial maize production was corroborated. Some parent populations stood out with high heterosis values of parents according to the model of Gardner and Eberhart (1966), and three hybrids of high yield and with specific heterosis for grain weight were observed. Bernini and Paterniani (2012) confirmed the yield potential and the heterosis of hybrids from $F_2$ populations of maize, with mean heterosis of 33% for grain
yield. The productivity level of hybrids from F₂ populations was high and compatible with the commercial witness. (Figure 2).

Pacheco et al. (2010) highlighted that, in addition to good agricultural performance, the main advantage of double-cross hybrids coming from the F₂ generation is related to the low cost of their seeds, which has allowed the interests of grain and seed growers to be served at the same time. The disadvantage of the hybrid from F₂ populations would be the lack of uniformity of the plants in the flowering period, resulting in lower seed production from the hybrids in the diallel crosses and in the production fields.

The methods of obtaining hybrids from F₂ or synthetic populations is the use of diallel crosses, especially through use of the models of Griffing (1956) and Gardner & Eberhart (1966), which allow estimation of the combining ability of the parent populations. After that, there is the need for extensive yield tests of the superior combinations in various environments (Paterniani & Bernini, 2010).

IAC now develops new types of conventional (non-transgenic) hybrids for growers of mid-level technology and to meet demands in São Paulo and Mato Grosso do Sul. They are hybrids with low cost, high yield, resistance to the main maize leaf diseases, early maturity, and low lodging and stem breakage, which are directed to properties with mid-level technology and have good adaptation for growing summer season and second crop maize.

![Figure 2](image_url)

**Figure 2.** Yield of the best hybrids of F₂ populations (P1, P2, and P3) of maize in three locations of the state of São Paulo (Bernini & Paterniani, 2014).
Main Intervarietal Hybrids of the IAC Breeding Program

- IAC 8333: result of the cross of two synthetic hybrids of high uniformity and good agronomic characteristics that have high genetic divergence; it was the first intervarietal hybrid as of 2000 to meet the needs of growers that use low- to mid-level technology, with the differential of having lower seed cost. The high yield potential, together with good agronomic characteristics, such as short plant height, early maturity, resistance to the main maize diseases, and orangish semi-flint grain, made IAC 8333 a good option for growers of the Central and South regions of Brazil.

- IAC 8390: material of excellent quality and yield for silage, since it has above average crude protein, starch, and digestible organic matter yield. The kernels of IAC 8390 are harder (flint) and more orangish. Although the plant of this hybrid is relatively taller, it has good resistance to lodging and breakage. IAC 8390 has good resistance and tolerance to the main maize leaf diseases, along with above average grain yield, and it is recommended for grain and silage production in the states of São Paulo, Minas Gerais, Mato Grosso, Mato Grosso do Sul, Goiás, and Paraná.

- IAC 8046 and IAC 8077: conventional intervarietal maize hybrids, non-transgenic, with yield potential of nine to ten tons of grain per hectare. The hybrids have large diameter ears, a characteristic that results in greater grain production per plant. IAC 8046 has long dent and semi-dent kernels, and the ear retains little silk, characteristics that are also suitable for fresh corn production. Moreover, IAC 8077 is more tolerant to drought.

- IAC 3330: a hybrid ideal for the second crop precisely due to high disease resistance, especially to Cercospora blight and to white (or tropical) rust. With medium plant size and semi-flint kernel, it is ideal for industry and for feed production. As this hybrid has an early cycle, it is recommended for sowing in late summer in locations with high disease pressure. As a second crop, it is recommended for the state of São Paulo and the Center-West region of Brazil.

- IAC 8053: recently released, in 2019, it can be used for grain production for feed and for fresh corn, or for making cakes, corn custard (curau), corn paste (pamonha), and juices. The properties of the ear are ideal for use in cooking. The kernels are large with a light yellow color, large ears with straight rows that facilitate silk removal, and a thin hull.

Some grain yield results of these intervarietal hybrids in various agricultural years are shown in Figures 3 and 4.

VARIETIES

A maize variety is a set of plants with common agronomic characteristics. It is a genetically stable material and, for that reason, with due care in its multiplication, it can be
Figure 3. Grain yields of maize (kg.ha⁻¹) in 3 environments in the South region of the state of São Paulo (2021).

Figure 4. Grain yield of maize (kg.ha⁻¹) in the Central region of the state of São Paulo (2021).
reused for several crop seasons without any loss in its yield potential.

The population breeding method most used for development of varieties is recurrent selection. In 1964, Lonquist suggested the use of modified ear-to-row selection, and Paterniani (1967) proposed the description of “selection among and within half-sib progenies”, essentially dealing with evaluation and selection of half-sib progenies and then of selection of the best plants within the progenies selected, in recombination lots.

The method consists of the following: Initially, ears are obtained from open pollination of the population to be improved. The ears of each plant constitute only one half-sib progeny. The ears are threshed and the progenies of each are placed in separate bags. The half-sib progenies are evaluated in production trials where all the traits of interest will be noted. Usually, 200 to 500 progenies are evaluated. The best progenies are chosen in accordance with the results of the trials. Generally, selection intensity in the order of 10% to 20% is practiced. This step constitutes the selection among progenies. The best progenies selected are recombined with each other in the following generation, using remaining seeds from these progenies. A suitable procedure consists of sowing an isolated lot of detasseling, where the progenies selected will constitute the female rows and the male rows will be sown with a mixture of seeds from the selected progenies, in the proportion of 3:1 (“Irish Method”) (Paterniani, 1978).

Genetic resources are essential for food security, especially development and maintenance of local varieties, furthermore highlighting the strategy of decentralized breeding to develop plant varieties adapted to favorable environments.

In IAC, the program obtained varieties that were higher-yielding, tolerant to acid soils, taller, tolerant to abiotic stresses, and with greater nutritional value, as, in this case, the opaque and latent variations of the varieties (IAC Maya latente, IAC Maya opaco 2, etc.)

In 2011, the variety IAC Airan was released. The cost of IAC Airan is extremely competitive – one of the lowest among the materials available on the market, with yield compatible with the varieties. Another advantage of IAC Airan is lower plant height and greater uniformity, ideal for mechanical harvest. This material is recommended for grain production in the main crop and second crop seasons in the Center-West region of Brazil. It is ideal for small growers, precisely because of its cost-benefit ratio and by being a viable crop with few technological resources.

A point of extreme importance in the production of varieties and conventional hybrids is the production of organic maize. Souza et al. (2019) evaluated intervarietal hybrids and varieties of CATI in this production system and showed that several of these low-cost cultivars had excellent performance and yield.
The CATI Program for Production of Varieties

The program for commercial varieties of maize of the state of São Paulo, together with the state Department of Agriculture (SAA), was developed by CATI at the Ataliba Leonel Farm in Manduri, São Paulo. The Agronomic Engineer Sylmar Denucci presents his history, which coincides with the CATI maize varieties program beginning in 1984:

“I entered in the DSMM/CATI in January, 1984, taking a position at the Ataliba Leonel Farm, Manduri, SP, SAA/SP. The glory years of HMD7974, produced by IAC, had already ended, then replaced by IAC 8214, also a double-cross hybrid that conserved 3 of the 4 lines of 7974. IAC 8214 had yield potential superior to 7974, but did not match its hardiness.

With the broad expansion of research and production of the maize seed industry occurring at that time, the share of the SAA/SP in this market significantly decreased year by year and intensified with the rise of growing second crop maize.

We, the extension agents of CATI, urgently needed genetic material of the variety type, hardy, good yielding, with lower plant height, and with a cost of production that allowed a final commercial seed price more affordable to small farmers and to family farms. We prepared ourselves and began our own work of selection in this regard. This work of mass selection, with constant effort of stratification, the method of which was described and published in Technical Bulletin (Boletim Técnico) 106 (confirmar) of CATI, gave rise to 2 open pollination varieties (AL 25 and AL 34, the abbreviation AL in honor of the Ataliba Leonel unit where the lines and single-cross hybrids of the HMD7974 and of its successor IAC 8214 were maintained and produced for approximately 3 decades), registered in the MAA, and released commercially in 1992. The varieties mentioned, coming from different populations, were very well received by farmers in São Paulo, especially small and medium-sized maize growers – the variety AL34, with normal cycle and semi-flint kernels, was preferred in the central and northern regions of the state; and AL25, with a semi-early cycle and semi-dent kernels, was preferred in the regions and areas with milder climate. Due to its characteristics, the AL25 variety also proved to be quite suitable for growing in the second crop (safrinha) period. Field-level confirmation of trial results that indicated the good performance of the two new varieties directly obtained by the DSMM/CATI encouraged continuity of the work of selection of varieties coming from the composites that were carefully established annually at Ataliba Leonel.

Still in the 1990s, other varieties were released: “AL Manduri” (flint kernels), “CATI AL30” (normal cycle, with yield potential superior to AL34), Cativerde 01 and 02 (dent kernels and specially selected for fresh corn production), and AL Bianco [flint kernels and white endosperm, for production of white maize canjica (sweet porridge) and corn meal].

In 2001, the variety AL Bandeirante
was released, with normal cycle and semi-flint kernels, shorter plant height and better plant architecture than those of the previous varieties, as well as superior yield potential. This variety was very well received in practically all regions of Brazil and until now is multiplied by private initiative.

To pair up with Bandeirante, the variety AL Piratininga was then released, with semi-dent kernels and a slightly earlier cycle. In fact, AL Bandeirante and AL Piratininga, conserving the fundamental characteristic of the open pollination and non-transgenic varieties AL34 and AL25, were adopted as evolutions of these, although they are distinct genotypes. At the end of the first decade of 2000, the variety AL Avaré arose. The emphasis on its selection, in addition to greater yield, was reduction in the average size of the plants and ears. Finally, the last variety released by the DSMM/CATI in which I participated in the breeding and selection work was AL Paraguaçu, registered in MAPA in the middle of the 2010s, with semi-flint kernels and potentially higher yield, and plant lodging and breakage rates lower than AL Avaré.

In 1983, the Ataliba Leonel Farm still had more than one hundred fixed staff and more than another hundred temporary workers. There were a lot of challenges. One of them was the need for diversification of seed production due to the reduction in annual need for single-cross maize hybrids to meet the demand of the SAA/SP and of private initiative, and the urgency of crop rotation for recovery of soil fertility hurt by years of growing exclusively maize. These and other objectives were achieved over the 16.5 years in which I was part of the staff of the unit, and 15 of those years being responsible for directing it.

Nevertheless, the “Ataliba Leonel Farm”, as that unit of the SAA/SP is still referred to until now, also came to suffer the consequences of successive state administrations that failed to prioritize agriculture and came to use the SAA/SP as a bargaining chip in composing political support during their governments. So, in spite of all the struggle, dedication, and creativity of its staff and of all the DSMM/CATI, Ataliba Leonel, just as so many other units of the SAA/SP, it is no longer able to maintain the importance and the services that for so many decades it was able to show and offer.

I and all the public servants that had their professional and personal lives directly related to and intimately marked by the magnificent opportunity of participating in the vibrant “life” that the Ataliba Leonel Farm once offered to all cannot understand or acquiesce in the sad situation to which that incredible “Farm” was reduced.

I retired through length of public service in August 2016.”

The Embrapa program for production of varieties

Currently, the genetic base available to the diverse breeding programs in Brazil is much better and broader. There was massive
introduction of early cycle materials developed by CIIMYT (International Maize and Wheat Improvement Center), much different from the past, when there were basically only late cultivars. Earlier cultivars were and are important for achieving gains in the second crop season, which has come to be the main season for maize, as well as for sowing early in the South of Brazil and for “escaping” the drought in the semi-arid region.

These cultivars have had a positive impact on the production and yield of the maize crop in Brazil, have allowed the occupation of marginal areas (Cerrado, systematized floodplains) and marginal seasons (the second crop season), reduced the risk of possible veranicos affecting all the maize cultivars of a determined region in the critical phase of development, and allowed the generation of new maize-based products.

Innovative products have been developed in this program, highlighting cultivars with the following features: adaptation to acid soils (BR 201 and BRS 1001); efficiency in use of phosphorus (BRS 3060 and BRS 1010); high protein quality (BRS 2121); fresh corn (BRS 3046) and sweet corn (BRS VIVI); and some varieties, such as those featuring tolerance to waterlogged soil (BR 4154 - Saracura); high provitamin A carotenoid content (BRS 4104, BRS 1055); high quality protein (BR 451, BR 473, and Assum Preto); sweet corn (BR 401); greater efficiency in nitrogen use (Sol da Manhã); very early maturity cultivars for the semi-arid region that “escape” the drought (Assum Preto and Caatingueiro); adaptation to the Northeast region (Gorutuba, São Francisco, Asa Branca, Cruzeta, and Sertanejo); and adaptation across Brazil (BR 106, probably the cultivar most grown in Brazil in its time).

The characteristics of some cultivars with low seed production cost developed by this program are described below:

- **BR 106**: composed of 3 Tuxpeno varieties adapted to Brazilian conditions, but with tall plants and late maturity, which were crossed with the variety Tuxpeno-1 introduced from CIMMYT as a source of early maturity and low plant height. Over nearly two decades, this was the maize variety most planted in Brazil and it has still been a source for extracting tropical maize lines greatly used in Brazil.

- **BR 4154-Saracura**: formed from a composite of 36 population, it was developed to have greater tolerance to temporarily waterlogged soil. The name “Saracura” is a reference to a bird commonly found on marshy lands; the variety is appropriate for planting in floodplains or areas with temporary excess of water and can be used for production of grain, fresh corn, and forage.

- **BRS Sol-da-Manhã**: was formed and selected with the aim of meeting the needs of farmers that have soil stress problems related to nitrogen. The various selection cycles of this variety were carried out in environments with low natural fertility and a low level of nitrogen.
• BRS Caatingueiro: is a very early maize variety that flowers between 41 and 50 days, with the advantage of reducing the risk of drought stress in the period in which maize is most sensitive to lack of water. This very early maturity allows harvest in 90 to 100 days, with yield ceilings ranging from 2 to 3 t of grain per hectare in the driest part of the semi-arid region.

• BRS Gorutuba: developed focusing on growers in the Sertão (dry hinterlands) of the Northeast region, where the rains are scarce and in a short period. This variety has open pollination and a very early cycle, appropriate for regions where the rainy period might not be long enough for early cultivars to complete their reproductive cycle without reduction in yield potential.

• Assum Preto: a variety with grain of better protein quality and a very early cycle; developed for the semi-arid region of the Northeast.

• BRS 451: variety with white grain and better protein quality, and lysine and tryptophan contents greater than those of common maize.

• BRS Missões: has an early cycle and yellow dent-type kernels with excellent yield potential. Recommended for growing in Rio Grande do Sul, Santa Catarina, and the south of Paraná.

• BRS Caimbé: synthetic variety with an early cycle. Recommended for family farming, under the main crop and second crop conditions.

• BRS 4103: especially recommended for low investment agriculture. It shows uniformity, an early cycle, and short plant and ear height. Because of its wide adaptation, it was registered in the Ministry of Agriculture for all regions of Brazil.

• BRS 4104: synthetic variety with an early cycle. It has greater concentrations of vitamin A precursor carotenoids. Carotenoids are substances present in foods that are transformed into vitamin A in the human body through chemical reactions. In this more nutritional variety, the average concentration of pro-vitamin A is from 2.5 to 3.2 times greater than the values found in common maize.

Breeding of Maize Populations in IAPAR

(Currently, Instituto de Desenvolvimento Rural do Paraná – IAPAR – EMATER or IDR-PR)

Using different recurrent selection techniques, the aim of this activity is continual and gradual improvement of agronomic traits of populations, seeking greater adaptation, resistance to biotic and abiotic stresses, nutritional quality, and yield. Initially, populations were introduced from IAC, ESALQ, Embrapa Milho e Sorgo, and CIMMYT, or collected on farm properties. Currently, the formation of composites and synthetics within the project is the main source
of populations for breeding purposes. For that reason, the activity makes continual analysis of the performance of commercial hybrids and evaluation of diallel crosses or top crosses involving varieties, hybrids, and lines.

The improved populations are useful for obtaining lines and also for commercial purposes as open pollination varieties, which even now represent an alternative for some segments of agriculture such as small farmers, for some growing seasons or conditions of greater risk in which hybrids cannot express their genetic potential, and for organic agriculture.

Since the beginning of the program, the varieties IAPAR 15, 26, 50, and 51 were released; and after promulgation of the Cultivar Protection Law, the varieties IPR 114, IPR 164, and, now in 2021, IPR 216 were released.

The varieties IPR 164 and IPR 216 are synthetic varieties obtained through crossing 6 commercial hybrids each one. These hybrids were selected based on the trials of early-cycle commercial hybrids of IAPAR. For multiplication of these hybrids, IAPAR relies on partners in the states of Goiás, Mato Grosso do Sul, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul.

**Final Considerations**

The maize seed market in Brazil is dominated by cultivars of transgenic single-cross and three-way-cross hybrids, with greater seed cost and production technology.

Maize production systems are very heterogenous since they range from highly technified systems to subsistence farming, and this explains the low mean yield in Brazil. Public research and technology production institutions have sought to serve new niche markets and produce hybrids and varieties with lower seed cost and conventional (non-transgenic) hybrids and varieties for farmers.

Conventional intervarietal hybrids and varieties constitute ideal alternatives for small farmers and mid-level technology maize growers, with lower seed cost, for crop seasons and growing conditions of greater risk, for regions of biotic stresses, and for marginal regions where hybrids cannot express their potential, as well as for organic growing, where the use of genetically modified seeds is prohibited.

Research and development institutions of public products (IAC, CATI, EMBRAPA, IAPAR, etc.) developed varieties and hybrids beginning with the first Brazilian Hybrid Maize Program at IAC in 1939. In the state of São Paulo, the peak of maize seed production developed by IAC and produced by CATI was in the 1970s and 1980s. Since then, the monopoly of multinational companies, the crisis of the public system, the scrapping of all public research and seed production institutions, the lack of financial and human resources, and political interests have impeded the maize seed production process.

This scenario has been discussed by the scientific community for years. Maize seed production in Brazil should be remodeled and improved with a view toward small growers.
This will only be possible with public-private partnerships and meeting the needs of specific niche markets.

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