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

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Abstract – Maize is one of the cereal crops most produced globally. It constitutes one species of most 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 to ensure 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 yields cannot afford to pay the relatively high costs of the high technology hybrid seeds or improve their production system, but it is possible to obtain satisfactory results through lower seed investments. Therefore, 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 no 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.

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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 a vital role in maize breeding. Many of the currently established maize varieties were synthesized from intervarietal crosses in evolutionary terms.

From the perspective of plant breeding, maize is the most outstanding example of successful use of heterosis, and breeding programs of private companies in general focus on the development of single transgenic 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 choosing the type of cultivar adopted in low-investment and subsistence agriculture, leading to the use of one's seeds and 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, despite high competition in the sector, the maize seed market mainly focuses on serving the central niche of current production, the feed production market. The companies representing this segment have continuously released genetically modified maize hybrids to ensure return on related R&D investments and market share, reducing the available conventional (non-transgenic) cultivars. In the 2019/2020 crop year, only 10% of all the maize planted was conventional seeds (Abimilho, 2020).

Considering the domination of the seed market by multinational companies, the Brazilian public institutions, such as Embrapa, the Universidade Estadual de Maringá (UEM), the Instituto Agronômico do Paraná (IAPAR), the Instituto Agronômico in Campinas (IAC) (Sawazaki and Paterniani, 2004) and the Coordenadoria de Desenvolvimento Rural Sustentável - CDRS (formerly Coordenadoria de Assistência Técnica Integral - (CATI), of the Department of Agriculture, have diversified their plant breeding programs and focused on meeting specific demands and market niches. An alternative adopted by the IAC was to direct breeding to the markets of intervarietal hybrids and special maizes for human consumption, such as popcorn and green corn.

This review presents a history of conventional maize breeding in Brazil and

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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.

History of Low-cost cultivars, Intervarietal hybrids and maize varieties

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 parents' mean and 55.7% exceeded the highest-yielding parent. Griffee (1922) mentioned data from various authors between 1892-1919, where, in 157 intervarietal hybrids, heterosis in yield ranged from 11.9% to 81.0% concerning the parents' mean, and from -3.0% to 43.7% concerning the highest-yielding parent.

As Jugenheimer (1958) reported in an extensive review, although intervarietal hybridization proved promising, it was not 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 high vigor and high yielding F1 generation. In 1918, Jones (1918) suggested using double-cross hybrids, which resulted from crossing two single-cross hybrids. Since double-cross hybrid seeds were quickly and economically produced, the interest of researchers returned to the method of hybrids from lines, and intervarietal hybridization was practically forgotten. In 1940, interest returned to the intervarietal crosses when the programs of obtaining double-cross hybrids reached a high point and stagnated, not providing a return on the effort made (Paterniani, 1967).

Conceptually, there are 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 directly by crosses between two or more parent varieties.

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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 to take advantage of traits of the economic value of some varieties introduced 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 crossed material (Krug et al., 1943).

According to 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 the selection of types practiced by farmers, collected from local maize growers, receiving names of the region or the municipality of collection, such as Cateto Vermelho, Cristal, Amparo, Armour, and Itaici.

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 the breeding of varieties obtained from maize samples from Mexico. Compared with the hybrids in 27 trials from 1955 to 1957, this exotic variety 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 until 1986/87, 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 to synthesize the highest-yielding intervarietal hybrids and, at the same time, introduce “supergenes” in the parent populations to obtain hybrids more resistant to unfavorable environmental factors. In 1966, the IAC Maya variety was released, which still maintains its drought and cold tolerance characteristics until now.

With the 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 IAC. The varieties developed by the IAC program in the past are

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as follows: • IAC Azteca: originating from maize samples from Mexico, from San Luis Potosí, of the Tuxpeno race. This variety showed the same yield capacity as the hybrid H 4624.• IAC Maya: obtained from crosses between 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 H 6999-B, a double-cross hybridwidely disseminated among farmers in Brazil's southern region and the North and Northeast. • Piranão: in 1971, from the cross between Piramex and a Tuxpeno material homozygous for the recessive gene br2, which reduced the size of plants. This material was selected for yield and standardization of height and other traits in generations after crossing. It was well-received in the market. According to Guimarães (2020), up to the 1970s, the maize crop in Brazil was based on late-cycle and tall size tropical cultivars. 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 was a great risk of frustration of the first crop seasons in the regular 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 common 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 had a much lower testing capacity with manual planting and harvest of experimental plots and crop trial networks with few locations. There were no cultivars tolerant to temporary flooding; consequently, no suitable cultivars were available to plant systemized floodplains. In the states in the North region of Brazil, subsistence agriculture had practically no improved variety that small local farmers could use. At EMBRAPA, many populations have been developed and improved, mainly aiming to adapt them to Brazilian environmental conditions. Network studies developed throughout the country generated crucial information regarding the potential of these new populations to develop hybrids and varieties. This great collective effort resulted in the dissemination of new

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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, the production of transgenic seeds (after they were released for use in Brazil), and 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 in 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 a misunderstanding that new materials were not available. However, data collection shows that there have been replacements and those 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 more significant than 60%, except for the 2015/2016 crop year. For the 2019/2020 crop year, the proportion of cultivars with a transgene event represented 67% of the total maize materials available on the market (Pereira Filho and Borghi, 2020, Figure 1). However, the demand for conventional cultivars has continued, especially among small and medium-sized growers and niche markets, such as maize as a direct human food (popcorn, fresh corn, and white corn). Cultivars with low seed costs also continue to demand refuge within transgenic crop areas, and they are practically not found in the Brazilian seed market.

The intervarietal hybrid was specially developed to meet the demand of small or medium-sized rural growers that use lower-yielding production systems and lack higher-yielding seeds, though at prices that do not make their production unfeasible. These hybrids, also

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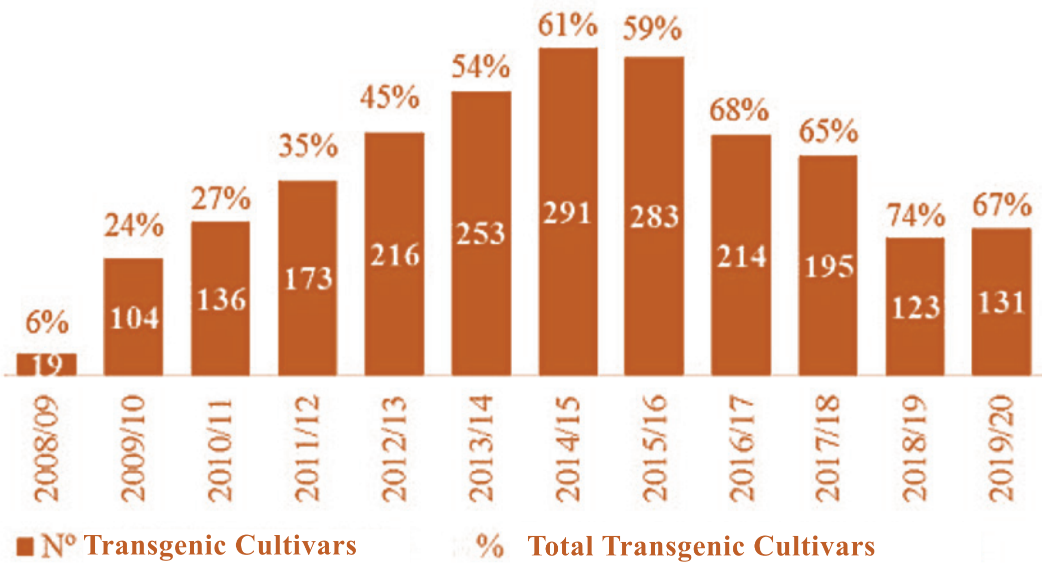

Figure 1. Evolution in the number of cultivars with transgenic events and their percentage in relation to the total number of cultivars, from data collection made by Embrapa Milho e Sorgo from crop years 2008/2009 to 2019/2020.
Source: EMBRAPA, Pereira Filho and Borghi (2020).

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, using the F2 generation of populations derived from single-cross F1 hybrids to generate double cross hybrids is one of the best alternatives for reducing costs.

The double-cross hybrids produced by crossing the F2 or F3 generation derived from single-cross hybrids should respond like the double-cross hybrids produced with F1 single cross hybrids, as no selection 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 sizeable 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 F2 or intervarietal hybrids is reduced because the steps of obtaining and multiplying lines are

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eliminated, with only the need for maintenance and production from the fields of the parent populations. The intervarietal hybrids allow heterosis without obtaining lines (Sawazaki and Paterniani, 2004).

The relevant point of obtaining a hybrid from F2 populations is the simplification of seed production, which reduces costs.

To better understand how this occurs, we do the following review: In producing hybrids from lines, the plants of a population are inbred, generally through successive self-fertilization from six to eight generations, until obtaining homozygotic or pure lines. Maintaining lines and obtaining hybrids from lines is expensively performed every year. Currently, obtaining lines through doubled haploids is an efficient alternative, but it does not apply to low- or medium-scale growers due to the high cost.

F2 parent populations are used to produce a hybrid from F2 populations. These parent populations could be maintained in isolated lots and used every year to obtain the hybrid from F2 populations (Pugh & Layrisse, 2005).

Amorim & Souza (2005) evaluated the viability of producing hybrids from F2 populations of commercial single-cross hybrids with this same philosophy. For this purpose, hybrids were obtained by paired inter-population and intra-population arrangements without replication of plants, and the F2 inter-population hybrids superior to the mean of the commercial hybrids were identified.

The study developed by Doná et al. (2009) showed promising F2 populations regarding per se performance, and the yield potential of hybrids from F2 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 F2 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 the production fields.

The method of obtaining hybrids from F2 or synthetic populations uses diallel crosses, primarily through 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,

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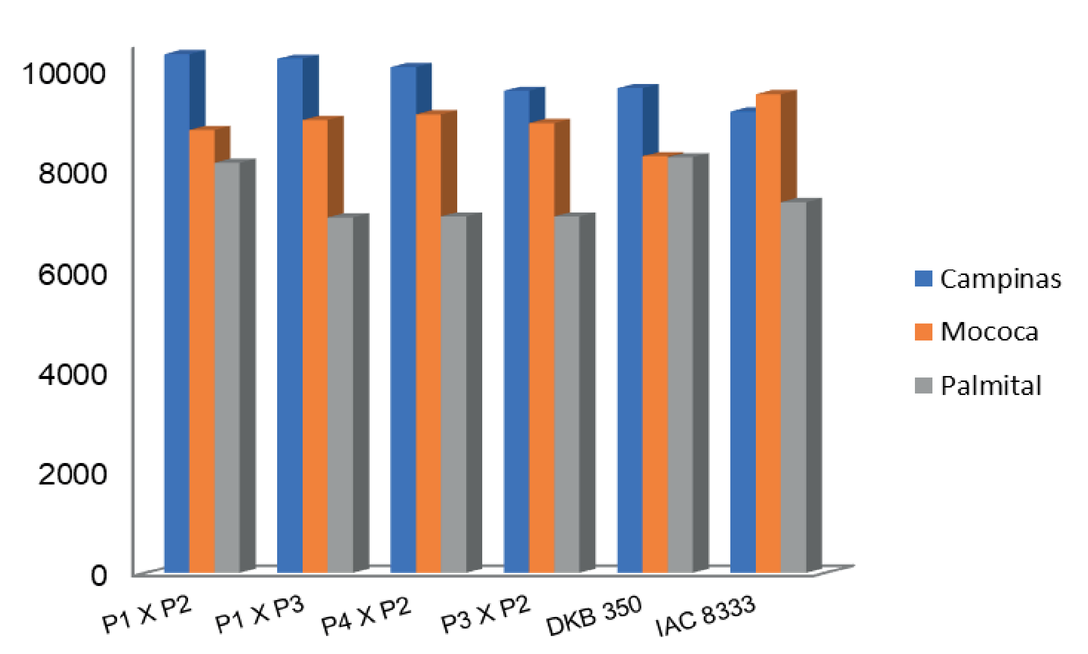

Figure 2. Yield of the best hybrids of F_2 populations (P1, P2, and P3) of maize in three locations of the state of São Paulo (Bernini & Paterniani, 2014).

2010).

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

The most relevant Intervarietal Hybrids of the IAC Breeding Program

• IAC 8333: a 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 and good agronomic characteristics, such as short plant height, early maturity, resistance to the primary 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 plants of this hybrid are relatively taller, it has good resistance to lodging and breakage. • IAC 8390 has good resistance and

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tolerance to the primary 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, yield potential of nine to ten tons of grain per hectare. The hybrids have large diameter ears, a characteristic that results in exceptional 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, the IAC 8077 is more tolerant to drought stress. • The IAC 3330 is a hybrid ideal for the second crop precisely due to high disease resistance, especially to Cercospora blight and to white (or tropical) rust. It is ideal for industry and feeds production with medium plant size and semi-flint kernel. 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 fresh corn, or 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 facilitating 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 reused for several crop seasons without any loss in its yield potential.

The population breeding method most used for developing 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. Then, 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 trial results choose the best progenies, And generally, the selection intensity is10% to 20%. This step constitutes the selection among progenies. The best progenies selected are recombined 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

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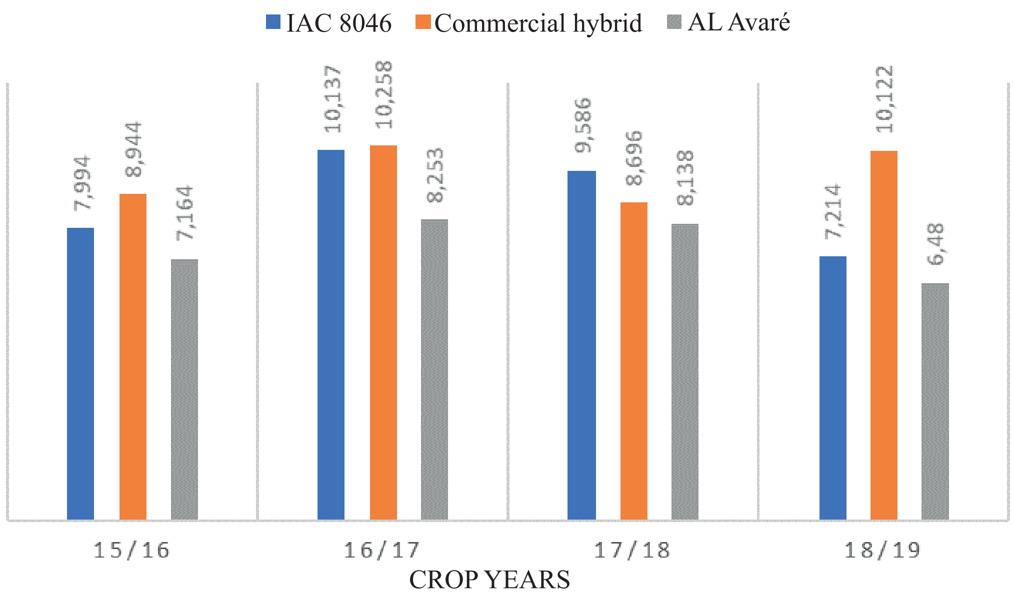

Figure 3. Grain yields of maize (kg.ha^{-1}) in 3 environments in the South region of the state of São Paulo (2021).

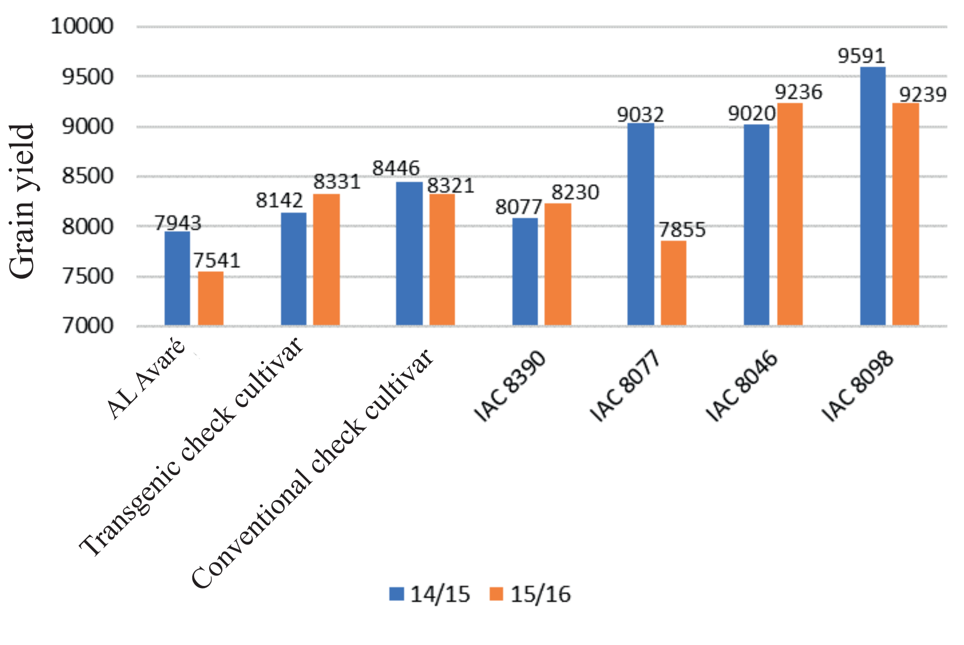

Figure 4. Grain yield of maize (kg.ha^{-1}) in the Central region of the state of São Paulo (2021).

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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 for developing and maintaining local varieties, highlighting the decentralized breeding strategy to develop plant varieties adapted to favorable environments.

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

In 2011, the variety IAC Airan was released. The cost of IAC Airan is highly competitive – one of the lowest among the materials available on the market, with a yield compatible with the varieties. Another advantage of IAC Airan is the lower plant height and excellent uniformity, which is ideal for mechanical harvest. Therefore, this material is recommended for grain production in the main crop and second crop seasons in the Center-West region of Brazil. Furthermore, the IAC Airan is ideal for small growers due to its cost-benefit ratio and a viable crop with few technological resources.

A point of extreme importance in producing 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 low-cost cultivars had excellent performance and yield.

The CATI (Coordenadoria de Assistência Técnica Integral)

The CATI, together with the state Department of Agriculture (SAA) and Departamento de Sementes, Mudas e Matrizes (DSMM) of the state of São Paulo, developed the Program for Maize Varieties Production and commercialization. The program was conducted at the Ataliba Leonel Farm in Manduri, São Paulo state, supervised by the Agronomic Engineer Sylmar Denucci. The history of Denucci coincides with the DSMM/CATI maize varieties program beginning in 1984. In the Agronomic Engineer Denucci's words, "By that time, the glory years of the HMD7974 hybrid produced by the IAC had already ended and replaced by the IAC 8214, a double-cross hybrid that conserved three of the four parental lines of HMD7974. However, despite yield potential superior to HMD7974, the IAC 8214 did not match the hardiness of HMD7974.

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

Thus, as extension agents of CATI, we urgently needed genetic germplasm of the variety type showing characteristics like hard grain, good yielding, lower plant height, and low production cost. In addition, such varieties

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could allow a final commercial seed price more affordable to small and family farmers. We started to work on the stratified mass selection method, which gave rise to two open pollination varieties (AL 25, Piratininga, and AL 34). The abbreviation AL was in honor of the Ataliba Leonel farm, where the lines and single-cross hybrids between the HMD7974 and its successor IAC 8214 were maintained and produced for approximately three decades. Registered in the MAA and released commercially in 1992. The varieties mentioned come from different populations and were very well-received by the São Paulo farmers, particularly the small and medium-sized maize growers. The variety AL 34, with normal cycle and semi-flint kernels, was preferred in the central and northern regions of the state; and AL 25, with a semi-early cycle and semi-dent kernels, was preferred in the regions and areas with a milder climate. Due to its characteristics, the AL 25 variety also proved to be quite suitable for growing in the second crop (safrinha) season. The confirmation of the trial results by field experiments reinforced the excellent performance of the two new varieties and encouraged the continuity of the selection of varieties program from the composites carefully established annually at Ataliba Leonel farm. Still, in the 1990s, the varieties AL Manduri (flint kernels), CATI AL30 (normal cycle, with yield potential superior to AL 34), Cativerde 01 and 02 (dent kernels 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] were released. In 2001, the AL Bandeirante variety was released, with normal cycle and semi-flint kernels, shorter plant height, better plant architecture than previous varieties, and excellent 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. The AL Bandeirante and AL Piratininga, conserving the fundamental characteristic of the open pollination and non-transgenic varieties AL34 and AL25, were adopted as evolutions, although distinct genotypes. At the end of the first decade of 2000, the variety AL Avaré was developed, emphasizing a reduction in the average size of the plants and ears and high yield. Finally, the last variety released by the DSMM/CATI in which Denucci 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 many challenges. One of them was the need for diversification of seed production due to the reduction in the 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

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years of growing maize exclusively. These and other objectives were achieved over the last 16.5 years in which Denucci was part of the Unit's staff, and 15 of those years were 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. Thus, despite the staff's struggle, dedication, and creativity of its staff, and the DSMM/CATI, Ataliba Leonel, many other Units of the SAA/SP, the importance and services of many decades can no longer be maintained. All the public servants who had their professional and personal lives directly related to and intimately marked by the magnificent opportunity to participate 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 the public service in August 2016."

The Embrapa breeding program for varieties production

Currently, the genetic base available to the diverse breeding programs in Brazil is much better and broader. There was a massive introduction of early cycle materials developed by the CIIMYT (International Maize and Wheat Improvement Center), much different from the past when there were only late cultivars. Earlier cultivars are essential for gains in the second crop season, which has become the primary season for early maize sowing in the South of Brazil and escaping the semi-arid region's drought.

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). They also 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); phosphorus-use efficiency (BRS 3060 and BRS 1010); high protein quality (BRS 2121); fresh corn (BRS 3046) and sweet corn (BRS VIVI); tolerance to waterlogged soil (BR 4154 - Saracura); high pro-vitamin A carotenoid content (BRS 4104, BRS 1055); high-quality protein (BR 451, BR 473, and Assum Preto); sweet corn (BR 401); great nitrogen-use efficiency (Sol da Manhã); very early maturity cultivars to escape the drought period in the semi-arid region (Assum Preto and Caatingueiro); varieties adapted to the Northeast region (Gorutuba, São Francisco, Asa Branca, Cruzeta, and Sertanejo); and Brazil (BR 106), which probably is the cultivar most grown in Brazil presently.

The characteristics of some cultivars with

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low seed production cost developed by this program are the BR 106 variety 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. The variety BR 4154-Saracura formed from a composite of 36 population was developed for great tolerance to temporarily waterlogged soil. The name "Saracura" refers 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 grain production, fresh corn, and forage. The variety BRS Sol-da-Manhã was formed and selected to meet the farmers' needs with soil stress related to nitrogen. The various selection cycles of this variety were carried out in environments with low natural fertility and a low nitrogen level.

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 reducing yield potential. • Assum Preto: a variety with a 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 common maize. • BRS Missões: has an early cycle and yellow dent-type kernels with excellent yield potential. Recommended for growing in the 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 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)

Innovative products have been developed in this program, highlighting cultivars with the following features: adaptation to acid soils (BR 201 and BRS 1001); phosphorus-use efficiency (BRS 3060 and BRS 1010); high protein quality (BRS 2121); fresh corn (BRS 3046) and sweet corn (BRS VIVI); tolerance to waterlogged soil (BR 4154 - Saracura); high pro-vitamin A carotenoid content (BRS 4104, BRS 1055); high-quality protein (BR 451, BR 473, and Assum Preto); sweet corn (BR 401); great nitrogen-use efficiency (Sol da Manhã); very early maturity cultivars to escape the drought period in the semi-arid region (Assum Preto and Caatingueiro); varieties adapted to the Northeast region (Gorutuba, São Francisco, Asa Branca, Cruzeta, and Sertanejo); and Brazil (BR 106), which probably is the cultivar most grown in Brazil presently.

The characteristics of some cultivars with low seed production cost developed by this program are the BR 106 variety 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. The variety BR 4154-Saracura formed from a composite of 36 population was developed for great tolerance to temporarily waterlogged soil. The name "Saracura" refers 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 grain production, fresh corn, and forage. The variety BRS Sol-da-Manhã was formed and selected to meet the farmers' needs with soil stress related to nitrogen. The various selection cycles of this variety were carried out in environments with low natural fertility and a low nitrogen level.

Final Considerations

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

Maize production systems are very heterogenous since they range from highly technified systems to subsistence farming, explaining Brazil's low mean yield. Public research and technology production institutions have sought to serve new niche markets and produce hybrids and varieties with lower seed costs 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 due to low seed cost, particular crop season, significant risk growing conditions, regions of biotic stresses, marginal areas, and organic farmers for whom the use of genetically modified seeds is prohibited.

Research and development institutions of public products (IAC, CATI, EMBRAPA, IAPAR, and others) 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.

The scientific community has discussed this scenario for years. Therefore, maize seed production in Brazil should be remodeled and improved toward small growers, and this will only be possible with public-private partnerships and meeting the needs of specific niche markets.

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