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INOVATION AND SPECIALTY MAIZE BREEDING FOR MARKET NICHES IN THE STATE OF SÃO PAULO

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Abstract – Maize is one of the most harvested cereals on the planet. In Brazil, it is the country's second largest grain production after soybean, with a large portion of production destined for animal feed. During the 2019/2020 harvest, 35% of total maize production was exported, 9.5% was destined for industrial processing and only 1.1% for human consumption. Specialty maize are those grains that are not destined for the dry grain commodities market, but have various other uses and are destined exclusively for human consumption. Specialty maize are also considered as an alternative profit source for farmers. From a plant breeding standpoint, maize is greatest example of success when it comes to the exploitation of heterosis and therefore most of the investment in genetic breeding done by private companies is in the development of simple GMO single-cross hybrids. In today's market, there are rarely any specialty maize cultivars available, creating a niche for public funded research and development centers to exploit with their conventional type cultivars. This article discusses the relevance of the specialty maize market niches and the role of the Maize Genetic Breeding Program of Instituto Agronomico (IAC) in the development of innovations in São Paulo through the launch of conventional cultivars aimed at small and medium producers and niches of specialty maize.

Keywords: *Zea mays*, conventional cultivars, green maize, popcorn, IAC

INOVAÇÃO E MELHORAMENTO DE MILHOS ESPECIAIS PARA NICHOS DE MERCADO EM SÃO PAULO

Resumo - O milho é um dos cereais mais produzidos no planeta. No Brasil, é o segundo mais produzido, com grande parte da produção destinada à alimentação animal. Na safra 2019/2020, 35% da produção foi voltada à exportação, 9,5% ao consumo industrial e 1,1% ao consumo humano. Milhos especiais são todos aqueles que não são cultivados para a produção de grãos secos como commodity, com usos diferenciados e destinados à alimentação humana, considerados alternativa de lucro ao agricultor. Do ponto de vista do melhoramento genético, o milho é o maior exemplo de sucesso na exploração da heterose e os programas de melhoramento de empresas privadas em geral focam no desenvolvimento de híbridos simples transgênicos. Há pouquíssimas cultivares de milhos especiais no mercado, assim as cultivares convencionais (não transgênicas) para alimentação humana representam um nicho promissor para empresas públicas de pesquisa e desenvolvimento. Esse artigo versa sobre a importância do mercado de milhos especiais e o papel do programa de melhoramento de milho do Instituto Agronômico (IAC) no desenvolvimento de inovações em São Paulo, por meio do lançamento de cultivares convencionais voltadas ao pequeno e médio produtor e aos nichos de mercado de milho verde, branco, pipoca e orgânico.

Palavras-chave: *Zea mays*, cultivares convencionais, milho verde, milho pipoca, IAC.

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Maize is one the three main grains produced throughout the planet. During the 2019/2020 harvest, total global production was accounted as 1.11 billion metric tons, making maize the world's leading grain followed by wheat and rice. Brazil is the world's third largest producer of maize, after the US and China, with a 10% global market share having harvested 101 million metric tons during the past harvest (USDA, 2020).

In Brazil, maize ranks second in total output after soybeans and a grand portion of that production is destined for animal feed. During the 2019/2020 harvest 35% of production was exported while 9.5% was destined for industrial processing and a mere 1.1 % was used for human consumption – Figure 1 (Abimilho, 2020).

According to the Agricultural Census done by the Instituto Brasileiro de Geografia e Estatística (IBGE, 2017), the state of São Paulo produced close to 4.5 million tons of maize in 2017, with the state's southwestern region being responsible for 38% of production.

In 2019, the demand for maize for animal feed represented approximately 73.8% of São Paulo's total output, followed by industrial use and human consumption. Human consumption absorbed 15.6% of the total demand and presented an increase of 0.7% in relation to 2018 (Miura; Freitas, 2019).

Because of its economic importance, maize is one of the agricultural products with the largest investment in the development of new cultivars and associated technologies. According to Leite

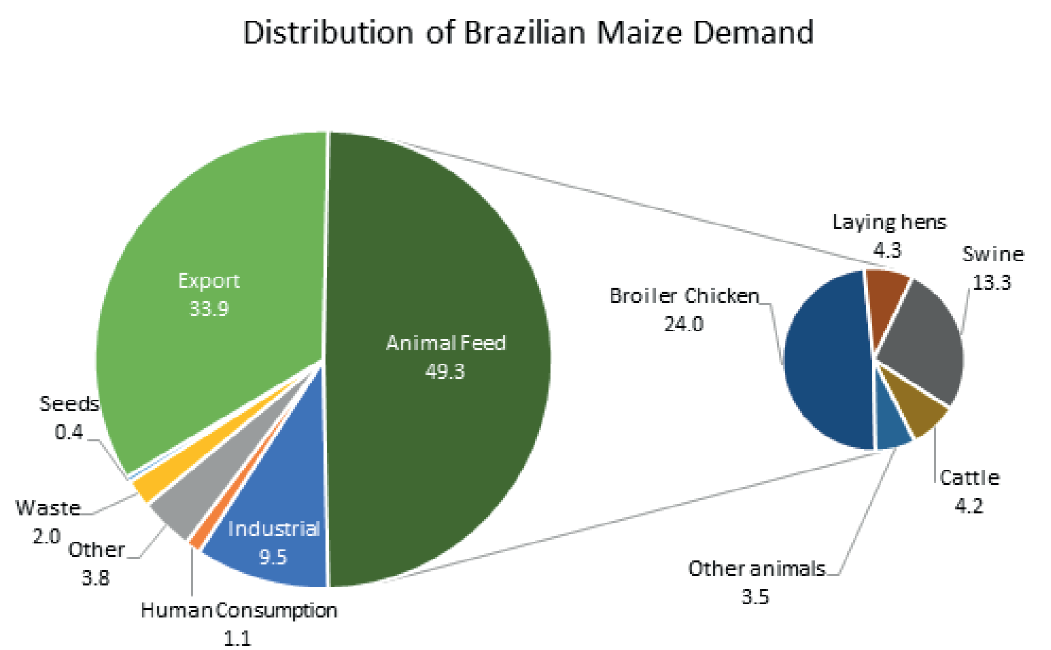

Figure 1. Distribution in percentages of Brazilian maize demand, 2019/2020 harvest.
Source: Abimilho (2020).

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(2015), the seed manufacturing industry plays an important part in Brazil's national agricultural innovation system and within that industry; the private sector occupies a distinguished role. In recent years, the seed industry has heavily relied on R&D activities, which have in turn grown due to the evolution of Intellectual Property Laws and established legal cultivar protections since de mid-1990s. Research and Development is decisive in the ever competitive seed manufacturing sector, in which:"Innovation plays a fundamental role in the success of firms (and because of it) the private sector invests heavily in research, primarily in genetic engineering" (Leite, 2015, p. 130).

The Brazilian maize seed manufacturing industry deals with immense volumes and despite of harsh market competition, this industry focuses primarily in servicing the demand for animal feed. Increasingly, the companies that focus on this sector launch genetically modified maize hybrids as a means of securing returns on R&D related investments and guaranteeing their market shares, diminishing the offer of Non-GMO conventional cultivars available for producers. In the 2019/2020 harvest only 10% of all maize planted and harvested originated from conventional seeds (Figure 2) (Abimilho, 2020).

Due to the dominion of multinational corporations in the seed manufacturing industry, many public institution like the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), the Universidade Estatual de Maringá (UEM), the Instituto Agronomico do Paraná (IAPAR), the Instituto Agronomico de Campinas (IAC) in the state of São Paulo (Sawazaki and Paterniani, 2004) and the Coordenadoria de Desenvolvimento Rural Sustentável (CDRS), previously named CATI, diversified their genetic breeding programs and focused on meeting specific demands and niche markets. One of the alternatives focused on by IAC was to direct their program for the specialty maize market.

Specialty maize are those grains that are not sold in commodity markets and have differentiated uses due to the variations in composition, color and endosperm format (Hallauer, 2000). The term includes common green maize, sweet green corn, popcorn, baby corn, corn with high oil content, high protein corn, and white corn for *Canjica*, among others, which possess their own market niches with a high added value.

Specialty maize and common maize, destined for grain, belong to the same specie (*Zea mays*), but possess many differences in their anatomical constitution. All maize grains have three basic parts: the pericarp, the endosperm and the germ.

Variations in the mechanical resistance of the pericarp, the distribution of the endosperm and the size of the germ are all responsible factors in the differentiation of common maize from popcorn for example. The endosperm is constituted by both soft and hard starch. Hard starch is responsible for the sudden expansion of a popcorn kernel once heated. In common maize, the amount of hard starch present is small and the germ occupies most of the space within the kernel. In popcorn kernels, the germ is reduced

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and the kernel is practically completely filled with hard starch. Moreover, popcorn has a more heat resistant pericarp that only tears when the endosperm pops.

Sweet corn on the other hand, is differentiated by the balance of starch and sugars in the endosperm (Aragão, 2002), resulting from the action of individual recessive genes or their combinations. So, while common maize presents an average sugar content of 3% and an starch content ranging from 60 to 70%, sweet corn contains sugar levels ranging from 9 to 14% and starch levels of 30 to 35% on mass. Super sweet corns can reach up to 25% of their weight in sugars and 15 to 25% of starch. Sweet corn is consumed on a smaller scale in Brazil, partly because of the lack of knowledge on producers' side of the required specific cultivars and the small size of market aligned activities.

Specialty maize are seen as alternative income source for growers, because, in general, they hold greater commercial value than commodity grains. With passing time, these maize have seen a gain in their market demand, with some cultivars, such as common green maize being consumed throughout the entire national territory on an annual basis. Both green and white maize can achieve a profitability of over 60% greater than maize grains sold in commodities market. Meanwhile, popcorn maize can have a selling price of 400% more than conventional grain (Table 1). Finally, certified organic maize can reach market values of 30 to 40% greater than commodity grains.

Seed manufacturing focused on the specialty grains market is scarce and is considered an incipient sector of the industry when compared to the number of cultivars available for commodity grains (Table 2). According to data from the Associação Paulista de Produtores de Sementes e Mudas (APPS, 2020), during the 2019/2020 harvest there were 196 different maize cultivar available in market. 130 of those were GMO seeds and 66 were conventional seeds. Of those conventional seeds, 5 were destined for the production of green maize, 3 for white and yellow *canjica* corn and only one for popcorn kernels. Such data lights into evidence the scarcity of

Table 1. Price comparison of wholesale prices of different maize types, São Paulo, June 2020.

Type of Maize	Unit	Price (R$) in SP	Price per kg
Commodity Maize Grain[1]	60 kg Bag	48.00	0.80
Popcorn Maize[2]	22.6 kg Bag	76.43	3.38
Special Green Maize Campinas[3]	kg	1.35	1.35
Extra Green Maize Campinas[3]	kg	2.80	2.80
White Maize– Angatuba[4]	50 kg Bag	70.00	1.40

Source: 1 Agrolink (2020), 2 CEAGESP; 3 CEASA Campinas; 4 MF Rural Marketplace

Table 2. Specialty maize cultivars available for the Brazilian market during the 2019/2020 harvest.

Use	Cultivar	Type	Grain Color	Company
GM/WCS/WGS	BM 3051	SI	YL	Biomatrix Sementes
GM	BRS 3046	HT	YL	Embrapa
G/GM/WCS	IAC 8046	HI Intervarietal	YL	IAC Sementes
G/GM	IAC 8053	HI Intervarietal	YL	IAC Sementes
GM/WCS	SAB40V62	SI	YL/YO	Priorizi Sementes
PC	IAC 125	TC Top cross	YO	IAC Sementes
G/DG	IAC 3330	TC Top cross	YO	IAC Sementes
DG/WCS	IPR 127	HD	WH	IAPAR
DG/WCS	IPR 119	HD	WH	IAPAR
Organic[1]	AL-AVARÉ	Variety	YL	CDRS (CATI)
Organic[2]	BRS-CAIMBÉ	Variety	YL	Embrapa/ Grãos orgânicos Ltda.

Grades: Use: G – Grain; WCS – Whole Cob Siloing; WGS – Wet Grain Siloing; GM – Green maize; DG – De-gemed Grain; PC - Popcorn.

Grain color: WH – White; YO – Yellow-Orange; OR - Orange; RD - Red; YL – Yellow

Source: Associação Paulista de Produtores de Sementes e Mudas (APPS, 2020); 1 (CATI, 2020) 2 *Safra 2018/2019 (CPORG, 2020).

specialty maize seeds and highlight the important role that public research institutions play in the development of these niche market seeds.

In view of the later, this article discusses the importance of the specialty maize market and the role of maize breeding programs by the IAC in innovations in the state of São Paulo, Brazil through the launch of new maize hybrids destined for small and mid-scale farmers and the market niches of White maize, popcorn and organic/non-GMO maize.

From an economic view point, its methodology includes a bibliographical review of the available information on specialty maize for the Brazilian market, utilizing secondary sources derived from the IBGE Agricultural Census, data bases from important sectors of maize's supply chain and the compilation of information from various reports. It is important to highlight the scarcity and scattered nature of economic data for the specialty maize market.

Background

The first genetic breeding program for hybrid maize in Brazil began in 1932 at the Instituto Agronomico em Campinas (IAC) in the state of São Paulo by Krug and other collaborators. They launched the first double-

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cross maize hybrid in 1939, after the US programs had already begun. The method that exploits maize's hybrid vigor, which revolutionized its genetic breeding and allows for the achievement of high yield productivities up until today, completes 90 years of application in Brazil.

Conceptually, the following types of hybrids exist: single cross (obtained through the crossing of two inbred lines); modified single cross (hybrid formed by two related progenies used as female parent and another line used as male parent); three-way cross (results from the crossing of a single cross hybrid and a third line); modified three-way cross (obtained in a similar fashion to the three-way cross, except replacing the third line with a single cross hybrid from the same line); double cross (a cross of two single cross hybrids, that is a four line crossing); top cross (cross between one varietal line and a varietal hybrid); and finally intervarietal , which is a cross between two existing varietals (Sawazaki e Paterniani, 2004). A diverse range of hybrids have been developed by IAC throughout the years.

At IAC, between the years of 1939 and 1942, various intervarietal hybrids were developed with the purpose of exploiting the economic value brought on by some characteristics of varieties that had been introduced to the Institute's germplasm bank. Starting in the 60's, the work at IAC focused on synthesizing more productive intervarietal hybrids while introducing so called "super genes" to the parental populations and creating hybrids that could withstand unfavorable environmental factors (Sawazaki e Paterniani, 2004).

Works done by the Rockefeller Foundation (1963, 1965) in Mexico, demonstrated that a maize line from the state of Michoacán had the capability of drastically reducing its growth cycle while under adverse hydric conditions, yet quickly resumed its growth once supplied with water. This trait was later denominated as Latent. The intervarietal hybrid that resulted from the crossing of IAC Maya and IAC-1, was produced and commercialized under the name Phoenix (Miranda & Miranda, 1993).

IAC's Popcorn Breeding Program was started decades ago and the first hybrid, IAC 112, was released in 1998. The program focused on the development of three-way and top crosses, due to the line's low seed yields. The main advantage of utilizing intermediate hybrids proved to be its reduced production costs, obtaining hybrids from more productive lines with intermediate levels of inbreeding (Oliveira, 2019). The IAC 125 was launched in 2006, with a heightened crop yield and a proper adaptation to different soils such as those in the state of Mato Grosso, Brazil during the second crop season. The main aims of the Popcorn Breeding Program are higher crop yields, an increased popping expansion and a greater resistance to common diseases.

A great challenge encountered by those researches that work with popcorn is the fact that the most important traits for the cultivar, which are its popping expansion and yield, present a negative correlation. This fact decreases the

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selection and obtainment of superior cultivars with both traits (Scapim, 2010).

The dependency on foreign seeds and the preference of packers for North American seeds are partially responsible for the lack of incentive for the production and availability of local cultivars with similar traits.

Intervarietal Hybrids Maize

Since the turn of the Millennium, the process of obtaining intervarietal hybrids utilizing synthetic commercial hybrids was reintroduced at IAC.

The intervarietal hybrid was especially developed in order to meet the demand of small and mid-scale farmers who suffered from low yields and that had no productive seeds available to them at a reasonable cost that would allow for an economically viable production. These hybrids, also denominated F_2 population hybrids, double cross F_2 generation hybrids, synthetic hybrids, or simplified double cross hybrids, are a result of the intercrossing of F_2 generations of single cross hybrids or a crossing of two synthetic varieties.

The double cross hybrids produced by the crossing of F_2 and F_3 Generations, derived from single cross hybrids should behave as those double cross hybrids of F_1 Gen as long as there are no selections that could cause a change in the genetic frequencies of the plant. According to the Hardy-Weinberg Law, the allele frequencies and genotypes of an allogamous population of sufficient size are to remain constant in the absence of migration, mutation or selection (Falconer, 1989; Hallauer & Miranda Filho, 1988: Pugh & Larysse, 2005).

Souza Sobrinho et al. (2002), compared the performance of double cross hybrids derived from F_1 and F_2 generations of single cross commercial hybrids and observed that F_2 double cross hybrids had a similar performance to those derived from the F_1 generation of single cross hybrids. Also, according to these authors, the utilization of F_2 generation of populations derived from F_1 single cross hybrids, for the purpose of hybrid generation is one of the most cost-effective alternatives.

The production costs for F_2 hybrid seeds is reduced because the stages of line procurement and multiplication are eliminated, having only the need for maintenance and production of fields with the parental populations. The intervarietal hybrids allow for the utilization of heterosis without the need of obtaining lines (Sawazaki; Paterniani, 2004). In the production of hybrids for line establishment, it is necessary for plants in a population to be subjected to endogamous reproduction, generally via self-pollination processes for six to eight generations, until a homozygous or pure line is attained. This process of line maintenance and obtaining hybrids from lines is expensive and requires a repetition on an annual basis.

In the production of F_2 population hybrids, only F_2 parental populations would be utilized, which can always be maintained in isolated lot and reused every season for the reproduction of

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the F_2 hybrid populations.

Pacheco et al. (2010) highlighted that beyond a good agricultural performance, the main advantage of double cross hybrids, extracted from F_2 generations, is in fact their lower seed costs, which has allowed to service at the same time, the interests of grain and seed producers. One disadvantage of using F_2 population hybrids, is the lack of plant uniformity during the flowering period, resulting in lower seeds yields in production fields.

In the works of Doná et al. (2009) and Benini & Paterniani (2012), there were promising performances found for some F_2 populations and the productive potential of intervarietal hybrids was corroborated as an alternative for commercial production of maize.

The first intervarietal hybrids made by IAC, IAC 8333 and IAC 8390, presented traits of elevated productivity and demonstrated to be competitive with other seed available in market, serving as evidence of the technical and economic viability of this technology (Duarte et al., 2007; Pacheco et al., 2010). Recently, two intervarietals hybrids were launched, which IAC 8046 and IAC 8077 are conventional, non GMO, maize hybrids with a crop yield ranging from nine to ten metric tons per hectare per year. These hybrids have a thick ear, a trait that results in a greater production of grains per plant. IAC 8046 has a long to semi-dented kernels and its ears retain a minimal amount of silk, traits that are very suitable for Green maize markets.

Specialty maize and their market niches

Canjica/White Maize

White maize is another type of specialty maize who's market is primarily focused for its use in *Canjica*. *Canjica* is a dessert recipe with origins in São Paulo and made since the early 18th Century (Ferreira, 2002) that is comprised of partially or completely de-germed kernels (Castro et al., 2009) mixed with sugar, milk and other spices. Kernels for *canjica* can usually be found in supermarkets, primarily of White maize, but sometimes in a lesser proportion, common yellow maize as well.

The production of this type of maize follows the same agricultural techniques of common maize harvested for grain. Its commercialization is mostly focused during the month of June, for the *Festas Juninas* and with a greater geographical emphasis in the northeast region of Brazil, much like popcorn type cultivars.

The white cultivars can present different types of kernels, ranging from dented, semi-dented, semi-flint and flint. Dented kernels present densely arrange starch molecules on the kernel edges while in the central part; the starch is less densely packed and farinaceous. Therefore, the kernel is mainly characterized by the upper indentation that results from the quick drying and contraction of the soft starch within it. Flint kernels on the other hand present a fairly reduced proportion of amylaceous endosperm and its hard texture is due to the dense mixed packing of starch and protein. This type of grain is preferred by the Brazilian food industry, achieving relatively superior market prices, while dented kernels are simply not accepted or bought for a much lower price by the industry (Cruz et al., 2002).

Canjica is obtained through the process of de-germination, which can occur via dry or wet processes. In the wet de-germination, the kernel is separated in three parts; endosperm (*canjica*), germ and pericarp (kernel skin). In the dry process, the final products are *canjica* and maize bran constituted mainly of the germ and pericarp (MAPA, 2013). During this process, after cleaning and drying the kernels, the kernel is de-germed and the endosperm is coarsely ground and classified by size for different types of *canjica.* The germ is subjected to an extraction process in order to obtain maize oil and bran. This de-germenation of maize is the most important process in order to ascertain the proper industrial yields of the maize and is performed using a machine called the de-germinator. Since dry de-germination is the most wide spread in the industry, hybrids that present more flint kernels are sought after, for these grains have a better industrial yield and present a *canjica* of better quality. When the kernels used are more dented, in other words, contain softer starch, the final product can be doughy and undesirably considered of inferior quality (Conrado, 2010).

In Brazil, there are still no genetic breeding programs that concentrate on obtaining white maize cultivars for particular traits required of *canjica* kernels. Ongoing research, focuses primarily on evaluating cultivars mainly for their crop yield. Still, there is a high probability that within the universe of the cultivars that have already been developed for grain production there can be found some that are more apt for the production of *canjica*. However, crop yields alone, do not suffice for the development of a proper white maize for *canjica*, it is important that research focuses on selecting genotypes that present more flint-type grains. The works by Bignoto et al. (2015), Conrado et al. (2014), Rovarís et al. (2014 & 017), and Sawazaki et al (2010) emphasize the need to continue search for new cultivars with high de-germed kernel yields.

The state of São Paulo has been in the past an important production center of white maize destined for the *canjica* market. The municipality of Quadra, located in the state's southwestern region, was once considered the Capital of White Maize. During the 1960's and 70's, a variety of white maize produced by IAC called *Pérola Piracicaba* or Piracicaba Pearl, after the city of Piracicaba where it was developed, possessed flint grains with a crème white color, it was highly sought after due to its high de-germed kernel yields.

The IAC having already developed white maize varieties with proper agricultural and industrial yields, like *Pérola de Piracicaba* and IAC Nelore, continues promoting research with other white maize populations with the intent of developing new cultivars that heed the needs of other market niches.

Recently, Embrapa has developed the BRS 015 White Farineous cultivar directed mainly for the bread and baked goods industry and the restricted gluten diet markets (Lima, 2019).

Yellow *canjica* is also an important source for the production of corn sweets and *canjiquinha*, which is widely used in Brazilian culinary. For this purpose, IAC 3330 stand outs with its hard kernels and a deep orange color caused by a greater amount of carotene, a vitamin A precursor, and its many health benefits.

Green Maize

The data gathered from the 2017 National Agricultural Census reveal that in Brazil, there were 71,045 entities producing green maize for horticulture, which produced a total of 348,904 metric tons of corn ears, circulating approximately R$ 282 million. The census data also showed that the three largest green maize producers on a national level were the states of Goiás, São Paulo and Minas Gerais, contributing 26%, 19% and 12% respectively to the total national output (IBGE, 2017). According to the Brazilian Association of Maize Industries (Abimilho), the consumption of *in natura* green maize reached up to 1.5 million metric tons in 2019.

The state of São Paulo holds a top position between the largest consumers of this type of maize, with a constant year round commercialization through CEAGESP, a public company that specializes in the wholesale distribution of São Paulo's agricultural products. Of the 65,052 metric tons of green maize produced in São Paulo in 2015. 51,919 tons were commercialized through the various CEAGESP locations, with the three top suppliers being the Paulista municipalities of Capela do Alto (31.6%), São Miguel Arcanjo (18%) and Casa Branca (11%) (CEAGESP, 2020).

Green maize refers to harvested precociously, somewhere between 20 to 25 days after pollination, when the stigma and style begin to present a brown color. It is consumed fresh, when the kernels are still soft and milky, with a moisture ranging from 70 to 80% (Sawazaki et al., 1979). In virtue of the short expansion of time that the maize remains in the field, approximately 90 days during summer and 100 days during winter, it can be considered a form of vegetable in the commercial sense, much like baby corn.

Green maize possesses higher sugar content, less starch and an overall high nutritional value, being used in a diversity of culinary recipes, such as cakes, cookies, ice creams, *pamonhas* pastry similar to the Mexican Tamale, etc. (Luz et al., 2014). In Brazil, the cultivation of green maize holds little comparison in volume with the nation's agribusiness sector, which focuses on commodity grains, yet is cultivated throughout the entire territory. This type of maize became an option of higher added value to producers thanks to its higher market value and its high demand for *in natura* consumption and the canned foods industry (Qwabe, 2011).

However, usually, green maize is harvested by small and mid-scale producers that many times use for this purpose subpar cultivars, with low sugar content and a rapid rate of starch conversion, unlike its North American and European counterparts (Albuquerque et al., 2008; Lez et al., 2014). This occurs due to the fact that green maize appropriate cultivars are still too scarcely available for willing producers (Table 2). It must be highlighted that there exist a difficulty of even acquiring conventional commercial hybrids, since GMO seeds dominate the distribution markets.

In order to serve the interests of both, industrial processors and farmers, green maize cultivars must meet certain attributes in order to improve their market acceptance. For example, they must have a large ear with long and fine green leaves that protect the maize from biological attacks, aligned and dented kernel in a cream or yellow-cream color, a thin pericarp and a slow rate of kernel hardening. It is also important that the maturation rate is fairly constant throughout the whole ear and the corn silk must remain lose in order to facilitate cleaning. A low to mid ear height is required to facilitate manual harvesting and a prolonged post-harvest shelf life is also necessary. The most adequate cultivars possess a mid-size, resistance to lodging and breakage, a sturdy peduncle, and a thin, light colored, cylindrical cob (Rodrigues, 2007).

Green produce tends to age naturally as they are living structures and there is no technology available with a minimum of economic viability that can fully stop this process. After harvested, green maize is considered a highly perishable good due to its elevated moisture content, which restrains significantly its shelf-life. For the industry, this means a short window for processing the maize ears. The evaluation and selection of genotypes with suitable post-harvest traits may reduce these losses and increase shelf-life. Until then, green maize ears must be keep refrigerated at 7 °C and sealed in hermetic containers in order to preserve them.

IAC recently launched the IAC 8053 hybrid, which can be destined both for feed grains, green maize and other culinary uses. The light yellow kernels are large and properly aligned inside of a large maize ear that facilitates the removal of silk and fine husks.

The Cativerde variety is also adequate for its use as green maize, possessing dented kernels, both tender and yellow, an ear with proper husk coverage and a 7 day post-harvest shelf-life (Source: DSSM, CATI, 2002).

Popcorn Maize

Popcorn varieties, both white and yellow kernels, are consumed throughout the entire territory of Brazil and also possess a great added value for producers. So much so that the harvesting of this maize is in rapid expansion, especially in the states of Mato Grosso and Goiás, as demand from food industry soars.

Currently, Brazil is the world's second largest producer and consumer of popcorn, second only to the US. In 2019, production focused on serving the internal market only was estimated at 220 thousand metric tons, with 75% of that production concentrated in the state of

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Mato Grosso. However, despite the fact that the market value of popcorn is close to double that of common maize, these cultures also have higher production costs (Blecher, 2019).

Most of the popcorn seeds planted in Brazil are imported from the US and Argentina, which is partly responsible for the elevated production costs. According to producers, the imported seed has a much greater quality when compared to national seeds. The main traits that drive the choice of seeds are: good crop yields and kernel quality. In this aspect, kernel quality is set as large kernels, a high popping expansion and an intense yellow color (Sawazaki, 2010). Due to the growing demand for "Gourmet" popcorn, the American mushroom popcorn has become quite popular as it explodes into a proper sphere with hardly any wings, contains no noticeable hulls and requires little fat in order to pop. It also does not degrade when mixed with hot syrups (GLOBO.COM, 2016).

According to IAC researcher, Eduardo Sawazaki (2010), there is a national effort of public research institutes to develop popcorn hybrids in order to become less dependent on imported seeds. Sawazaki also states that the private sector holds the imported seeds in a privileged position, inhibiting the national seed companies of developing their own seeds. This large bottleneck hinders the investment in the development of local popcorn hybrids as "the industries that are large grain importers prefer American hybrids due to a higher popcorn quality (Clube da Pipoca, 2018)".

The two three-way hybrids that IAC launched in 2016 are high yield grains and have a high popping expansion. IAC 268 has a light yellow kernel and stands out with a high resistance to foliar diseases and *Pratylenchus brachyurus* nematodes. IAC 367 has orange kernels that meet market expectations. Both have quality popcorns with a popping expansion over 45 milliliters per gram, which means that each gram of kernel produces 45 mL of popped kernels (market requirements are set at 40mL/g or over). "This is the minimum value accepted for microwave popcorn", Sawazaki explains. With small, pearl type kernels, IAC 268 and IAC 367 have a potential crop yield of 4.5 tonnes per hectare, being able to reach 5 tonnes of kernels per hectare.

In order to obtain a higher popped kernel yield, the kernels must be pristine, without cracks, other mechanical damages, plague and fungal infections and have a moisture content between 13.5 to 14%.

Organic Maize

Conventional type cultivars can be used in organic crop systems, since there is an explicit prohibition of utilizing GMO seeds in both national and international legislations and standards for the production of certified organic crops. Therefore, the production of organic maize grains, mainly targeted for the export markets, has the ability of elevating the demand of conventional seeds for this specific niche.

It is estimated that organic maize represented only 0.3% of Brazil's total maize

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output during the 2015/2016 harvest according to IBD Certifications. The estimated production of 20 thousand metric tons of certified organic maize is met with an expanding market (Souza, 2019).

After GMO cultivars where legalized and regulated by the Brazilian Federal Government in 2008, there has been a decrease in the supply of conventional maize genotypes. As stated before, during the 2019/2020 harvest, a mere 10% of all commercial seed were conventional types. This scenario might be the most relevant technical barrier to the consolidation of organic maize production in Brazil (Santos et al., 2011).

Souza et al. (2020) evaluated the adaptation and yield grains of maize cultivars in organic conditions of Ipeúna, São Paulo, and concluded that hybrids AGRI 340, JM 4M50, the intervarietal hybrids IAC 3330, IAC 8077, IAC 8046 and IAC 8390, as well as the AL Avaré variety, are all potential progenitors for organic system breeding.

The Coordenadoria de Desenvolvimento Rural Sustentável (CDRS), presented the Paraguaçu variety as the first organic maize cultivar in the state of São Paulo, having received recently, its certification by the Association of Certifications - Biodynamic Institute (IBD), Latin America's largest organic certifier.

Conclusions

In virtue of the large production of GMO hybrids for animal feed, it is imperative that the need of conventional seeds of small and mid-scale farmers is met with the development of new cultivars. The maize breeding programs of Instituto agronomico have focused on developing differentiated maize hybrids in order to meet the demands of specialty markets (white maize, green maize, popcorn, and organic maize). However, currently there are great difficulties in continuing those programs and meeting demands. It is important to highlight that the maize hybrids developed by IAC are available for private seed companies to reproduce in partnership with the institute or under license.

The market tendency is for the specialization of seeds intended for small maize niches that demand the production of seeds on a smaller scale. These niches can be targeted by small scale farmers as a way to maintain them in the maize production business with a higher added value product. The challenge ahead for public research institutes that develop these seeds are having a constant flow of seeds readily available for producers and with proper distribution channels. The research and production of these cultivars by public institutes has an immense value for agriculture in the state of São Paulo.

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