ARTICLE

Plant breeding in Brazil: Retrospective of the past 50 years

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Abstract: *The importance of plant breeding in Brazilian agriculture has grown a lot in the last 50 years. This occurred mainly because of the: increase in graduate programs, which qualified hundreds of professionals; creation of EMBRAPA and other research institutes or state companies, with an emphasis on the production of new cultivars and; promulgation of the cultivar protection law, which stimulates investments in seed production. The retrospective of what happened, enabling the country to move from being an importer of grains, fruits, and fibers to one of the largest exporters of these products worldwide, was the focus of this work. Taking as reference some agricultural products, this article highlights the significant contribution of plant breeding in recent years. Also, some of the enormous challenges that still have to be overcome, in which the participation of Brazilian breeders will be fundamental to continue the progress of agriculture in the coming years.*

Keywords: *Genetics, plant breeding, Brazilian agribusiness, success with breeding.*

INTRODUCTION

At the beginning of the twentieth century, the production of grain, fruit, and fiber in Brazil was concentrated in the Atlantic Forest biome and was largely itinerant, that is, the forest was cleared for growing annual crops, usually for only a few years, and then a new area of forest was cleared, and this procedure continued. After growing annual crops, perennial crops were often established, such as sugarcane or coffee, for example, depending on the region with little use of technology. In the case of coffee, seeds were sown directly in manually opened plant holes. This type of land use drastically reduced the areas of Atlantic Forest in the South and Southeast regions of Brazil (IBF 2021).

Before the 1970s, the areas of the *Cerrado* (Brazilian tropical savanna) biome, which occupy more than 200 million hectares, had practically no agricultural use. Although the topography in this biome was highly favorable to mechanization of the different crop management operations, it had limited use, due to soil fertility problems, that is, low pH and phosphorus content and high aluminum content. Intensification of the use of the *Cerrado* after the 1970s was fundamental for development of the Center-West region of Brazil and, after the year 2000, of the MATOPIBA region, an acronym of the initials of the states of Maranhão, Tocantins, Piauí, and Bahia. Grain, fruit, and fiber production in these regions has contributed to IDH (Human Development Index) growth and, consequently, to the growth of already existing cities and the creation of numerous others. More important, especially in the Center-

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West region with longer use of the *Cerrado* biome, is the contribution to enhanced quality of life of the population in these cities (Hosono et al. 2016).

The success of agriculture in Brazil over the last five decades is based on various factors, including the dedication of many farmers and development of their business skills; government incentives in various financing programs, for example, the use of limestone, irrigation projects, and grain storage facilities; annual financing of crop and other expenditures; intensifications of agricultural extension services performed by government agencies and also by companies that market crop inputs; and the generation of agricultural technologies adapted to tropical conditions, technologies that did not yet exist in other countries with more technologically developed agriculture. This last factor involved numerous areas of knowledge, with effective co-participation in this process. However, the production of new cultivars, which is the focus of this publication, was fundamental for the success of Brazilian agribusiness.

MEMORABLE FACTS IN PLANT BREEDING IN BRAZIL

Although plant breeding in Brazil began long ago in some research institutions, it was mainly concentrated in the state of São Paulo at the Instituto Agronômico de Campinas - IAC (Carbonell 2012). As years passed, especially in the past five decades, some factors contributed to the growth and development of plant breeding in Brazil, including the following:

In the 1970s, the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and other crop and livestock research institutes or companies in the states were created. They were decisive factors for development of agriculture in Brazil. The most prominent objective in all these institutions was recommendation of new cultivars to farmers (Lopes et al. 2012).

It has frequently been said that successful use of agricultural technologies has depended on the efforts of EMBRAPA, since the time of its creation, in sending professionals for training in universities abroad. However, in the specific case of plant breeding, most professionals in public and private companies have been trained in Brazilian universities. The first graduate studies program in Genetics and Plant Breeding in Brazil was that of ESALQ/USP - Escola Superior de Agricultura Luiz de Queiroz, affiliated with the Universidade de São Paulo - in 1964. A few years later, other programs were established in this area of study (Geraldi 2012).

Promulgation of the cultivar protection law (Lei Nº 9.456, de abril de 1997) was another significant fact for the growth of plant breeding (Santos et al. 2012). The protections of this law stimulated investment of private companies in the production of some crop seeds in addition to hybrid maize production, which was already being carried out by numerous companies due to its natural patent.

Therefore, all these factors were and are fundamental in expanding the supply of new cultivars of various species that have contributed and will continue to contribute decisively to development of agriculture in Brazil.

CONTRIBUTIONS OF PLANT BREEDING IN BRAZIL

To discuss the contribution of plant breeding in Brazil, dozens of species should be included, involving species that produce grain, fruit, vegetable crops, and others. Success has been expressive in all of them. However, this publication will focus on some specific species.

The expansion of soybean crop

Soybean (*Glycine max*) was introduced in Brazil many years ago. Initially, however, cultivating the crop was only economically viable in the states of the South of Brazil, where the area and crop production were quite small. This scenario changed from 1970 on when cultivars adapted to cerrado conditions were obtained. Yet, solving some problems required a great deal of effort and commitment. The first problem is that soybean was domesticated in locations of 30° to 45º North latitude in the region of China (Sedivy et al. 2017). In 1804, it was introduced in the United States (USA); however, growing was concentrated in high latitude regions, similar to those for soybean growing in China. In the second decade of the twentieth century, soybean growing began to migrate to the South region of the USA. Success was not immediate because, at first, plants flowered very early and grain yield was quite low (Kong et al. 2010). Garner and Allard (1930) associated, for the first time, early flowering of soybean with length of the day, the photoperiod. This provided an explanation for what was occurring, i.e., soybean is a short-day species. When grown in regions of lower latitude, the hours of darkness necessary for flowering accumulated rapidly and, consequently, plants not yet very developed flowered very early, resulting in low grain production, as already mentioned. However, variability among the lines was found in relation to sensitivity to length of the day for flowering to begin. Thus, lines with lower sensitivity to day length began to be selected and, consequently, they had greater probability of success in growing.

The expansion of soybean growing in Brazil was even more challenging than in the USA, because of the lower latitude of Brazil. It was necessary to involve the long juvenile period (LJP) trait in the lines to overcome this problem. To that end, a line originating from the Philippines was introduced, which was crossed with some lines grown in the South region of Brazil. The progenies coming from these crosses were selected in the state of São Paulo (Kiihl 2013). This was very successful and completely changed the scenario of Brazilian agriculture. Studies reported that genetic control of the LJP trait is oligogenic (Destro et al. 2001, Sedivy et al. 2017). However, genetic control of the response to photoperiod trait is more complex: more than ten genes related to control of the trait have already been identified, and among those most studied are *E1*, *E3*, and *E4* (Xia et al. 2012, Sedivy et al. 2017). Currently, information in the literature in respect to these genes is extensive; yet it is important to mention that soybean breeders in Brazil effectively obtained plants with excellent performance even in regions quite close to the equator without understanding completely the genetic control of the trait.

An additional aspect that should be emphasized is the lack of use of nitrogen fertilizers in the soybean crop for growing in the cerrado biome. This only became possible through selection of soybean lines more tolerant to cerrado conditions and also in selection of *Bradyrhizobium* strains with greater efficiency in nitrogen fixation (Coelho 2000). Considering that soybean production in the 2019 crop year was 114.3 million metric tons, it is estimated that Brazilian farmers saved approximately 32 billion reals (5-6 billion U.S. dollars) in reference to what would have been spent in purchasing 7.3 million tons of nitrogen fertilizers.

The success of growing soybean in Brazil over the past 50 years is illustrated in Figure 1. The increase in planted area of approximately 27 times in relation to planted area in 1970 (from 1.32 to 35.88 million ha) is striking. That, together with the increase in yield of 40.17 kg ha^{-1} $year^{-1}$, that is 3.5% a year, contributed to increase grain production of this important source of protein and oil, a 76-fold increase in production in relation to 1970 (from 1.50 to 114.27 million tons).

The question of biotic stresses (pathogens and pests) also required an extensive combination of management practices and use of more resistant cultivars. Nevertheless, nearly all pathogens have numerous races and this is therefore a problem that must be constantly monitored. Details in respect to what has been done and the challenges of breeding for resistance in soybean is presented by Matsuo et al. (2017). Information in relation to the relative maturity trait is presented by Bezerra et al. (2017) and Alliprandini et al. (2009) and will not be discussed in this study.

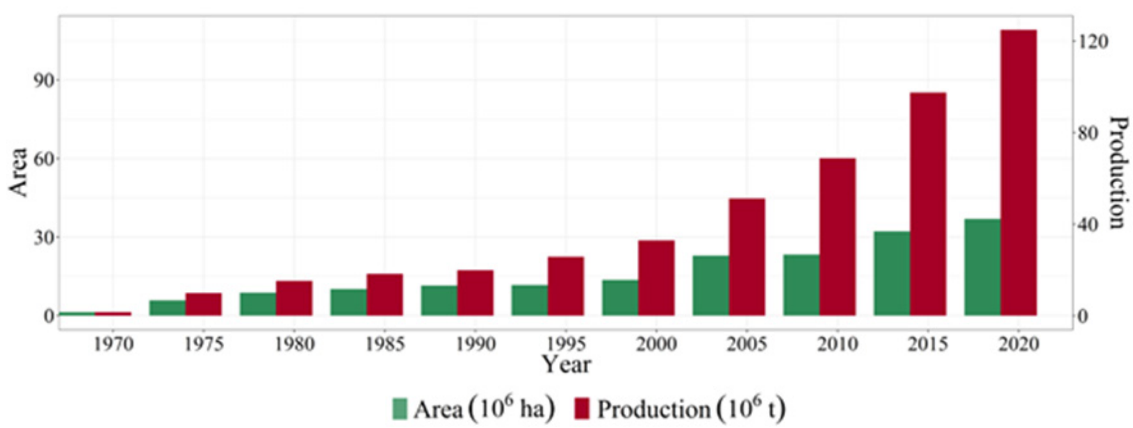

Figure 1. Area (million ha) and production (million t) of the soybean crop in Brazil in the period from 1970 to 2020. Data: FAO (2021).

Regarding the context of the cycle trait, it should be emphasized that, especially over the past decade, there has been great demand for earlier maturity cultivars to thus increase the probability of success in growing maize in a second crop season in the same area in which soybean was grown. The problem is obtaining cultivars that have both early maturity and high yield, which was not possible with already existing early maturity cultivars that had a determined growth habit. Success came through identification of early maturity plants with indeterminate growth habit. In this case, yield was equivalent to that of indeterminate lines grown before. Nevertheless, the challenge remains of continuing to increase grain yield with an increasingly shorter cycle, for example, a cycle from 90 to 100 days from planting to harvest. An additional challenge is to obtain cultivars resistant to various pathogens, such as rust (*Phakopsora pachyrhizi*) and white mold (*Sclerotinia sclerotiorum*).

Growing second-crop maize

The case of maize growing in recent years is also noteworthy in the context of the contributions of plant breeding in Brazil. Up to the middle of the 1980s, maize was grown only in what is called the summer crop season (the first crop). In the Southeast region, for example, sowing was from September to November, depending on rainfall. However, the earlier the seeds were sown, the higher the yield achieved (Arias et al. 1997, Santos and Ramalho 1999). However, at that time, no one thought of sowing maize in December, much less from January to March.

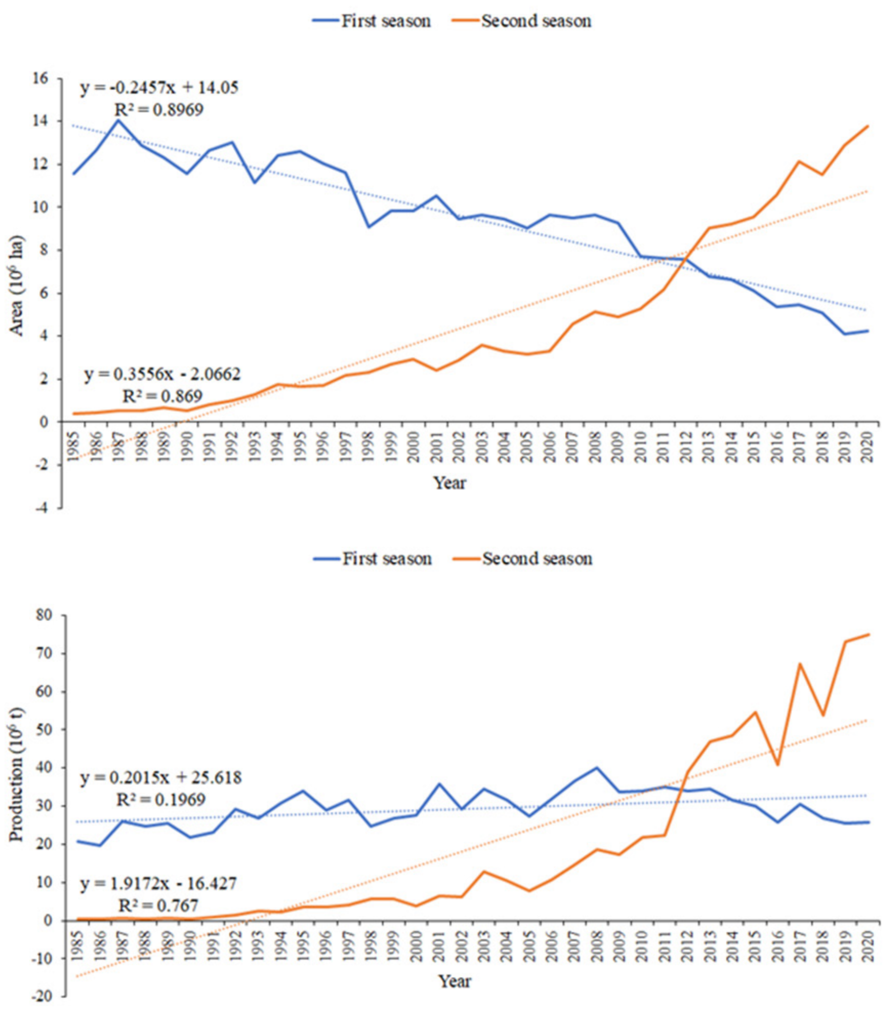

Figure 2. Area (million ha) and production (million t) of the maize crop in Brazil for the first and second crop season in the period from 1985 to 2020. Data: CONAB (2021).

The scenario of maize growing in Brazil changed due to competition with the soybean crop for sowing in the summer season. As sowing of maize in the summer crop is earlier in the South region than in the Southeast region, second crop maize began to be planted in the months of February to March in the southern state of Paraná. In the beginning, this strategy was not likely to be very effective. However, what occurred over the past 36 years was surprising: first crop maize declined in importance and the second crop, previously known as the *safrinha* (minor crop), came to predominate (Figure 2), especially in the Center-West region, which currently concentrates the highest production of soybean and maize in Brazil. In the first crop, the yield in 1985 was 1788.76 kg ha^{-1} and in 2020 the yield was 6064.88 kg ha^{-1}, which correspond an increase of 6.64% per year, while in the second crop season, the yield in 1985 was 1297.05 kg ha^{-1} and 5456.07 kg ha^{-1} in 2020, an increase of 8.91% per year. This increase in yield evidently depended on adaptations in management strategies, but plant breeding, recommending new cultivars each year, was decisive.

The dimension that plant breeding reached in the second crop season and the marked occurrence of the hybrid × crop season interaction required that programs for obtaining hybrids were conducted specifically for these conditions. What was achieved in terms of maize growing in the second crop season in Brazil was exceptional, above all considering the short period over which this occurred. However, some challenges remain, such as obtaining cultivars that are more resistant/tolerant to some pathogens that are of lesser importance for the summer (first) crop season. In addition, in many regions, the maize cycle in the second crop season should be as short as possible, aiming to avoid frosts, as occurs in the state of Paraná, and to have more time between the harvest in the second crop and preparing the area for sowing in the next crop season, as occurs in all the regions of maize growing. One of the ways of doing this is to "speed" the process of grain moisture loss after physiological maturity, because at physiological maturity, grain moisture content is around 30%. If harvest is performed few days after physiological maturity, the moisture in the grain will require a long time in grain dryers and, under these conditions, the price obtained by farmers in sale of the grain is considerably lower. Thus, the aim is to select hybrids that have faster dry-down.

It is noteworthy that one of the alternatives for this, still little explored, would be in the direction opposite to what was done in the relatively recent past. For many years, when there was only the summer crop season, selection in maize always aimed at obtaining hybrids with the greatest possible quantity of husk on the ears. That was because harvest only occurred a relatively long time after grain physiological maturity. In this situation, aiming not to reduce the yield and quality of the product due to adverse climate conditions and to pests, hybrids with a greater amount of husk were always desired. However, clearly, the more husk covering the ears, the longer the time for reducing grain moisture. Thus, with the aim of rapid reduction in moisture, selection should likely be made for obtaining hybrids with less husk on the ears. As mentioned, under these conditions, drying of grain on the ears may be faster and should likely also reduce competition for carbohydrates between grain filling and development of husk on the ears.

Performance of other annual grain production species with economic and social importance

There are many other annual plant species of great economic and social importance for Brazil, though not with the same projection as soybean and maize. All of them have shown considerable increase in yield. Estimates of the linear regression coefficient between the independent variable (X) of year in the period from 1970 to 2019 and the dependent variable (Y) of grain yield for different crops is shown in Table 1. The linear regression coefficient was always positive and the coefficient of determination for most of the species was of large magnitude, above all considering the type of information involved. It can be inferred that growth in grain yield was consistent over the past fifty years.

Table 1. Estimates of linear regression between the independent variable (X) of year and the dependent variable (Y) of yield (kg ha^{-1}) for some crops of economic and social importance in the period from 1970 to 2019

Crop	b_0	b_1	(b_1/b_0)*100	R^2 (%)
Rice	431.64	97.78	22.65	89.43
Oats	635.66	27.01	4.25	70.11
Rye	734.41	15.13	2.06	62.76
Barley	575.84	53.93	9.37	78.70
Dry bean	363.25	12.61	3.47	71.84
Wheat	600.66	41.38	6.89	82.61

Once more, it should be noted that the increase in yield should not be attributed only to plant breeding. Nevertheless, for all these species, the cultivars in use by farmers in Brazil were made available especially by companies and public universities.

The university/company partnership in breeding of sugarcane

Brazil has quite a long history of breeding sugarcane, which has been detailed in some studies (Landell and Alvarez 1993, Matsuoka et al. 1999). According to the authors, the oldest breeding program in Brazil, created in 1928, was that of IAC. Another program with intense participation in sugarcane breeding was that of the Cooperativa Central dos Produtores de Açúcar e Álcool do Estado de São Paulo, created in 1968, which, unfortunately, ended its activities in 1990.

Noteworthy advances were also made through creation of the Programa Nacional de Melhoramento da Cana-de-Açúcar (PLANALSUCAR) in 1971 by the Instituto do Açúcar e Álcool (IAA), which was responsible for creating the first RB (República do Brasil) sugarcane cultivars. However, the IAA ended its activities in 1990 and, consequently, also the PLANALSUCAR. All its human resources and physical and technological structures were transferred to seven federal universities, which gave rise to the Rede Interuniversitária para o Desenvolvimento do Setor Sucroenergético (RIDESA). After that, other universities came to participate in RIDESA so as to cover all the sugarcane production regions in Brazil. An important aspect is that all funding of breeding programs, quite a considerable value, is primarily provided by the private sector (Barbosa et al. 2012).

In addition, RIDESA made it possible for undergraduate and graduate students to be involved in sugarcane breeding programs, which is fundamental for qualification of new breeders and allows the continuity of research. Numerous studies have been published, showing the concern in making sugarcane breeding more efficient (Peternelli et al. 2017, Santana et al. 2017, Moreira et al. 2021).

Other sugarcane breeding programs in Brazil, mainly in private companies associated with those of the public sector, especially IAC and RIDESA, are dynamic and contribute to great expansion in sugarcane production in Brazil (Figure 3). Area planted to sugarcane in 1970 was 1.73 million ha; in 2019, it was 10.08 million ha, that is, 5.8 times the area of 1970. Production increased from 79.75 million tons in 1970 to 752.90 million tons in 2019, a 940% increase, indicating an increase in yield per area, even considering that expansion of the area occurred in marginal regions, some of them with limitations to sugarcane growing. Numerous clones have been made available to farmers in recent years, which, along with improvement in management practices, have contributed to greatly increased yield.

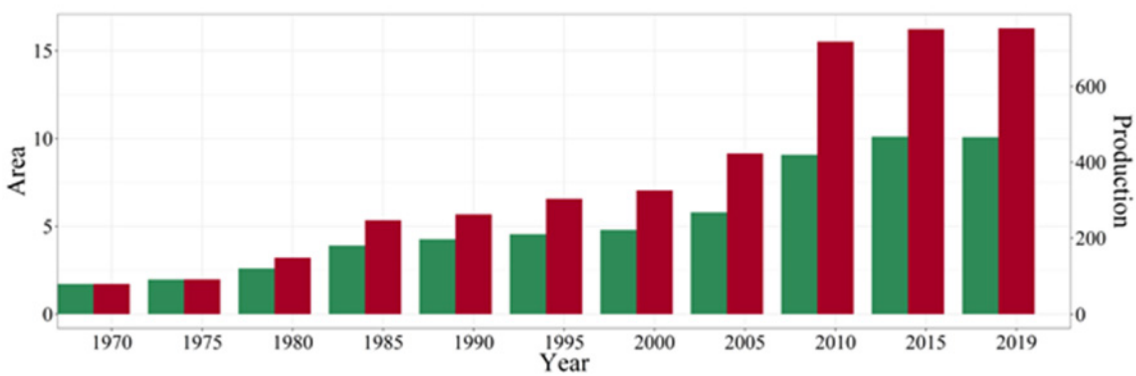

Figure 3. Area (million ha) and production (million t) of the sugarcane crop in Brazil in the period from 1970 to 2019. Data: FAO (2021).

Eucalyptus breeding for cellulose, wood, and energy production

Eucalyptus breeding in Brazil began with the introduction of some species by Edmundo Navarro de Andrade for the Companhia Paulista de Estradas de Ferro at the beginning of the twentieth century. However, breeding truly began some years later, in 1941 at IAC with Carlos Arnaldo Cruz (Castro et al. 2016).

From 1976 on, there was great expansion in planting forests in Brazil through tax incentives granted by the Brazilian government, seeking to meet demand for production of cellulose and charcoal for the steel industry. As a result, eucalyptus breeding is currently predominantly performed by private companies.

What has occurred in terms of eucalyptus breeding has been reported by various authors (Assis et al. 1996, Vencovsky and Ramalho 2000, Assis and Resende 2011, Castro et al. 2016). The following is a synthesis of what has been achieved up to now. Many companies introduced species, especially through the 1960s and 1970s. From these introductions, tests of species and origins were carried out (Marques Junior et al. 1996). However, eucalyptus canker (*Cryphonectria cubensis*) in Espírito Santo, especially in plantings of *Eucalyptus grandis*, stimulated the search for a source of resistance. Researchers found that *E. urophyla*, from Indonesia, combined good yield and canker resistance. Soon they also perceived that hybrids of *E. grandis* and *E. urophyla* exhibited considerable heterosis in terms of wood volume.

Expressive genetic progress occurred at the end of the 1970s when researchers of the Aracruz Celulose company, now called Suzano, came to use clonal plants. In a population of allogamous plants, as is the case of eucalyptus, any individual is a single cross hybrid (SH), formed by the random union of two gametes. Thus, one of the manners of perpetuating the best plants, the best SH, is by means of cloning. Cloning is actually the fastest and most efficient process of taking advantage of heterosis. In addition, clonal selection makes it possible to take advantage of all genetic variance, whether additive, dominance, epistatic effects, and other forms of generation of variability.

In the beginning, new clones were obtained through mass selection, that is, the selection of superior individuals in commercial plantings. This process was intensely used by companies and had enormous success. The estimate of genetic progress in the Aracruz company for wood volume from 1986 to 1994, for example, was higher than 2.5% a year. This progress was also clearly a result of evaluation of an increasing number of clones over the years (Gonçalves et al. 2001). Nevertheless, with the expansion of clonal plants, the areas with forests obtained by seeds were rapidly becoming fewer in number, and the possibility of selecting new clones from these plantings decreased. Thus, it was necessary to intensify the processes of intrapopulation or interpopulation recurrent selection.

From the 1980s on, molecular markers began to be used in eucalyptus, as in other cultivated species, in practically all companies. With DNA sequencing, various studies, above all using simulation, showed the potential for use of genome-wide selection, above all to accelerate the selection process (Resende et al. 2008). However, the efficiency of this process still requires confirmation in the field.

The success of breeding the eucalyptus crop in Brazil is more evident considering the duration of each selection cycle. Performing early selection of individuals to be cloned in the progeny test at three years, the time from hybridization until recommendation of the clones requires at least 15 years. Thus, in 50 years, only three cycles could be conducted. However, this delay in each cycle in relative. Once the program has been implemented, a new breeding activity can be initiated and, as each step ends, new clones will be obtained nearly every year. This has been the strategy adopted by most companies in the sector.

It is noteworthy that a large part of cellulose is exported to dozens of countries (Figure 4). Cellulose is among the 11 products of greatest export value from Brazil. Paper production, however, is primarily directed to the domestic market. Another notable fact is that eucalyptus is used to produce energy, firewood, or charcoal, especially in the state of Minas Gerais, which has the largest area planted to eucalyptus in Brazil. Charcoal, for example, is directed to the numerous steel mills in the state. Charcoal production from eucalyptus is important in the context of environmental protection. In 1983, for example, charcoal production derived from native forests, especially the cerrado, was approximately 82%. Only 18% were planted forests. Currently, practically 100% of the charcoal consumed, which is much higher than at the beginning of the 1980s, is derived from eucalyptus.

Selection of the plant in the progeny test and of its respective clone in the clonal test has shown low heritability (7.0%) (Reis et al. 2011). In addition, it is necessary to accelerate the process from hybridization up to recommendation of the clone. Therefore, some companies of the sector have begun what is called the clonal progeny test. Theoretically, this breeding process is highly efficient (Resende and Higa 1994) because the clones are evaluated without the initial progeny test. Specifically, the seeds obtained in the recombination lot, i.e., seeds of the half-sib or full-sib progenies, are cloned in the nursery soon after germination. The clones of the different individuals of each progeny are evaluated

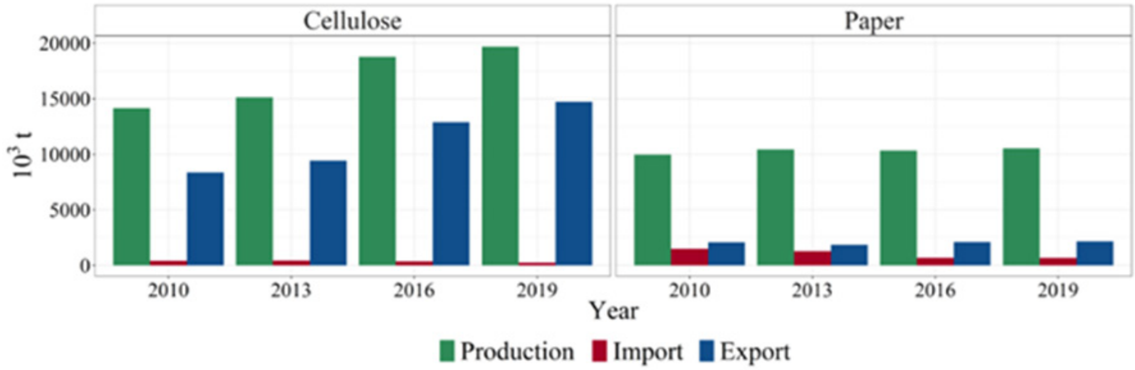

Figure 4. Production, imports, and exports in thousand tons of cellulose and paper from eucalyptus in the period from 2010 to 2019. Data: IBA (2021).

and, thus, their performance depends on the per se performance of the progeny that gave rise to it. The assumption is that the clone is better evaluated and that it is not necessary to perform the progeny test before the clonal test.

A difficulty in breeding eucalyptus or any other perennial plant is related to the genotype × environment interaction, especially the clone × year interaction. When a clone is recommended, it is expected that the environmental conditions under which it is grown during the selection process will be repeated in the future. Nevertheless, past experience shows that this does not always occur. As a result of this interaction, frustrations in recommendations of new clones are not uncommon and, evidently, there are large losses for companies. To reduce uncertainties and make more sustainable recommendations of clones, the use of clonal composites instead of monoclonal plantings has been proposed. The idea is that the clonal composite, for example, a composite with ten clones, can function as a guarantee. That is, if one or more clones are not well adapted to the new growing conditions, the other clones can compensate the losses in the field area. In monoclonal plantings, such losses cannot be compensated (Rezende et al. 2019).

Coffee: prominent product in Brazilian exports

In Brazil, two species of coffee are of considerable importance: *Coffea arabica* L., a polyploid and autogamous species that is difficult to propagate asexually, and *Coffea canephora* Pierre ex Froenher, known as conilon or robusta coffee, a diploid and allogamous species that is easily propagated asexually. Although robusta coffee has great economic and social importance, the arabica species occupies a larger area and has higher commercial value. Thus, in this publication, emphasis will be given to arabica coffee.

Coffee was introduced in Brazil various times in its history. Indications are that the first introduction was at the beginning of the eighteenth century and the second at the end of the nineteenth century. Coffee breeding, however, occurred many years later, in 1932 at IAC (Carbonell et al. 2012). Many basic studies have been performed, but two were most distinctive for the coffee crop in Brazil. The first was selection of a naturally occurring plant in the municipality of Urupês (SP), which after a few selections made at IAC, gave rise to the cultivar Mundo Novo (Carvalho et al. 1952). This cultivar revolutionized the coffee crop from the 1950s on. The second was the cross made between 'Mundo Novo', with tall plant height, and the cultivar Caturra, with short plant height. The cultivar Catuaí was obtained from that cross. Obtaining 'Catuaí' was a process of great dedication, persistence, and ability in conducting a breeding program, carried out by Dr. Alcides de Carvalho (Guerreiro Filho et al. 2018). Hybridization was carried out in 1949 in Campinas, and the scientific article that signaled recommendation of 'Catuaí' was published in 1972, that is, 24 years after hybridization. The seeds of some $F_{2:3}$ progenies originating from this hybridization were distributed to farmers in 1965. The progenies continued to be evaluated by IAC but, at the same time, information on the response on the farm properties supported the recommendation. Some lines of 'Catuaí' have been recommended: 'Catuaí Vermelho' and 'Catuaí Amarelo'. It should be noted that 'Catuaí Amarelo', line 62, was highly successful under conditions quite distinct from those under which it was selected, highlighting especially the Cerrado conditions in Minas Gerais.

In coffee breeding, various traits besides yield are considered, such as resistance to pathogens, especially rust (*Hemileia vastatrix*); to nematodes; to pests, especially coffee leaf miner (*Leucoptera coffeella*); and to others. There are not many coffee breeders in Brazil, and they are active in few research institutions, such as IAC, IAPAR, Embrapa, EPAMIG, and universities that normally work in cooperation with Embrapa and state research companies.

The estimates of linear regression between the independent variable (X) of year and the dependent variable (Y) of grain yield in the period from 1970 to 2019 showed an annual increase of 22.94 kg ha^{-1} $year^{-1}$. Percentage gain in relation to the yield of 1970 is 8.9% per year. An expressive part of this coffee production was under *Cerrado* conditions, where clearly the crop was successful only through selection of lines for these growing conditions. The success of crop management practices was also highly significant, but the breeding program conducted in Brazil was decisive.

PERSPECTIVES FOR PRODUCTION OF GRAIN, FRUIT, AND FIBER FOR THE COMING TWO DECADES IN BRAZIL

Taking what is currently happening as a reference, some inferences can be made regarding factors involved in demand for grain, fruit, and fiber in Brazil for the coming decades. We cite the following:

a) Considering the social aspect, the consumption of foods and other products derived from agriculture will increase.

b) Demand in the world market will grow. Brazil should continue to be a large exporter.

c) The effect of biotic and abiotic stresses will increase as a result of intensification of growing areas through succession of two or more crops per year, through global warming, and through the use of marginal areas for growing some species.

d) The cost of inputs used in crop management is likely to increase.

These factors and some others lead to the inference that there will be the need for increased yield of grain, fruit, and fiber per area. These increases will certainly depend in large part on the success of breeding programs in Brazil. However, some aspects should not or must not be overlooked. For example: i) the yield achieved by some species in Brazil is already relatively high and, therefore, obtaining the same genetic progress reported above will be much more difficult. ii) The search for sources of resistance/tolerance to stresses should certainly involve use of germplasm accessions, which likely have lower yield and lower quality than the products now on the market. Under these conditions, more time will surely be required to achieve the standard of the cultivars already being grown. iii) Improvement in the efficiency of use of production inputs, such as water and fertilizers, will need to be the focus of various breeding programs. Plant breeding has already shown that it is possible to achieve this objective, but it will also require more time.

The above discussion makes it clear that achieving necessary success in plant breeding will depend on some factors:

a) Training of more plant breeders with ability in finding solutions for the problems cited;

b) The efficient use of tools in addition to the selection traditionally carried out in the past. The use of molecular markers has already involved an enormous amount of human resources and capital, yet the return was less than expected. Its efficiency must increase.

c) All agree that programs for obtaining cultivars must be accelerated. In recent years, some methodologies have been proposed from what has been called Speed Breeding (Watson et al. 2018). However, they urgently need to evolve from theory to practice.

d) What has been communicated as Plant Breeding 4.0 (Wallace et al. 2018) proposes the intensification of analyses involving all the information possible in selection beyond the phenotypic mean obtained in the experiments, such as data related to soil structure and fertility, climate conditions, information on plant physiology, and use of genomics. Indications are that the tools to be used in these biometry predictions are available, including artificial intelligence, neural networks, machine learning, and deep learning, among others. However, it should be emphasized that these predictions will only effectively be useful if the information from the phenotyping experiments of the lines/hybrids/clones is obtained with increasing precision (Bernardo 2021).

e) Finally, it should be highlighted that the genotype × environment interaction, especially the genotype × year interaction, is expressive. Thus, the success of new cultivars will depend on strategies to lessen the risks of these interactions. The option adopted by some seed companies in recommending a larger number of cultivars annually seems to be a good alternative. With this strategy, new cultivars are made available and intensification of seed production will depend on performance on the different farm properties in subsequent years. This response will provide the company with greater information to determine whether to intensify seed production of the recommended cultivars.

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