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Review Article

Adaptation of soybean to low latitudes using alleles for long juvenile period

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Abstract

The adaptation of soybean to low latitudes was driven by the use of alleles for the long juvenile period, allowing the successful cultivation of the crop in tropical and subtropical regions. Several cultivars were developed from crosses that incorporated these alleles, contributing to the expansion of soybeans in Brazil. Introductions were made from Mississippi developed by Edgar E. Hartwig, and from Florida developed by Kuel Hinson, both soybean breeders of the U.S.D.A. The modified backcrossing method was fundamental for the introduction of the alleles for the long juvenile period in these introductions. In this way, it was developed the Brazilian soybean germplasm, enabling the adaptation of the crop in regions with lower than 20º South Latitudes. The present work played a fundamental role in this adaptation process, carrying out studies on the inheritance of the juvenile period trait in soybeans. The results of these studies contributed significantly to the development of cultivars adapted to low latitudes for many countries and to the success of soybean in Brazil.

Keywords: *Glycine max*; flowering; soybean genetics; inductive phase; short-day plant; recurrent parent; donor parent; photoperiod.

Introduction

The first historical record of soybeans in Paraná dates to 1936, when farmers from Rio Grande do Sul and Santa Catarina began to settle in the West and Southwest Regions, basing their activity on pig farming (Bonato & Bonato, 1987). In 1941, under the coordination of the Plant Production Promotion Division of the Ministry of Agriculture, 1,895 m^2 of soybeans were cultivated with the aim of producing seeds, with the seeds produced being distributed in 1942.

The crop did not expand much until the beginning of the 1950s. In 1953, the occurrence of frosts drastically affected coffee in the north of the state, forcing farmers to use cereals for intercropping, in order to balance the costs of renewing crops coffee plantations. After a new frost in 1955, soybean cultivation was suggested to mitigate the consequences of this climatic phenomenon on coffee plantations.

Paraná's response was immediate. From 43 hectares, harvested in the 1954/55 harvest, it increased to 1,922 hectares in the following harvest. From then on, the area grew, especially in the 1970s, reaching 2,410,800 hectares in 1979/80. In the 1956/57 harvest, it assumed the position of second largest national producer. In 1985, the state accounted for 24.1% of Brazilian soybean production (Table 1 and Figure 1).

During this period studied by Bonato and Bonato (1987), the state of Paraná had the highest average national soybean yield, resulting in excellent total production. In the first half of the 1980s, the average yield of soybeans in Paraná was around 2,150 kg/ha. Until the 1984/85 harvest, the maximum average yield was 2,221 kg/ha, obtained in 1975 (Table 1). The forecast for the 2020/2021 soybean harvest in the state of Paraná is as follows: cultivation of 5.54 million hectares, grain yield of 3,633 kg/ha and production of 20.1 million tons (Table 2 and Figure 1) (Companhia Nacional de Abastecimento [CONAB], 2020a). The forecast for the 2020/2021 Brazilian soybean harvest is as follows: cultivation of 37.9 million hectares, grain yield of 3,529 kg/ha and production of 133.7 million tons (CONAB, 2020b).

Figure 1 was prepared based on Tables 1 and 2, taking into account everything from the 1951/52 harvest to the estimated 2020/21 harvest. In this figure, it can be seen that the cultivated area line did not undergo abrupt changes from one harvest to another. With the growth of the cultivated area over the decades, the 2020/21 harvest has an estimated 5.5 million hectares cultivated, an average grain yield of 3,633 kg/ha and production of 20.1 million tons of soybeans. The average grain yield line suffered significant decreases in some harvests due to the occurrence of droughts, in the 1977/78, 1978/79 and 1985/86 harvests, as observed by Fendrich (2003). The same also happened in the 2008/09, 2011/12 and 2018/19 harvests. It can be seen, in the lines of Figure 1, that when there is a decrease in average grain yield. This reduction is reflected in a drop in total grain production. This manuscript was based in the book chapter written by Souza Junior, Kiihl, Harada and Destro (2021).

Estimates of the juvenile period and inductive phase in soybean genotypes

The success in adapting Brazilian soybean cultivars to low latitude regions was achieved thanks to the incorporation of the late flowering trait into the germplasm used by breeders. The objective of the work done by Harada, Gonçalves, Kiihl and Destro (2015) was to establish a methodology to estimate the juvenile period and the inductive phase of soybean genotypes. A total of 11 cultivars representing the successful trajectory of the genetic progress of soybean breeding in Brazil were used.

The experiments were carried out under greenhouse conditions in the city of Cambé, PR, Brazil. Seeds were germinated at 14 day intervals and, after emergence, the plants were subjected to continuous light for periods varying from 0 to 56 days. The number of days for flowering under the different light regimes and sowing times was evaluated. A decreasing exponential regression model was adjusted, through the differences between the maximum and minimum partial points of the function, to estimate the juvenile period (Figure 2). More details of the material and methods of this work can be seen in Harada et al. (2015).

Table 1. Harvested area, average grain yield and quantity produced from soybean crops in the state of Paraná, in the harvests from 1951/52 to 1984/85.

Harvest	Harvested area (1,000 ha)	Grain yield average (kg/ha)	Quantity produced (1,000 t)
1951/52	0.058	741	0.043
1952/53	0.018	722	0.013
1953/54	0.024	796	0.019
1954/55	0.043	1.349	0.058
1955/56	1.922	1.020	1.960
1956/57	5.253	855	4.491
1957/58	3.103	1.164	3.613
1958/59	2.787	1.769	4.931
1959/60	5.059	1.456	7.364
1960/61	6.400	1.400	8.963
1961/62	10.53	1.323	13.93
1962/63	13.31	1.348	17.94
1963/64	16.93	1.094	18.53
1964/65	34.31	1.286	44.11
1965/66	54.31	1.528	82.96
1966/67	82.94	1.366	13.29
1967/68	119.6	1.365	163.2
1968/69	172.4	1.239	213.6
1969/70	304.2	1.210	368.0
1970/71	357.7	1.291	461.7
1971/72	452.7	1.520	688.2
1972/73	817.8	1.622	1.326
1973/74	1.340	1.932	2.589
1974/75	1.632	2.221	3.625
1975/76	2.083	2.160	4.500
1976/77	2.200	2.136	4.700
1977/78	2.349	1.341	3.150
1978/79	2.340	1.709	4.000
1979/80	2.411	2.240	5.400
1980/81	2.266	2.200	4.983
1981/82	2.100	2.000	4.200
1982/83	2022	2.134	4.315
1983/84	2.178	1.892	4.121
1984/85	2.196	2.009	4.413

Source: Adapted from IBGE (Brazilian Statistical Yearbook, 1952/85), and Bonato and Bonato, 1987.

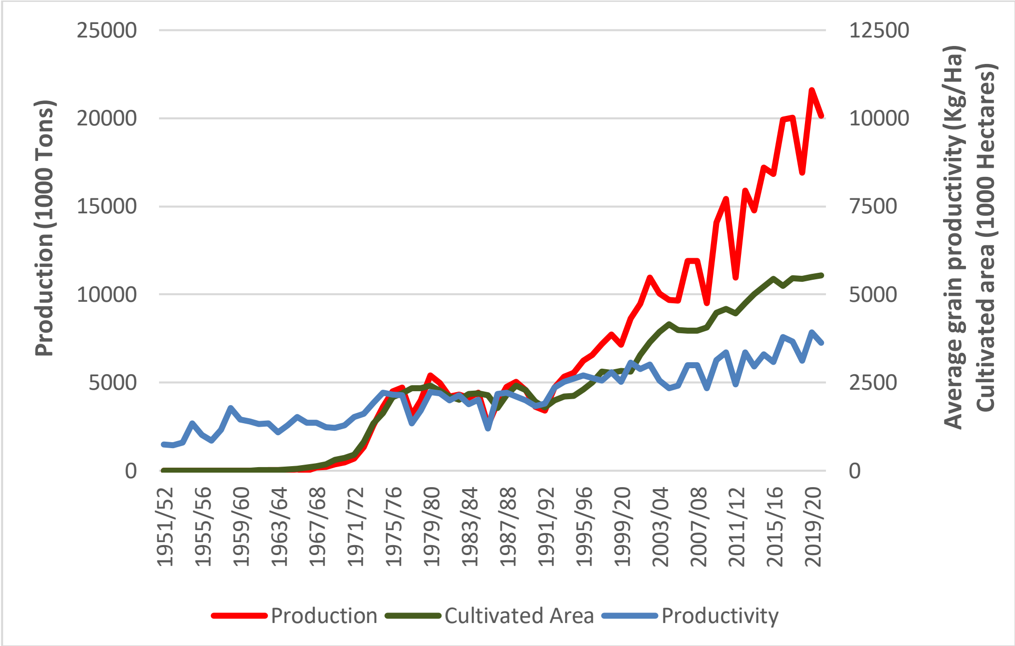

Figure 1. Evolution of the cultivated area, production and average grain yield of soybeans in the state of Paraná.
Source: Adapted from IBGE (Brazilian Statistical Yearbook, 1952/85), Bonato and Bonato, 1987, and CONAB (2020a).

Results showed that, except for 'Viçoja', all the other cultivars fitted into the model. 'Paraná' had an almost linear behavior with the equilibrium point at the zero value. 'Paranagoiana' was the cultivar with the largest and most significant juvenile period while 'Viçoja' and 'ÚFV-1' showed the lowest juvenile periods. The methodology developed appeared to be robust and it was validated by the known behavior of such cultivars when sown under short day conditions that occur either in low latitudes or anticipated and delayed sowing seasons.

Adaptation of soybean to low latitudes through alleles for long juvenile period

Soybean is considered a short-day (long-night) plant. Much of the world's area cultivated with this crop is located at latitudes greater than 30º, where temperate climate conditions prevail. Brazil represents an exception within this context. In the last two decades, with the expansion of the crop in large areas of the Cerrados, the agricultural production process with soybeans occurs, predominantly, in regions with tropical and subtropical climates. The adaptation of soybeans to the latitude conditions of the Central-West, North and Northeast regions was one of the major challenges faced by Embrapa Soja's breeding program. This expansion was greatly facilitated by the development of improved and adapted cultivars, including for equatorial zones.

Currently, more than half of Brazilian production is harvested in states located at latitudes lower than 20° SL. Regions located at latitudes lower than 10º represent the expansion area for soybeans, especially in the states of Maranhão, Piauí, Tocantins and Pará (Almeida, Kiihl, Miranda, & Campelo, 1999).

It is recognized that the expansion of soybeans in low latitudes was boosted by the launch

of cultivars with agronomic traits that are better adapted to the edaphoclimatic conditions of the tropics. This genuinely Brazilian technology, represented by the seeds of 'tropical cultivars', has allowed the exploitation of soy in regions previously considered unsuitable for its economic cultivation. The continuous process of recommending cultivars for regions of medium and low latitudes allowed extensive areas of the tropical Cerrado region to be incorporated into the agricultural production process, including enabling the economic exploitation of other crop species (Almeida et al. 1999).

Table 2. Harvested area, average grain yield and quantity produced from soybean crops in the state of Paraná, in the harvests from 1985/86 to 2020/21.

Harvest	Harvested area (1,000 ha)	Grain yield average (kg/ha)	Quantity produced (1,000 t)
1985/86	2.140	1.200	2.568
1986/87	1.776	2.170	3.854
1987/88	2.149	2.220	4.771
1988/89	2.407	2.100	5.055
1989/90	2.286	2.000	4.572
1990/91	1966	1.840	3.617
1991/92	1.798	1.900	3.415
1992/93	2.000	2.360	4.720
1993/94	2.110	2.525	5.328
1994/95	2.121	2.610	5.535
1995/96	2.312	2.700	6.241
1996/97	2.496	2.630	6.566
1997/98	2.820	2.550	7.191
1998/99	2.769	2.789	7.723
1999/20	2.836	2.516	7.134
2000/01	2.818	3.060	8.623
2001/02	3.283	2.887	9.478
2002/03	3.638	3.016	10.971
2003/04	3.936	2.550	10.037
2004/05	4.148	2.340	9.707
2005/06	3.983	2.422	9.646
2006/07	3.979	2.995	11.916
2007/08	3.977	2.991	11.896
2008/09	4.069	2.337	9.510
2009/10	4.485	3.139	14.079
2010/11	4.591	3.360	15.424
2011/12	4.461	2.453	10.942
2012/13	4.753	3.348	15.912
2013/14	5.010	2.950	14.781
2014/15	5.225	3.294	17.211
2015/16	5.451	3.090	16.845
2016/17	5.250	3.795	19.922
2017/18	5.465	3.668	20.045
2018/19	5.438	3.112	16.922
2019/20	5.503	3.925	21.598
2020/21[1]	5.541	3.633	20.131

[1]Forecast.
Source: CONAB (2020a, b).

Dr. Romeu Afonso de Souza Kiihl, who has worked for several decades in the state of Paraná, in his doctorate at Mississippi State University in the 1970s, studied the inheritance of the trait juvenile period in soybeans. In this research, the pure lines 'Santa Maria' and PI 159925 were studied, which showed late flowering under short day conditions (day length less than 14 hours).

In its first study, the pure line D72-7842, similar in flowering to the Bragg cultivar,,was crossed with 'Santa Maria'. It was concluded that the number of days to the onset of flowering under long-day conditions could not be used to predict the number of days to the onset of flowering under short-day conditions. Continuing Kiihl's studies, Otávio Tisselli Filho used the modified Tracy x (Hill x PI 159925) backcross, verifying that the genetic control of the long juvenile period of PI 159925 is controlled by the recessive allele of a gene, which greatly facilitated its use in obtaining adapted types with this trait. Thus, it was predicted that those late-flowering types would have adequate growth under short-day conditions, to allow mechanized harvesting, and would not require an extremely long period to have adequate plant development (Hartwig & Kiihl, 1979).

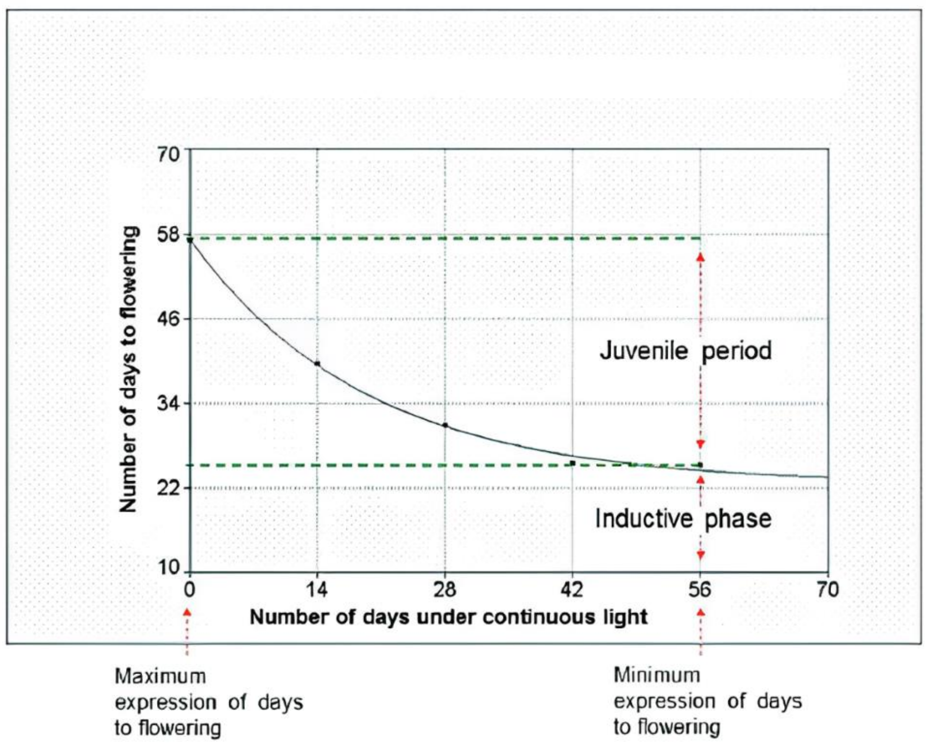

Figure 2. Representation of the estimates of the inductive phase and the juvenile period, based on the regression of the number of days to flowering (Y), depending on the number of days under continuous light (X), for a hypothetical soybean genotype.
Source: Harada et al. (2015).

From this research, it was concluded that backcrossing programs could be carried out, using productive cultivars or pure lines adapted to the south of the United States of America as recurrent parents and the genotypes 'Santa Maria' and PI 159925 as donor parents for flowering late. These programs would result in valuable cultivars for tropical and subtropical regions. These programs can be conducted outside the production area. The evaluation can be concentrated on plants that present adequate development (Hartwig & Kiihl, 1979). Thus, to designate the trait that allowed soybeans to adapt to low latitudes, in the works of Dr. Romeu Kiihl, it was called late flowering under short day conditions. Subsequently, in the work developed by Tisselli Filho (1981), this trait was mentioned as a long juvenile period. Finally, long juvenile period came to be used in a widespread way to designate late flowering under short day conditions.

The trait long juvenile period in soybean cultivars delays flowering under short day conditions. This trait is very important to increase the range of soybean adaptation to low latitudes and provides greater flexibility for the sowing period within the same latitude (Carpentieri-Pipolo, Kiihl, & Almeida, 2002).

Dr. Romeu A. S. Kiihl, in a personal communication, especially for this manuscript, mentions that the long juvenile period trait is not necessary to develop soybean cultivars for low and medium latitudes. However, long juvenile period is very useful because of wide adaptation of sowing time and the production of seeds in the winter time. TMG 1188 RR and TMG 1288 RR cultivars when sowed in November, in Central Brazil, have good yields and adequate height. TMG 1188 RR does not have any allele for long juvenility and when sowed in the winter under irrigation is very short and produces few pods. TMG 1288 RR has long juvenile period alleles and shows good growth and yield when cultivated in the winter time under irrigation, in Central Brazil.

The genetic control of flowering time in short days is determined by a genetic system different and independent from that which determines flowering in classical sowing times (in long-day flowering). Long-day flowering has more complex genetic control, being greatly influenced by the group of genes with dominant alleles, wich is controlled by genes E1/e1 to E5/e5 (Destro, Sediyama, & Gomes, 1990; Bonato & Vello, 1999). Simple late flowering under short day conditions is controlled by recessive alleles (Destro, Carpentieri-Pipolo, Kiihl, & Almeida, 2001). Regarding late flowering in short days, Kiihl, in a personal communication to Destro et al. 2001 and as a record for this publication, reported that the sources of recessive alleles for the long juvenile period, in introduced genotypes or in natural soybean mutants selected in Brazil, as well as their respective gene numbers, are as follows:

PI 159925: 1 gene and recessive allele;
Paranagoiana: 1 gene and recessive allele;
SS-1: 1 gene and recessive allele;
IAC 73-2736: 1 gene and recessive allele;
Bossier: 1 gene and recessive allele;
Paraná: 1 gene and recessive allele;
Davis: 1 gene and recessive allele;
BRS Simbaíba: 1 gene and recessive allele;
BR-23: 2 genes and recessive alleles;
MG BR 42 (Garimpo): 2 genes and recessive alleles;
BR 10 (Teresina): 2 genes and recessive alleles;
BRS Celeste: 2 genes and recessive alleles;
BRS MT Pintado: 2 genes and recessive alleles;
BR 83-147: probably 2 genes and recessive alleles;
Santa Maria: 2 or 3 genes and recessive alleles;
Tropical: probably 3 genes and recessive alleles;
PI 240664: minimum 3 genes, recessive alleles and
Doko: n (not all genes present in Tropical).

Kiihl (personal communication for this manuscript), in an unpublished study, observed that three F_2 populations, in winter sowing in Brasília, DF, presented the following results:

'Paraná', 'Davis' and 'Bossier' flowered early as expected, with a plant height of

25 to 30 cm. In the 'Parana' x 'Davis' cross, all F_2 plants showed early flowering, reaching a plant height of between 25 and 30 cm. In the cases of 'Paraná' x 'Bossier' and 'Davis' x 'Bossier' crosses, it was found that 15 in every 16 plants showed early flowering, and 1 in every 16 plants showed late flowering (in short days). Thus, Dr. Kiihl concluded that the late flowering in short days in these two crosses was determined by recessive alleles of two genes. Dr. Kiihl concluded that 'Paraná' and 'Davis' had the same allele, or similar alleles at the same locus, which combined with the recessive allele of 'Bossier', results in plants with a long juvenile period.

These results were later confirmed by Carpentieri-Pipolo et al. (2002) in a greenhouse and field study, conducted under conditions of short days and early sowing, in Londrina, PR (23°22' South Latitude). The genotypic ratio of 15:1 in the F_2 generation observed in the 'Paraná' x 'Bossier' cross indicated a case of digenic interaction, with an epistatic effect of two loci, with recessive alleles. Recessive homozygosity at just one locus does not produce a long juvenile period. This work confirmed the study by Dr. Romeu Kiihl, previously carried out in Brasília, DF. In other words, in the crosses studied in these two studies, the plants, in order to present the trait long juvenile period, need to be homozygous recessive at both loci.

Use of different sources of long juvenile period by soybean breeders

Introductions were made from Mississippi developed by Edgar E. Hartwig (example: Hill, Hood and Jackson), and from Florida developed by Kuel Hinson (example: Viçoja (F61-2890), Mineira (F58-6421 and Hardee), both soybean breeders of the U.S.D.A. The modified backcrossing method was fundamental for the introduction of the alleles for the long juvenile period in these introductions. In this way, it was developed the Brazilian soybean germplasm, enabling the adaptation of the soybean in regions with lower than 20º South Latitudes.

Soybean breeders used different sources for the long juvenile period. Part of the soybean breeding work to obtain some of the cultivars adapted to low Brazilian latitudes is mentioned here. For the introduction of the long juvenile period in soybean germplasm, the modified backcross method was used, thus enabling the cultivation of soybeans in low latitudes, resulting in the great collaboration given by soybean breeders for the success of the crop in Central and North/Northeast Brazil. In the modified backcross method, the desired agronomic type is crossed with the donor source of the long juvenile period, and then crossed with another genotype that also has desirable traits. Below, some examples are mentioned to illustrate the incorporation of the long juvenile period in Brazilian soybean germplasm.

Development of the Numbaira cultivar

The Numbaira cultivar was obtained from work carried out at IAC, Iapar and Embrapa Soja. Because it performed well in experimental beds in Paraná, and because it had a late cycle, it was included in tests carried out by the Cerrados Agricultural Research Center – CPAC and by the State Research Companies of Minas Gerais and Goiás states, in regions of Central Brazil (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 1981b).

According to Kiihl et al., 1981, the Numbaira soybean cultivar, which before its release was identified by the acronym Lo 75-1494, comes from the cross Davis x IAC 71-1113, carried out in 1970/71, in Campinas, in Legumes Section of the IAC and developed using the genealogical method. IAC 71-1113 is a late-flowering F_5 line, selected from the Hill x PI 240664 cross.

The selections were made at the IAC in Campinas, in the state of São Paulo, up to the fourth generation, and the final selection, corresponding to an F_5 progeny (Lo 75-1494) was carried out in Londrina, PR, in the Iapar, in the 1974/75 harvest. The Lo 75-1494 lineage was initially tested in the 1975/76 harvest in Londrina, PR and Guarapuava, PR, by Iapar, and was later sent by Embrapa Soja for testing in Central Brazil. The tests were carried out by CPAC (Federal District and Mato Grosso), Emgopa (Goiás) and Epamig (Minas Gerais), in the years 1977/78 to 1979/80. From 1978/79 onwards, it was also tested by Unesp – Ilha solteira Campus.

'Numbaira' is resistant to bacterial pustule and, despite having a lower seed oil content than 'UFV-1', its high grain yield and excellent plant architecture allowed its launch as a new option for the states of Goiás, Mato Grosso and Minas Gerais and the Federal District.

Development of cultivars IAC-6, IAC-7 and IAC-8

Viçoja x (Hill x PI 240664) → IAC-6
Davis x (Hill x PI 240664) → IAC-7
Bragg x (Hill x PI 240664) → IAC-8

Viçoja, Davis, Bragg and Hill are cultivars with good traits and PI 240664 is an introduction originating from the Philippines that presents the trait of late flowering in short days (long juvenile period), but with greenish seeds, susceptibility to bacterial pustule and highly dehiscent.

Seeds of F_2 plants from the Hill x PI 240664 cross were sent, in 1968, to the Legumes Section of the IAC by Dr. Kirk Athow, then a consultant working at the Federal University of Viçosa. The F_3 progenies were visually evaluated in 1968/69, being the best traits selected. None of them met the desired traits of resistance to bacterial pustule and pod dehiscence.

The selected lines were evaluated in the winter of 1969, at the Ribeirão Preto experimental station, where those that showed late flowering in short days were selected. Such lines were backcrossed for other types of good agronomic traits. From these crosses, using the genealogical method (“Pedigree Method”), it was possible to select lines with good productive potential, good agronomic traits and with the trait long juvenile period. The final evaluations and adaptation and grain yield tests were carried out by Dr. Manoel Albino Coelho Miranda.

Part of the F_2 seeds from the various backcrosses were gathered in bulk, and a sample was provided to Iapar in 1974. With the union of the Iapar programs with Embrapa Soja in 1978, it was possible to test the selected lines in Central and North/Northeast of the Brazil.

Development of Tropical Cultivar

As described by EMBRAPA (w/d), the Tropical soybean cultivar originates from the crossing of the Hampton x E 70-51 genotypes, carried out at the Campinas Agronomic Institute (IAC), São Paulo, in the 1969/70 agricultural year, by the researcher Dr. Romeu A. S. Kiihl. The E 70-51 line was selected from the Hill x PI 240664 cross and showed late flowering in short days, and excellent resistance to pod dehiscence and susceptibility to bacterial pustule. Tropical probably inherited all the alleles for late flowering in short days from PI 240664.

The selection work was carried out at the IAC until 1974 and continued at the Instituto Agronômico do Paraná (Iapar), in 1975, until obtaining a uniform F_6 progeny that received the name 'Lo 75-2280'. This lineage proved to be late and, for this reason, in 1975, it was sent to the Cerrado Agricultural Research Center (CPAC), through the National Soy Research Center (CNPSo), for evaluation in locations with lower latitudes. In 1977, this line, through seeds from CPAC, was introduced into the State level Research Execution Unit, in Teresina, PI (Uepae de Teresina, PI), where it was tested and evaluated, in a latitude around 5º SL, by researcher Gilson Jesus de Azevedo Campelo.

Due to the relevance of its performance, Uepae de Teresina, PI, provided the shipment of seeds of this lineage to institutions in the North and Northeast of Brazil, aiming to expand agronomic information about its behavior in different locations with low latitudes. The Tropical cultivar is resistant to bacterial pustule, and its number of days from sowing to flowering and maturation is 50 and 110 days, respectively. The plant height is 90 centimeters and the insertion height of the first pods is 24 centimeters, which allows for better efficiency in mechanical harvesting. 'Tropical' was the first cultivar developed for low latitudes with a long juvenile period.

Dr. Irineu Alcides Bays, a great supporter and researcher for low latitudes, made a point of, in the state of Amapá with one foot in the Northern Hemisphere and the other in the Southern Hemisphere, sowing the Tropical cultivar on the Equator. Dr. Bays died on a plane trip to Maranhão, where he intended to move in order to develop soybean cultivation in the region. He gave his life for soybean.

Development of the Doko cultivar

According to Almeida et al. (1981) and EMBRAPA (1981a), the Doko soybean cultivar, launched in 1980, originated from the RB 72-1 population, resulting from six crosses (E 70-46 x Viçoja, E 70-47 x Viçoja, Hill x E 70-47, E 70-46 x Pickett, E 70-47 x F 65-1376, and Davis x IAC 70-308) carried out at the IAC, in the Legumes Section, in 1969/70, by Dr .Romeu Afonso Souza Kiihl. E 70-46, E 70-47 and IAC 70-308 are late-flowering F_4 lines, resistant to bacterial pustule or pod dehiscence, from the cross Hill x PI 240664. Viçoja, Hill, Pickett, Davis and F 65-1376 are genotypes with good agronomic traits, however, early flowering and low height. Due to its traits, the Doko cultivar probably resulted from one of the two crosses made with Viçoja. Therefore, Viçoja x (Hill x PI 240664).

In the winter of 1973, 90 tall plants were selected from the RB 72-1 population, in Pindamonhangaba, SP, by RAS Kiihl and Geraldo Guimarães. In the 1973/74 agricultural year, small multiplications were established in the research fields, with 8 to 24 plants being selected from each multiplication, which were sent to Campinas (IAC) and Londrina (Iapar). From 1974 onwards, the selection continued independently at the IAC by Manoel A. C. Miranda, and at Iapar by Leones Alves de Almeida.

In the 1974/75 agricultural year, Lineage Lo 75-2760 was obtained in the Iapar improvement field. In the following agricultural year, it was tested in the locations of Londrina and Guarapuava, PR. In 1976, this lineage became the responsibility of Embrapa, due to the agreement signed with Iapar. Embrapa continued the improvement program, indicating that cultivar, from the 1976/77 harvest, to participate in trials in Central Brazil, in joint work by CPAC, Epamig and Emgopa.

The Doko cultivar was the pioneer of the Brazilian Cerrados due to its higher grain yields in first-year crops. It is a cultivar that presents resistance to bacterial pustules, susceptibility to frogeye spot, late cycle, good plant height and insertion of the first pods, generally above 20 cm, called, due to this, Canela de Ema. It is more tolerant than the UFV-1 cultivar to high concentrations of aluminum with consequent greater root deepening. The Doko cultivar is ten days later than the IAC-2 cultivar, therefore being a new option for Central Brazil. In addition to the cycle, the grain yield and the plant's architecture allowed its launch in the states of Goiás, Mato Grosso and Minas Gerais and also in the Federal District.

Doctors Leones, Irineu and Romeu believed that the Doko cultivar would be the Trailblazer of the Cerrado (which they were correct), and that the 1494 lineage would be the Queen of the Cerrado due to its agronomic type and excellent yield (but this case did not happen) and chose a combination of names that would mean productive field in the future (they did not find a word that could be used for Cerrado): Numbaira. However, the prophecy came true, as MG/BR 46 (Conquista), daughter of Numbaira, was widely used in Central Brazil for some years.

Development of the UFV-1 cultivar

The UFV-1 soybean cultivar originated from a selection in Viçoja (D49-2491 x Improved Pelican). The name prior to launch was Viçoja-Mutante, UFV 72-1, and its launch was made in 1973. The UFV-1 cultivar presents flowering in 68 days, maturation in 158 days, plant height of 89 cm and height of the first pod of 23 cm. It is a cultivar developed by Professor Dr. Tuneo Sediyama and his team, and presents good grain yield, adaptability and phenotypic stability. Due to these traits and the good quality of the seeds, this cultivar quickly became one of the most preferred cultivars by farmers in Central Brazil (Sediyama et al., 1981).

Development of the FT-Cristalina cultivar

The FT-Cristalina cultivar originated from a natural cross in UFV-1, and the lineage was named Muta Soja 4 (M-4). The breeder Francisco Terasawa made this selection. In 1974, Dr. Romeu observed that the M4 lineage was very similar to the Davis cultivar. Thus, this selection probably originated from the natural cross Davis x UFV-1. This cultivar was called “Soja Rainha dos Cerrados” (OCEPAR/EMBRAPA SOJA, 1988; Sediyama et al., 1981).

An important name for soybean breeding in Brazil, and more specifically for the Southern Region, is that of the great breeder Francisco Terasawa, who developed many highly productive soybean cultivars. His creations include FT-Cristalina, FT-2, FT-5 and FT-Abiara, which played an important role in the development of soybeans in Brazil.

Regarding Francisco Terasawa, it is worth mentioning his qualities as a breeder and entrepreneur. With great courage and boldness, he developed a breeding program at a time when there was no law to protect cultivars obtained with great effort and own investment. Francisco, 'Chico' as he was affectionately called, also trained several young breeders.

Development of the BRSMT Pintado cultivar

The cultivar BRSMT Pintado originates from the cross Sharkey x [Hartwig x (BR 87-567 (3) x FT-Estrela)]. The crossing was carried out in 1991/92, and the generations were advanced in Londrina, PR. The lineage that originated the BRSMT Pintado cultivar received the acronym MTBR 95-123247. It has an average duration of 115 days from emergence to maturation, when sown in the first fortnight of November in Mato Grosso, mean plant height of 76 cm, good resistance to lodging and pod dehiscence and good physiological seed quality. It is resistant to bacterial blight, frogeye spot, stem canker and common soybean mosaic virus.

As a special trait, it presents high resistance to races 1 and 3 and moderate resistance to races 4, 10, and 14 of the soybean cyst nematode. Embrapa Soja and the Mato Grosso Agricultural Research Support Foundation developed this cultivar (Hiromoto et al., 1999). It has good tolerance to rain at harvest, an important trait for tropical regions.

Development of cultivars from crosses with Bossier

The cultivars MG/BR 22 (Garimpo) and BR 23, derived from crosses with Bossier, are examples of cultivars with a long juvenile period and medium cycle. These intersections are mentioned below:

Bossier x Paraná → MG/BR 22 (Garimpo)
Bossier x Davis → BR 23

Development of the BRS Celeste cultivar

The BRS Celeste soybean cultivar originated from the Bossier x BR 1T cross. In some locations in the Brazilian Cerrados, it produced 4,000 kg/ha, demonstrating its high productive potential and stability. It has good resistance to lodging and is resistant to diseases such as cancer stem, frogeye spot and bacterial pustule. Its great highlight is, in addition to high grain yield, its tolerance to root-knot nematode (*Meloidogyne javanica)*. The average mass of 100 seeds is 13.4 g, which provides savings when purchasing seeds for sowing (Souza, Moreira, Farias-Neto, & Abud, 2001).

Development of cultivar BR 11 – Carajás, BR 28 – Seridó, BR 10 - Teresina and BR 27 – Cariri

The IAC 73-2736 lineage is a mutation in 'Hardee', which presents late flowering, selected by Mr. Massamori Kage, at Fazenda Vera Cruz, in the municipality of Guaíra, SP. In the 1971/72 agricultural year, Mr. Massamori Kage sowed his selection as a border for a trial that Dr. Romeu had installed at Fazenda Vera Cruz. This border caught Dr. Romeu's attention due to its excellent appearance and size. Mr. Massamori offered Dr. Romeu a sample of seeds that were sown in 1972/73, in Campinas, SP, receiving the designation IAC 73-2736.

The BR 11 – Carajás soybean cultivar originated from the UFV-1 x IAC 73-2736-10 cross, carried out at CNPSoja, in Londrina, PR, in 1975. Selection work was carried out up to the fifth generation, using the winter to accelerate the program. To the line was given the designation BR 79-251. It was introduced in the state of Piauí in the 1979/80 agricultural year, through Uepae de Teresina. Due to the good traits presented (size and cycle), it was evaluated in the municipalities of Teresina (from 1979/80 to 1982/83). In Elizeu Martins (1980/81 and 1981/82), and in São Pedro do Piauí (1981/82) with good results. It is resistant to bacterial pustule and wildfire (Campelo, Bays, Kiihl, & Almeida, 1984b).

The soybean cultivar BR 28 – Seridó, tested as lineage BR 83-9221, is an F_6 progeny from the cross of Santa Rosa x BR 78-11202. Held at CNPSoja, in Londrina, PR. The BR 78-11202 lineage is sister to the BR 11 – Carajás cultivar. This cultivar presented good agronomic traits for low latitude regions, such as grain yield, plant height and insertion of the first pods. It is resistant to the fungus that causes frogeye spot (Campelo, Paludzyszyn-filho, Kiihl, Almeida, & Hirooka, 1987a).

The soybean cultivar BR 10 – Teresina comes from the crossing of the genotypes UFV-1 x IAC 73- 2736-10, carried out in 1975, at CNPSoja, in Londrina, PR. Selection work was carried out up to the sixth generation, using winter multiplication to advance generations. The line was given the designation BR 79-172. Due to its good agronomic traits, it was recommended for the entire state of Piauí, with the exception of semi-arid regions (Campelo, Almeida, Kiihl, & Bays, 1984a).

The soybean cultivar BR 27 – Cariri was originated from the cross BR 78-22043 x (Bragg x IAC 73-2736) carried out at CNPSoja, Londrina, PR. An F_6 progeny resulted in the inbred line tested with the designation BR 83-10073. It was introduced in the state of Piauí by Uepae de Teresina, in the 1983/84 agricultural year, where it presented good agronomic traits, such as grain yield, plant height and insertion of the first pods. It is resistant to the fungus that causes frogeye spot. Its cultivation was recommended for the state of Piauí, where it presents good soil fertility conditions and good rainfall distribution (Campelo, Paludzyszyn-filho, Kiihl, Almeida, Hirooka, 1987b).

Development of the Paranagoiana cultivar

The Paranagoiana cultivar is a late mutation in the Paraná cultivar. The late plant was selected by Emgopa researcher Alberto Vasconcelos Costa, in the municipality of Santa Helena de Goiás, GO. Half of the seeds were worked on by researcher Dr. Alberto, and the other half of the seeds by researcher Dr. Romeu. 'Paranagoiana' belongs to maturation group IX or X. The Paraná cultivar belongs to maturation group VI.

Development of the Ocepar 9 – SS1 cultivar and its derivatives

The soybean cultivar Ocepar 9 – SS1 is a natural mutation in 'Paraná', originating on the Alceno Stein property, in Toledo, PR. It was tested under the designation OC 83-62. The Paraná cultivar belongs to maturation group VI, while the Ocepar 9 – SS1 cultivar is in maturation group VIII. It is approximately 30 days later than the Paraná cultivar. It is resistant to bacterial pustule and frogeye spot (OCEPAR/EMBRAPA SOJA, 1988).

The soybean cultivar MA/BRS 65 (Sambaíba) originated from a plant selected from the cross FT 5 x (Dourados 14 x Ocepar 9 – SS1). The inbred line was tested under the designation MA/BR 92-3640. It was introduced in the state of Piauí by Embrapa Meio-Norte. It is resistant to bacterial pustule, frogeye spot and stem canker (EMBRAPA MEIO-NORTE, 2000).

According to Campelo et al. (1997), the soybean cultivar Embrapa 63 (Mirador) originated from a F_4 plant selected from the population of the cross Dourados-2 (2) x [Amambai (2) x Ocepar 9-SS-1]. The crossing, conducting segregating generations and progeny testing were carried out at CNPsoja, in Londrina, PR. The segregating population of this crossing was conducted, up to the F_3 generation, using the modified genealogical method (SPD), which consisted of advancing generations through descendants of seeds from a pod for each plant selected in the population. The progeny, identified as BR 89-9917, was selected and tested in preliminary and regional trials in the states of Piauí and Maranhão, starting in 1992/93.

Adaptability and stability tests, at field level, showed that the cultivar Embrapa 63 (Mirador) has stable behavior and high grain yield when cultivated in the conditions of the agroecosystems of the Cerrados of Mid-North Brazil. It presented a harvest point of 122 days, a plant height of 76 cm and a height of insertion of the first pods of 18 cm, traits suitable for mechanical harvesting. It also showed good resistance to lodging and pod dehiscence and medium to good seed quality. It is moderately resistant to bacterial blight and common soybean mosaic, and resistant to bacterial blight, frogeye spot and stem canker.

The soybean cultivar Embrapa 30 (Vale do Rio Doce) originated from a progeny identified as BR 89-1560, from the crossing of the BR 85-29003 lineage with the Dourados cultivar, carried out at Embrapa Soja, Londrina, PR. In Piauí, it was introduced through Embrapa/Uepae de Teresina, in 1990/91, where it presented a large size, medium cycle and high grain yield capacity. It showed average flowering at 50 days and maturation at 122 days. The average height of the plants was 81 cm and the mean height at the insertion of the first pods was 20 cm (Campelo, Kiihl, & Almeida, 1998). The Embrapa 30 cultivar presents the recessive allele of OC 9 – SS1 for a long juvenile period.

Breeding methods used to develop cultivars

In the 1960s and 1970s, the most widely used breeding method in Brazil was Plant Introduction. Due to the existence of pure elite lines and productive adapted cultivars in the South of the United States of America, in latitudes around 30° LN, these genotypes were introduced, tested, and the best genotypes were released as cultivars in the South of Brazil. Among the cultivars developed by the introduction method, the following can be cited as examples: Andrews, Bienville, Bossier, Bragg, Campos Gerais, Cobb, Davis, Florida, Hampton, Hardee, Hill, Jackson, and Lancer (Sediyama et al., 1981).

With the development of soybean genetic improvement, breeders began to use hybridization. The breeding methods most used in soybeans are the same as those for autogamous plants and are well described in the books by Borém (1997) and Destro and Montalván (1999). These methods are the following: population method ("Bulk method"), genealogical method ("Pedigree Method") and the SSD Method and derivatives ("Single Seed Descent").

With the use of these methods and the significant genetic gain in soybean grain yield in the state of Paraná and Brazil, breeders also began to use the backcrossing method. This method is used to improve one or a few traits, and serves to transfer genes incorporated into soybeans from other species.

Final comments

This review was made of the contributions made by researchers and professors who worked or work with the genetic breeding of soybeans, emphasizing the progress due to the alleles for the long juvenile period, especially Dr. Romeu A. S. Kiihl.

With the knowledge derived from studies with a long juvenile period, begun with Dr. Romeu A. S. Kiihl, in the 1970s, and from all other basic and/or applied work carried out by researchers and professors who dedicated themselves to the adaptation of soybeans to Central Brazil or to the North/Northeast, in 2022/2023 Brazil is the world's leading soybean producer. The results of these studies contributed significantly to the development of cultivars adapted to low latitudes for many countries and to the success of soybean in Brazil.

The success in increasing grain production and yield was due to the integration of the entire production chain, including from highly technical rural producers to commercialization, with emphasis on genetic breeding and soybean management. The success in soybean improvement was due to 1) the mechanization of trials, which greatly increased the precision of experimentation and testing capacity, and 2) IT, which allows rapid data analysis. For the future of soybean genetic improvement, significant contributions are also expected from genomics and gene editing.

Acknowledgements

This review was made of the contributions made by researchers and professors who worked or work with the genetic breeding of soybeans, emphasizing the progress due to the alleles for the long juvenile period, especially Dr. Romeu A. S. Kiihl.

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