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# Explanations for the Rise of Soybean in Brazil

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Additional information is available at the end of the chapter

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## 1. Introduction

### 1.1. Historical developments of Soybean Culture

Early reports indicate that the soybean culture came to Brazil around 1882, to the state of Bahia where the Teacher Gustavo Dutra conducted the first studies to evaluate cultivars. Between 1900 and 1901, the Agronomic Institute (IAC), in Campinas, São Paulo state, promoted the first distribution of soybean seeds to producers in the state.

In this same period, soybean culture reached the state of “Rio Grande do Sul”, where climatic conditions are similar to the southern U.S. The original introductory varieties came from the southern U.S. Soybean production first occurred in the city of Santa Rosa in the state of “Rio Grande do Sul”, in 1914 [1]. Research began during the 1930’s with the following breeding objectives: increased productivity; greater plant height and appropriate pod height to facilitate mechanization; development of lodging and pest resistance, and increased seed quality with high oil yield and protein [3].

The first national farm statistics, the Agricultural Yearbook of the “Rio Grande do Sul” state, was published in 1941 and indicated that the production area of only 640 hectares generated 450 tons. By 1949, the production in Brazil had grown to 25,000 tons. This was the first time that Brazilian production figures were recorded in international statistics. By 1970, soybean production had spread throughout the temperate and sub-tropical latitudes (near or above the 30°S Lat).

During the 1970’s, soybean was established as the main crop of the Brazilian agribusiness, rising from 15 million metric tons to over 15million metric tons. There was an increase of the cultivated area from 1.3 to 8.8 million hectares, and of the productivity from 1.14 to 1.73 t / ha. Soybean culture was concentrated in the southern region of the country, with more than 80% of the total production [1].

Several factors contributed to the establishment and development of the soybean culture in southern Brazil: similarity with southern U.S, the region from which soybeans were introduced to Brazil; introduction of liming and correction of soil fertility; tax incentives; increased use of vegetable oil vs. animal fats; establishment of a significant industrial soybean processing infrastructure; crop mechanization; emergence of dynamic and efficient cooperatives; establishment of a well-coordinated network of research; and improvements in roads, ports and communications [1].

Another important factor that explains the rise of soybean production in southern Brazil was that prevailing photoperiod and temperature characteristics directly influenced phenological development and yield. Spread of soybeans out of this region to central and northern Brazil and lower latitudes would depend on the development of new phonologically adapted varieties to these areas [2].

Brazil is located in the eastern part of South America between 5°16' N and 33°44' S latitudes (Figure 1). Photoperiod differences between the southern and northern portions of the country have inhibited the expansion of soybean from the original southern base to central and northern Brazil.



**Figure 1.** Map of Brazil, with its divisions into states, positioned in the South American continent between the parallels of 5°16' N and 33°44' S latitudes.

Research development of varieties adapted to these new areas of production began at the Agronomic Institute (IAC) in Campinas, "São Paulo" State, and the National Center for Soybean Research. In the 1970s, breeding studies were initiated from crosses of North American cultivars, which had the long juvenile trait. Thousands of genotypes are maintained in the Embrapa soybean (CNPSo) germplasm bank in Londrina, "Paraná" State. The Brazilian Agricultural Research Corporation (Embrapa) is under the Ministry of Agriculture. Its mission is to facilitate solutions for research, development and innovation for sustainable agriculture for the benefit of the Brazilian society. The National Center of Soybean Research (CNPSo) is a unit of Embrapa.

The entire germplasm collection is maintained at the Embrapa Genetic Resources in Brasília (Brazil's capital). Most of these accessions are plant introductions from North America which are derived from original plant introductions from China, Japan and other countries with wide genetic diversification [4].

## 1.2. Expansion of Culture

Because of Brazil's research efforts, developed cultivars were adapted to the short photoperiods of central and northern Brazil. This allowed the soybean expansion to the "Cerrado" region of Brazil, an area of more than 200 million hectares of undeveloped potential crop land. Brazil is now the second biggest soybean producer in the world with an average yield close to 3,000 kg/ha.

The world and Brazilian production, supply, and trade of soybeans are presented in Tables 1 and 2, respectively, from the 2006/2007 to 2009/2010 growing seasons. Brazil is established as the second largest producer, only behind the United States, and now contributes with about 33% of the world's exported soybean. In the case of end-of-year stocks, the Brazilian product represented approximately 29% of the world supply. During this four-year period, Brazil produced an annual average of 232,550 million metric tons of soybeans, which accounted for 26.50% of the world production (61.70 million tons).

Balance	2006/2007	2007/2008	2008/2009	2009/2010
Initial stock	53.206	63.155	52.886	43.973
Production	237.126	221.006	211.964	259.896
Imports	69.066	78.118	77.168	86.661
Total supply	359.398	362.279	342.018	390.530
Exports	71.315	79.589	77.253	89.575
Consumer	224.928	229.804	220.792	237.435
Final stock	63.155	52.886	43.973	63.520

**Table 1.** World balance of supply and demand for soybeans in thousands of metric tons. Source: USDA. Preparation: [5].

In the 2010/2011 season, Brazilian soybean production rose to 75.0 million metric tons, covering a cultivated area of 24.2 million hectares and an average yield of 3,106 kg/ha. "Mato Grosso" was the state with the greatest production (20.4 million metric tons), cultivated area (6.4 million hectares), and yield (3,190 kg/ha). "Paraná" state was the second largest producer, with production of 15.4 million metric tons, cultivated area of 4.6 million ha and yield of 3,360 kg/ha [6].

Balance	2006/2007	2007/2008	2008/2009	2009/2010
Initial stock	16.641	18.189	18.898	12.037
Production	59.000	61.000	57.800	69.000
Imports	53.000	150.000	44.000	185.000
Total supply	75.694	79.339	76.742	81.222
Exports	23.485	25.364	29.986	28.350
Consumer	34.020	35.077	34.719	36.175
Final stock	18.189	18.898	12.037	16.697

**Table 2.** Brazilian balance of supply and demand for soybeans in thousands of metric tons. Source: USDA. Preparation: [5].

In the most recent growing season (2011/2012), Brazil produced around 66.5 million tons from an area of 24.7 million hectares, with an average yield of 2,692 kg/ha [6]. The decrease on the production was due to a severe drought that occurred throughout the soybean-growing region. Soybean occupied about 48.9% of Brazil's cropland in that growing season and contributed to about 42% of the country's agricultural output. The central states of "Mato Grosso", "Mato Grosso do Sul" and "Goiás", with more than 10 million hectares, represent approximately half of all Brazil's soybean cultivated area.

Many factors contributed to the establishment of soybean, firstly in southern Brazil (in the 1960's and 1970's) and later in the "Cerrado" region of central Brazil (in the 1980's and 1990's) [1]. With respect to the central region of Brazil, the wide and rapid soybean acceptance can be attributed to:

Transfer of the national capital from Rio de Janeiro to Brazil's interior in the 1960's, what resulted in a great deal of infrastructure construction including roads, communication, and economic development;

Tax incentives were made available for open new areas of agricultural production, as well as for the acquisition of machinery and construction of silos and warehouses;

Establishment of agro-industries in the region, stimulated by the tax incentives that expanded the agricultural frontier;

Low land values in the central region compared to the southern region during the 1960-1980 period, encouraging the purchase of new farms;



The relatively plain topography of the "Cerrado", which was highly favorable to agricultural mechanization;

Good physical soil condition in the region; Improvements in the transport system, such as road, railway, and water transport that aided the marketing of soybean and other crops grown in the region;

New farmers, from southern Brazil, moving into the area, who already had a high technical knowledge of soybean production;

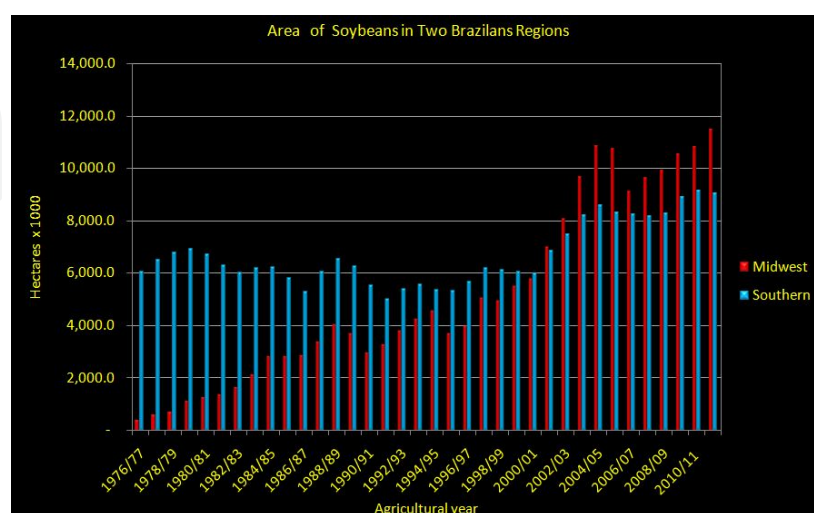
Rainfall in the region, which is highly favorable for summer crops, in contrast to the frequent dry spells occurring in the South, notably in "Rio Grande do Sul" [1].

Currently, soybean (*Glycine max* (L.) Merrill) is cultivated in almost all regions of the country. The biggest innovation that has aided the extension of soybean production across this vast north/south expanse was the development of the long juvenile trait.

The creation of CNPSo - Embrapa in 1975 consolidated the soybean research and greatly enhanced its production and quality. The transfer of this new technology to the farmers aided the expansion of soybean in Brazil. During the 1980's and 1990's soybean expanded again, this time into the tropical region in central Brazil.

From only 2% of the national production in 1970, soybean production in "Mato Grosso" in central Brazil expanded to 20% of the production in 1980, and then to 40% and 58% in 1990 and 2002, respectively. This transformation has promoted the state of "Mato Grosso" to the national leader on the production and yield of soybean [1].

Data from the Brazilian Institute of Geography and Statistics (IBGE) demonstrates the expansion of cultivation into the interior of the country in the period between 1976 and 2012 (Figure 2).



**Figure 2.** Brazilian soybean area in two regions in the period between 1976 and 2012. Source: [6].

Data for soybean production in two regions are shown in Figure 3 for the period between 1976 and 2012. The production increase in central Brazil made it the largest soybean producer in the country.

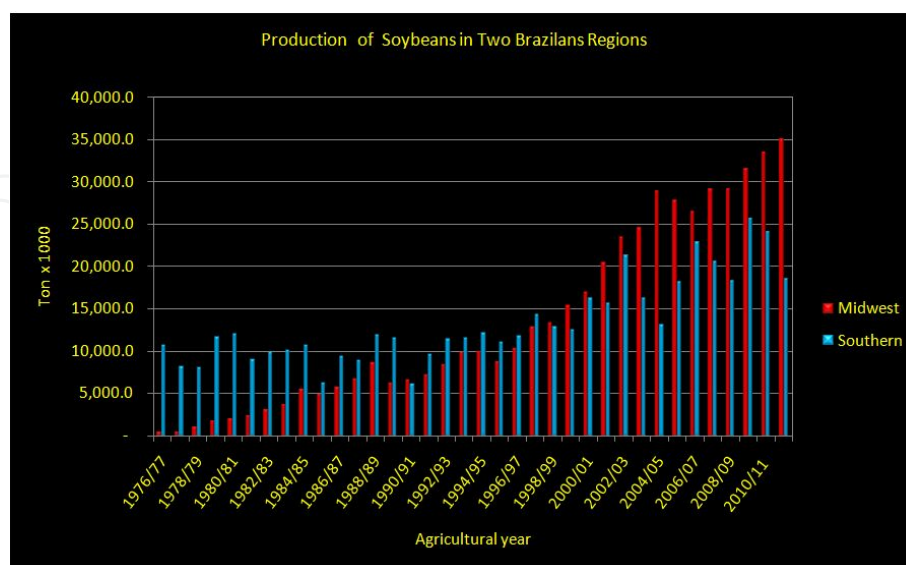
The southern region, which consists of “Rio Grande do Sul”, “Paraná”, and “Santa Catarina”, is now the second biggest producer. The stunning increase in soybean production during this period is similar to the rise of sugar cane during the colonial period and the rise of coffee during the Empire era.

The explosive growth of soybean production in Brazil (30 fold increase across a 30-year period) has profoundly changed the Brazilian agriculture. It has boosted farming activities; modernization of the transport system; expansion of the agricultural frontier; professionalization and expansion of the international trade; modification and enrichment of the Brazilian diet; acceleration of the country's urbanization; and population movement from coastal to the interior areas [1].

By the 2010/2011 growing season, soybean production had reached the equatorial region of northern Brazil. Thus, a crop that originally was grown only in southern Brazil became well established in central Brazil and continued to advance into northern Brazil.

Data in Figure 4 shows that 82% of production come from the states of “Mato Grosso”, “Paraná”, “Rio Grande do Sul” and “Goiás”.

However, 13% of soybean production come from the northern state “Tocantins” and the northeast states “Maranhão”, “Piau” and “Bahia”.



**Figure 3.** Brazilian soybean production in two regions, in the period between 1976 and 2012. Source: [6].



**Figure 4.** Brazilian soybean production in 2010/2011 harvest, divided among the states with the highest percentage of harvested grains. Source: [7].

## 2. Flowering of soybean

### 2.1. Photoperiod and Photoperiodism

Soybean culture is sensible to photoperiod and temperature and, due to the great diversity among cultivars, problems of adaptation to certain areas may occur [2]. In environments with constant photoperiods, temperature greatly influences flowering time [8]. There is an inverse relationship between temperature and the average number of days to first flower [9]. Days to first flowering are minor when over night temperatures range from 21 to 27°C. As temperatures fall below this range, first flowering is delayed. Above 27°C, flowering is largely inhibited [10].

The length of a day is known as photoperiod and plant developmental responses (i.e. phenology) to photoperiod are called photoperiodism [11]. Photoperiod affects not only days to first flowering, but also lengths of subsequent developmental stages. Variations in the day length are determined by latitude and planting date and both affect photoperiod because of tilting of the earth's axis. Plants may respond differently to these changes, as they cause



modifications on some processes such as seed germination, inhibition of stem elongation, synthesis of chlorophyll and anthocyanin, leaf expansion, flowering and tuberization. The process by which light regulates plant development is called photomorphogenesis [12].

Soybean is strongly influenced by photoperiod so the culture grows and develops according to which photoperiod is subjected. Soybean is classified as a quantitative short-day plant, which means developmental timing is greatly speeded up and reproductive growth enhanced when day length falls below a critical level. This critical level (called the critical photoperiod) differs with cultivar and maturity group. Soybean responds differently to day length. Differences were observed during the flowering period of soybean when grown on different dates. The discovery of the importance of photoperiod on soybean flowering enabled the soybean classification as short-day plants [8].

Another important concept is the meaning of critical photoperiod, which is related to the quantity of light hours that can cause flowering. The time interval, in number of days between emergence and flowering, is influenced by temperature and photoperiod. There is a limit of the short-day length necessary to induce or to stop flowering. This period is characterized as critical photoperiod [13]. The length of the critical photoperiod also varies among soybean cultivars [14].

The soybean, classified as a short-day plant, only flowers, or flowers more rapidly, when the number of light hours does not exceed the critical period of the considered cultivar for each 24-hour cycle [15].

When undergoing photoperiodic induction, leaf buds are transformed into flower buds. The development of the flower primordial in the "Biloxi" cultivar started under short days and the flowers opened after three weeks, showing that there is a period between the received induction and anthesis [16]. The authors concluded that initiation of floral induction in soybean occurred with the expansion of the first primary leaves. Further research with "Biloxi" demonstrated that floral buds were initiated when there was a minimum night length of 10 and a half hours along two or three consecutive photoperiods [17].

When soybean is grown in its adapted area, floral initiation occurs approximately three weeks after germination. Flowering will occur three to five weeks later. Thus, there is a period of approximately three weeks between both developmental stages [18]. Therefore, days to first flower can range from 45 to 50 days depending on the prevailing photoperiod/temperature and genotype. The minimal period for optimal yield is 45 days from emergence to first flower [19].

Floral induction occurs during the night. It is determined by the duration of darkness and not the number of light hours. This has been demonstrated by studies in which flowering occurred as a result of changes in the night length but not in the day length; and by other studies in which interruption of night time by light breaks altered the flowering response [20]. For example, soybean flowered under either short or long days, as long as nights were short [21].

Several researches in soybean characterized influences of photoperiod in the sub period between emergence and flowering plants [22-25].

Once soybean ends the juvenile phase and is able to perceive the stimulus, and photoperiod conditions are inductive, the plant enters the inductive phase and vegetative meristems change and start producing floral primordials. After the inductive phase is complete and floral organogenesis starts, the plant is in the post-inductive phase until flowering occurs [26].

The sub-period between emergence and when soybean responds to the photoperiod stimulus is termed as the juvenile phase. Recent research showed that soybean has little sensitivity to photoperiod during the juvenile phase [27].

The lengths of such sub-periods are determined by the degree of photoperiod sensitivity of the genotype. Thus, under long days and/or low temperatures, the rate of floral induction and flower development is minor. Developmental rate is important for yield determination, because if the plant develops too rapidly towards first flowering and seed initiation, there will not be enough time to build enough dry matter for optimal yield. Vegetative dry matter accumulation stops at the start of seed filling [26].

## 2.2. Phytochrome

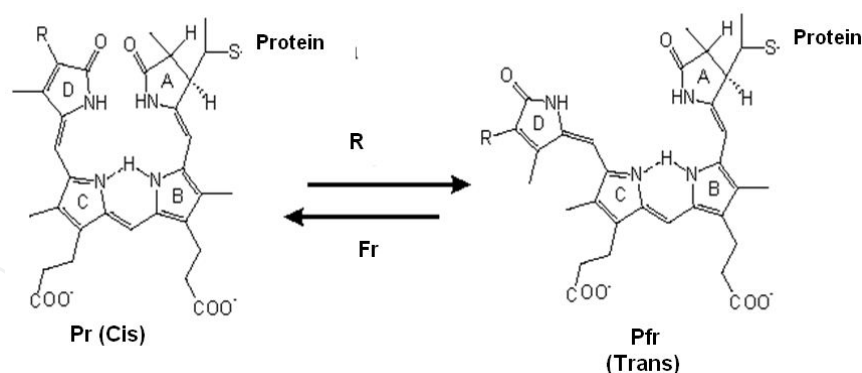
Promotion or inhibition of the rate of phenological development in soybean is regulated by the phytochrome pigment in the plant. This has been amply demonstrated by night-break studies in which the effect of a long night (or short day) on promotion of flowering is inhibited when a light flash is given early in the night period [28]. Period from emergence to first flower is not only controlled by this mechanism, but also by the rate of phenological development for later reproductive periods [14].

Phytochrome is a blue pigment consisting of an apoprotein, which in turn is connected to a tetrapyrrole fitocromobilina, which serves as achromophore. The chromophore is synthesized in the plastid and is the unused portion of the phytochrome protein responsible for light absorption. The combination of the chromophore with the apoprotein occurs in the cytoplasm.

The phytochrome is found throughout the plant, but the highest concentration is found in the apical meristem of the stem. This is a plant pigment associated with membranes. The phytochrome molecule has two forms, one more stable and inactive and other more unstable and active, working to activate or inactivate reactions, respectively.

Both forms can be transformed into one and another. One form of the phytochrome pigment absorbs far red light (Pfr) at a wavelength of about 730 nm, while the other form of the pigment (Pr) absorbs light in the red range of about 660 nm (Figure 5).

During the day, plants have both forms, with a predominance of Pfr since normal daylight typically has a ratio of red/far red light of about 1.20. During the night, the Pfr form spontaneously converts into Pr. This reversal is essential for the measurement of time by plants as it determines how phenological developmental rate is affected.



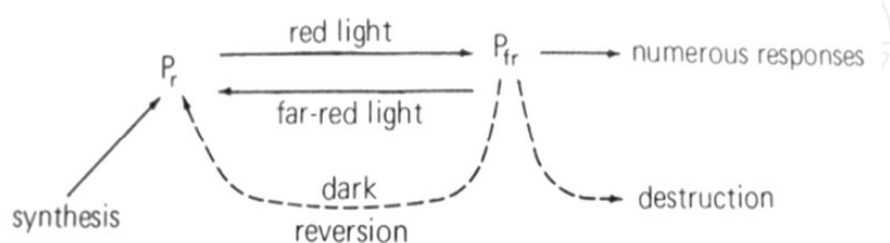
**Figure 5.** Photoisomerization between C and D rings of the chromophore. The absorption of red for Pr, resulting in the change of the ring D of the cis form (inactive) to the trans form (active) characteristic of Pfr. The protein bound to the chromophore is also changed in its shape.

Temperatures during the night affect the rate of this dark reversion of Pfr to Pr [29]. Application of a red flash of light in the night period inhibits the dark reversion of Pfr to Pr and prevents the effect on the developmental rate induced by normal dark reversion of Pfr to Pr.

Research in the late 1980's identified genes in the *Arabidopsis thaliana* plant that are related to the phytochrome encoding. Five phytochrome genes were isolated from this species: PHYA, PHYB, PHYC, PHYD and PHYE that encode the PHYA, PHYB, PHYC, PHYD and PHYE apoproteins. These proteins constitute the chromophore of the phytochrome [30].

In tomato plants (*Lycopersicon esculentum* Mill.) five genes that encode apoproteins were identified: PHYA, PHYB1, PHYB2, PHYE and PHYF [31]. When a phytochrome has the PHYA apoprotein, it is called type 1 phytochrome. All others are called type 2 phytochromes.

The difference between the two types is that the first one is accumulated mainly in plants grown in the dark and is easily degraded by light. The mechanisms that contribute to the abundance of the type 1 phytochrome in the dark is that the PHYA gene is preferentially transcribed under these conditions and its expression is inhibited by light [32].



**Figure 6.** A summary of some transformations of phytochrome. Dashed lines indicating dark reversion and destruction do not seem to occur with type 2 Pfr molecules [32].

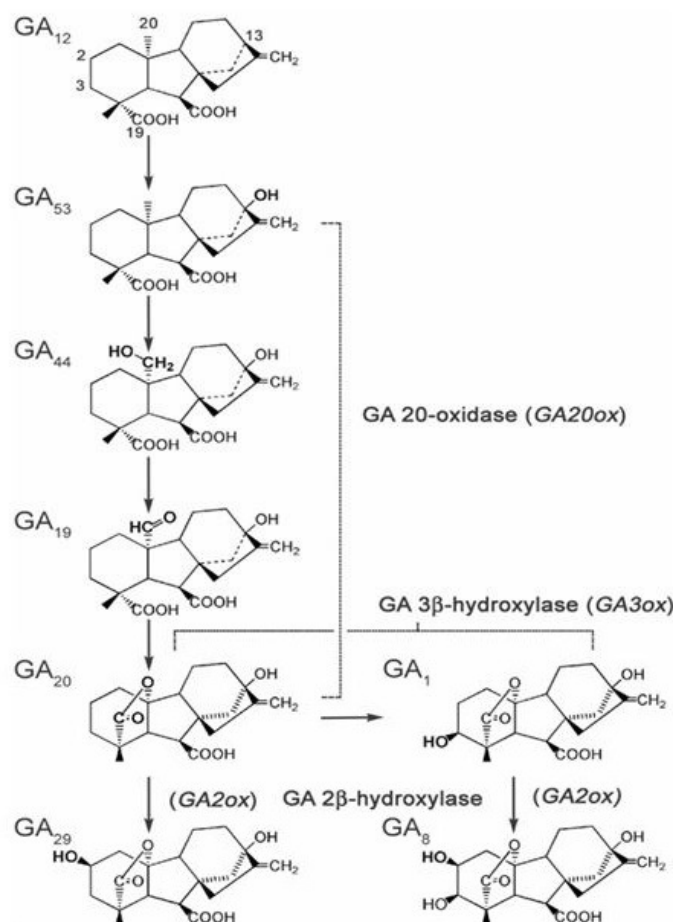
The phytochrome forms Pr and Pfr interconvert as shown in Fig. 5. (type 1 phytochrome). The second type of phytochrome may be more stable under conditions of darkness [32]. The

mode of action of photoreceptors in the photomorphogenesis process is still unknown [32]. There are two hypothesis:

1. The photoperiodic response is perceived in the leaf and has a rapid effect on plasma membrane permeability, which sends the flowering response to the apes of the stem.
2. Reduced effect on gene expression.

### 2.3. Gibberellin

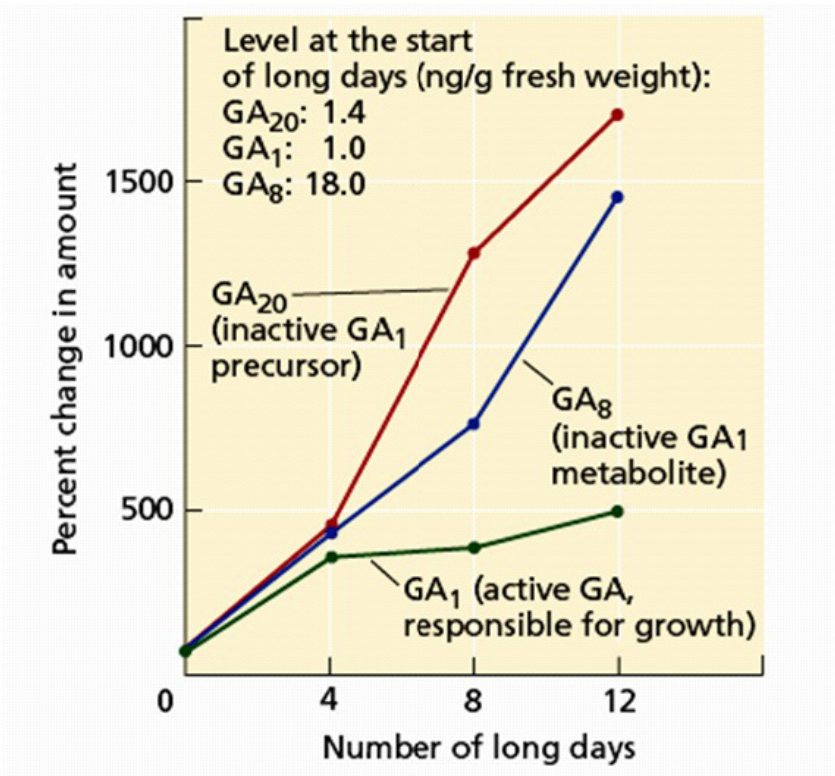
The conversion of Pfr phytochrome to Pr occurs slowly under absence of light. In this condition, the synthesis of the enzyme gibberellin 20 oxidase and  $3\beta$ -hydroxylase is reduced. They are responsible for turning gibberellin 12 (20 carbons) to gibberellin 1 (19 carbons). Under longer periods of darkness, the following occurs: low concentration of the far red phytochrome; reduced synthesis of gibberellin 20 oxidase and  $3\beta$ -hydroxylase; higher concentration of gibberellin 12 and a lower concentration of gibberellin 1. This low concentration of gibberellin 1 is responsible for flowering in soybean [33]. The authors described the steps related to Figure 7 as follows:



**Figure 7.** Pathway responsible for the production of the pea plants in GA<sub>1</sub> [33].

GAs in pea pericarps (ovaries) are synthesized mainly via the early 13-hydroxylation pathway.  $GA_{12}$  is a 13-hydroxylated to  $GA_{53}$ ; Carbon 20 (noted as 20 in the figure) is sequentially oxidized by a GA 20-oxidase from  $GA_{53}$  to  $GA_{44}$ , to  $GA_{19}$ , and finally to  $GA_{20}$ .  $GA_{20}$  is then oxidized by a  $3\beta$ -hydroxylase to  $GA_1$  (a growth-active GA). Both  $GA_{20}$  and  $GA_1$  can be oxidized by a  $2\beta$ -hydroxylase to  $GA_{29}$  and  $GA_8$ , respectively. The latter conversion inactivates  $GA_1$ . In Figure 8, constructed from previous data [34, 35], an increase occurs in the levels of  $GA_1$  gibberellin in spinach plants submitted to long days.

Morphologically, the end of the juvenile period occurs when soybean becomes responsive to photoperiodically-induced reproductive growth. The internal metabolism which leads to plant blooming seems to be influenced by several factors such as concentration of carbohydrates and gibberellin. It is difficult to exactly determine what regulates this stage of plant development [33]. Studies on maize plants indicated that gibberellin-deficient mutants showed a delayed transition from the juvenile to adult stage. This fact may be associated with a long juvenile period. The application of endogenous gibberellin regulated time in this transition phase [36]. Juvenile plants cannot be induced to flower even under appropriate photoperiod. At this time, the buds of the apical meristem do not respond to the floral stimulus, or the young leaves cannot produce enough stimulus for the induction of floral buds [33]. Research has confirmed the second hypothesis.



**Figure 8.** The fivefold increase in  $GA_1$  is what causes growth in spinach exposed to an increasing number of long days but before stem elongation starts at about 14 days. After [34]; redrawn from data in [35].



Buds of juvenile *Bryophyllum* species were grafted on to adult plants with flowers and they produced flowers. The author concluded that the meristems were competent to flower, but the young leaves produced insufficient amounts of the floral stimulus [37]. In a work with *Perilla*, a short-day plant, it was shown that the second node of the young leaves produce less floral stimulus, and therefore require more inductive photoperiods to induce flowering, as compared to fully mature leaves [38]. The most recent studies on the flowering control of the *Arabidopsis* plant state that the process is regulated by four separate ways:

1. the photoperiodic (long day) pathway, which operates in the leaves;
2. the convergent autonomous (leaf number)/vernalization (low temperature) pathway;
3. the carbohydrate (sucrose) pathway; and
4. the gibberellin pathway.

The latter three pathways all operate in the shoot apical meristem. The four pathways converge on a number of floral pathway integrators that together regulate floral initiation [33].

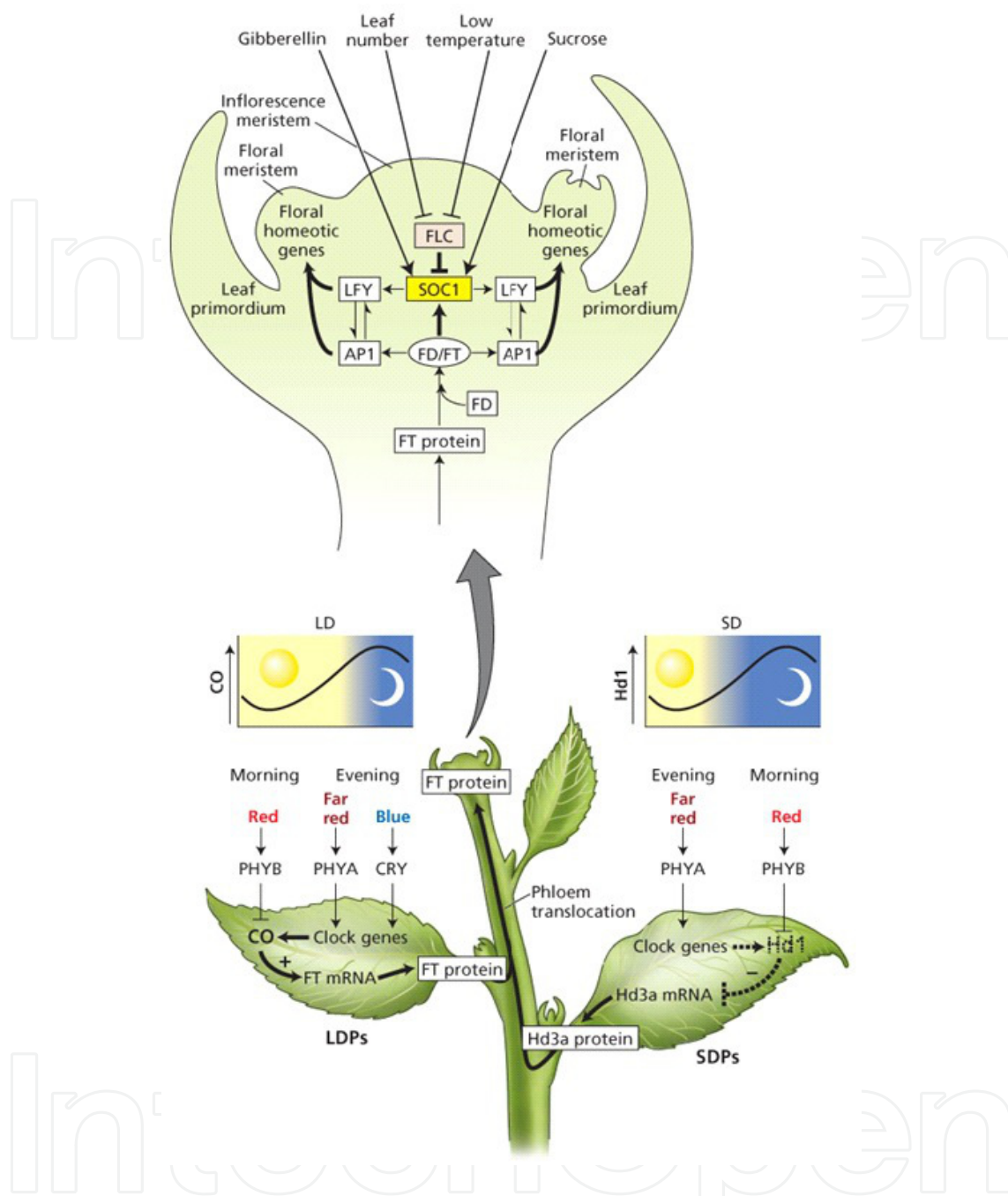
Recently, the T locus was identified which contains the FT gene related to flowering. It is expressed in leaves, encoding products that fit the description of a universal flowering stimulus. This finding comes against the research carried out for decades which sought that signal [39]. More studies are still seeking to define the paths of integration that exist among the different routes.

Figure 9 provides a complete consideration on this subject. This topic briefly addresses the GA pathway, when it operates, and what is known about its integration with the other pathways.

The photoperiodic pathway is located in the leaves and involves the production of a transmissible floral stimulus, the FT protein [33]. The gene flowering locus T (FT) is a major output of both the photoperiod and the vernalization pathways controlling the floral transition. FT protein acts at the shoot apex of the plant in concert with a transcription factor, flowering locus D (FD).

In long-day plants (LDPs) such as *Arabidopsis*, the FT protein is produced in the phloem in response to CO (CONSTANS) protein accumulation under long days (LD). It is then translocated via sieve tubes to the apical meristem. In short-day plants (SDPs) such as rice, the transmissible floral stimulus, the Hd3a protein (*Hd3a* – heading date gene), accumulates when the repressor protein, Hd1 (*Hd1* – heading date gene), is not produced under short days (SD), and the Hd3a protein is translocated via the phloem to the apical meristem [33].

A major quantitative trait locus (QTL) controlling response to photoperiod, *Hd1*, was identified by means of a map-based cloning strategy. High-resolution mapping using 1505 segregants enabled us to define a genomic region of ~12 kb as a candidate for *Hd1*. Further analysis revealed that the *Hd1* QTL corresponds to a gene that is a homolog of *CONSTANS* in *Arabidopsis*.



**Figure 9.** Multiple developmental pathways for flowering in *Arabidopsis*: (a) the photoperiodic (long day) pathway, which operates in the leaves; (b) the convergent autonomous (leaf number)/vernalization (low temperature) pathway; (c) the carbohydrate (sucrose) pathway; and (d) the gibberellin pathway. Fonte: [33].

In *Arabidopsis*, FT binds to FD, and the FT/FD protein complex activates the *AP1* (*Apetala1*) and *SOC1* genes (suppressor of over expression of *CO1*), which trigger the *LFY* (Leafy) gene expression. *LFY* and *AP1* then trigger the expression of the floral homeotic genes. The autonomous (leaf number) and vernalization (low temperature) pathways act in the apical meristem to negatively regulate *FLC*- flowering locus C, a negative regulator of *SOC1*. The sucrose and gibberellin pathways, also located in the meristem, promote *SOC1* expression [33].

## 2.4. Juvenile Period - Floral Induction in Soybeans

Some plants are indifferent to photoperiod, i.e., flowering and other developmental events are independent of photoperiod. In Brazil, this phenomenon was observed in the "Santa Maria" soybean variety and it was concluded that it was indifferent to day length [40].

Studies with soybean defined four stages of development related to flowering [41]:

Phase I - Juvenile - short days do not induce flowering;

Phase II - Inductive – flowering is induced by a minimum number of short days;

Phase III - Regulation - the number of flowers increases with the continuous conditions of induction and

Phase IV - Post-regulation - there is no effect of day length on flowering.

There is a stage in soybean development called the juvenile period. Juvenility is the name given to the initial phase of vegetative growth when soybean is not responsive to short-day-induced reproductive development. Until that period is completed, the plant is not cannot start floral initiation, even if it is grown under short days [42]. A determination of the juvenile period of one genotype can be carried out using the technique described in the literature [43]. A plant that flowers later, even under conditions of short days, has a long juvenile period relative to other soybeans. Such genotypes are described as having the long juvenile character [44].

Considering growth and flowering, it can be observed that each cultivar has a typical response in relation to the sowing date [45]. When sowing is early, there is also early flowering and lower plant heights in the most photoperiod sensitive cultivars. Research has shown that when the photoperiod is favorable, there is a combination of two or more endogenous hormones in the plant that produces biochemical changes in the meristematic cells of vegetative nodes. These cells begin to multiply and differentiate into flower buds [46]. After the juvenile period, a sequence of two short days sensitize the soybean leaves through phytochrome [46]. During the day, plants have both forms of phytochrome, with a predominance of Pfr. During the night, the Pfr form converts spontaneously to Pr. This reversal is essential for the measurement of time by plants and for the way they respond to photoperiod.

When cultivars having similar maturity are sown at the same time, they may bloom at different times. This is attributed to different juvenile periods [47]. During this period, some metabolic pathways, which are necessary for flowering initiation, are not triggered. The beginning of the studies concentrated on the phenotypic aspects of flowering, relating the effects and not the causes of the observed morphological changes. More complex research opened new perspectives to understand such process. There are two hypothesis for the fact that during the juvenile period, plants are not induced to flower even under inductive photoperiod:

1. The buds of the apical meristem are not competent to flowering.
2. The young leaves are still unable to produce enough stimulus for the induction of floral buds [33].

Phenotypic observations reported in many articles have characterized plant response to photoperiod. Cultivar "Doko" was observed to have a long juvenile period [48], based on a long time to flower under short and long daylengths. Late flowering from several sowings was related to the possible existence of a long juvenile period [49]. The "Doko" cultivar was obtained from a program of selections which were sowed in summer and winter and has long juvenile period [50].

## 2.5. Genetic Inheritance of Flowering

Genes affecting flowering response, have been studied in *Pisum sativum* and *Arabidopsis thaliana* [51, 52]. The results show that mutations in these species can change various aspects of the photoperiodic control of flowering. Some of these mutations can eliminate the photoperiodic responses, which are responsible for flowering induction. Others may simply slow down or speed up responses to photoperiod [33]. Much of the regulatory systems of flowering are under either positive or negative control and the presence of mutant plants with changes in photoperiodic responses is very common.

Most mutations result in the loss or alteration of the gene activity. After the mutation, the genes that promote flowering are changed. Mutations that eliminate plant response to photoperiod can block the production of floral stimulus or may interfere with the ability of the meristem to receive the message [33]. Grafting studies have identified genes in *Pisum sativum* that promote or inhibit flowering and control the sensitivity of the apical meristem signals [52]. Most cultivars of soybean, respond to photoperiod as follows: when the number of daylight hours is below the critical photoperiod, there is flowering induction. Only few cultivars have the long juvenile character in which the effect of genes to promote flowering is reduced.

Early studies showed that a long juvenile character in soybean is genetically controlled and can be transferred in a breeding program [53]. Under short days, the authors identified recessive genes that control the trait. The literature on the subject shows that the long juvenile character is conditioned by recessive genes which can be pleiotropically influenced by other genes in the plant [42, 54-59]. Research conducted under "long-day conditions" indicates that the dominant alleles are responsible for the late cycle: E1/e1 and E2/e2 described by [60], E3/e3 reported by [61], E4/e4 described by [62] and E5/e5 by [63]. In the "short-day conditions", the opposite occurs [53-55]. Under these conditions, the gene J1/j1 was described [64]. Other studies were conducted to determine the type of inheritance. Research was performed under "conditions of short days" with the genotypes "Hill", "Bragg", "UFV-1", "IAC 73-2736" and "PI 159925" [65]. It was observed that the "long juvenile" character is controlled by one, two or more recessive genes [3]. These and other studies were fundamental to our understanding of the flowering process of soybean plants grown in locations with different latitudes such as occurs in Brazil.

## 2.6. Long Juvenile Period in Soybean - Practical Application

The possibility of using plants exhibiting the long juvenile character was the solution found by some soybean breeders to delay flowering in short day conditions [42, 54, 58, 66]. Re-



search on the adaptation of soybeans to the tropics began at the Agronomic Institute (IAC) and the National Center for Soybean Research, in the 1970s. There were crosses among American cultivars which had the long juvenile character. Several genotypes with this trait were identified and used in breeding programs: "Santa Maria", "PI 159925" and "PI 240664" [67]. Identification of the character was done through research by EMBRAPA where long juvenile genotypes were planted from September 20 to October 10. By this method, genotypes were identified that had a sufficient delay in days to first flower to optimize dry matter accumulation and yield [66, 68]. The first cultivars developed and recommended for these areas were "Tropical", "Timbira", "BR-10 (Teresina)" and "BR-11 (Carajás)" [68]. Later the following cultivars were released: "BR-27 (Seridó)", "BR-28 (Cariri)", "Embrapa 9 (Bays)", "Embrapa 30 (CVRD)", "Embrapa 31 (Mina)", "Embrapa 32 (Itaqui)", "Embrapa 33 (Cariri RC)", "Embrapa 34 (Teresina RC)", "Embrapa 63 (Mirador)", "MA/BRS-64 (Parnaíba)", "MA/BRS-65 (Sambaíba)", "MA/BRS-163 (Pati)" and "MA/BRS-164 (Seridó RCH)"

The most commonly used cultivars as sources of the long juvenile character are: "Doko", "Doko RC", "Garimpo RCH", "BR/IAC-21", "UFV-16", "UFV-17", "UFV-18", "CAC-1", "CS 301", "MG/BR-46", "MT/BR-45", "BR-9", "FT-Cristalina", "Cristalina FT-RCH", "Tropical", "BR-10", "BR-11" and "Embrapa-33". They allow for a wider sowing time, planting during the offseason, and planting at low latitudes (short-day conditions) [3]. Currently the soybean crop in Brazil has been attacked by the Asian soybean rust, which leads the country to adopt a control measure called fallowing. In such areas, soybean cannot be planted during the off season. The adopted measure is a protection against the Asian soybean rust which has led the country to adopt a control measure called fallowing. In order to stop the rust, production areas are left vacant for part of the year. Asian soybean rust is a disease caused by *Phakopsora pachyrhizi* Sydow which caused a loss of two billion dollars to the Brazilian soybean crop in the 2005/2006 harvest.

### 3. Conclusions and Prospects of Soybean in Brazil

The achievement of Brazilian research in the development of soybean cultivars adapted to low latitudes has allowed expansion into the central and northern areas of the country. Until 1970, commercial cultivation of soybeans in the world was restricted to regions of temperate and subtropical latitudes which were near or higher than 30° Lat. Brazilian researchers were able to break this barrier by developing cultivars adapted to the short days of the tropics, enabling soybean cultivation anywhere in the country. In the "Cerrado" region, more than 200 million hectares were converted into cultivated areas of soybeans and other grains [1].

Currently, states with the highest soybean production are: "Mato Grosso", "Paraná", "Rio Grande do Sul" and "Goiás". They produce 82% of Brazil's soybeans. Soybean production is also progressing into new areas in "Maranhão", "Tocantins", "Piauí" and "Bahia", which account for 13.0% of Brazilian production.

The projections of the Ministry of Agriculture, Livestock and Supply (MAPA) show that Brazil is a major supplier of food. The region of Matopiba (Figure 10), an area including the



states of “Maranhão”, “Tocantins”, “Piauí” and “Bahia”, has potential for growth of grain production and will stand out in the Brazilian agricultural land scape for years to come. The trend shown in the study (Brazil - Projections of Agribusiness 2010/2011 to 2020/2021), released by the MAPA [69].

Increased soybean production area can occur through a combination of expansion into new areas or replacement of other crops. The production of sugar cane and soybeans are two activities that compete for land in Brazil. The two together will create an increase of 7.4 million hectares, 5.3 million hectares for soybeans and 2.1 hectares for sugarcane. The soybean plants that have the long juvenile characteristic can also be used in crop rotations, particularly in areas of “Sao Paulo” state that have previously been grown to sugar cane. Cultivars have been developed which are adapted to 1.2 to 1.4 million hectares of this area [70].

Most expansion should occur in areas of high yield potential, such as included in the region that is now called “Matopiba”. “Mato Grosso” is not expected to have a large increase in arable land, mainly because land prices in the state are more than double that for land in the “Matopiba” region. Since agricultural expansion into these new areas includes large tracts of farm land, land price is a deciding factor.

Production				Consumption			Exportation		
Year	Projection	*L. Lim.	**U. Lim.	Projection	*L. Lim.	**U. Lim.	Projection	*L. Lim.	**U. Lim.
2012/13	72,764.7	61,176.9	84,352.4	39,349.0	33,725.9	44,972.2	32,985.5	26,829.9	39,141.1
2013/14	74,531.2	61,196.3	87,866.0	40,140.8	33,748.6	46,533.1	33,573.3	25,990.3	41,156.3
2014/15	76,241.0	61,344.5	91,137.4	40,921.0	33,839.2	48,002.7	34,262.6	24,693.8	43,831.4
2015/16	77,958.6	61,650.0	94,267.2	41,703.6	33,994.5	49,412.7	35,705.5	24,497.3	46,913.7
2016/17	79,672.0	62,062.8	97,281.3	42,485.8	34,196.5	50,775.0	36,972.7	24,235.3	49,710.1
2017/18	81,385.8	62,565.6	100,206.0	43,268.0	34,436.6	52,099.4	37,671.2	23,258.6	52,083.8
2018/19	83,099.3	63,141.3	103,057.2	44,050.2	34,708.1	53,392.3	38,595.2	22,438.5	54,751.9
2019/20	84,812.7	63,778.5	105,847.0	44,832.4	35,006.1	54,658.7	39,774.6	22,022.7	57,526.5
2020/21	86,526.2	64,468.1	108,584.2	45,614.6	35,326.9	55,902.3	40,744.4	21,430.0	60,058.8

**Table 3.** Projections for the production, consumption and trade of soybean (thousand tons).Adapted from [7]. \*Lower Limit \*\*Upper Limit

The estimates for soybean indicate a future Brazilian production of 86.5 million metric tons in 2020/2021 (Table 3) . The annual growth rate is expected to be 2.3% from 2010/11 to 2020/2021. This rate is close to the global rate for the next ten years [7]. The domestic consumption of soybeans is expected to reach 45.6 million metric tons at the end of the 2020/2021 season, representing 52.7% of the production. The projection is for an annual rate of increase of 1.9%. As it is known, soybean is an essential component in the manufacture of animal feed and is a gaining importance as human food [7]. The projected expansion for the-

area with soybeans in Brazil should exceed 30.0 million hectares in by 2020/2021. This is an increase of more than 5.3 million hectares from the current level. The expansion of soybean production in the country comes from a combination of expanding areas and increased yield. Production is forecast to increase at a rate of 2.0% per year with area of production expanding at the annual rate of 1.9% [7]

Soybean meal and oil will have a moderate increase in future years. Bran exports shall grow at 1.1% per year and the soybean oil exports at 0.5% per year. Domestic consumption for both is expected to grow at high rates. The consumption of soybean oil is expected to grow at an annual rate of 2.2% between 2010/11 and 2020/2021, while the soybean meal consumption is expected to grow at 2.5% per year.



**Figure 10.** Matopiba. The new agricultural frontier in Brazil. Fonte: [69].

These data reflect the dynamism of the internal market for these products, given the human and animal consumption. The relationship between consumption and production of soybean oil in future years is around 78%. Most of the oil is for human consumption and the other part has been used for the production of biodiesel. About 22% of the production will be exported. For soybean meal, between 47.0 and 49.0% should be directed to domestic consumption, and about 50% exported. This brief account of the soybean in Brazil demonstrates the importance of this crop to the national economy. The expansion of the area for production of soybean was due largely to basic and applied research involving genetic and physiological mechanisms affecting the timing of flowering and other developmental events. Thus, much of soybean's expansion has been due to the quality of Brazil's national agricultural research.

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