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SOWING TIMES IN ADAPTATION, STABILITY, PRODUCTIVITY, AND OIL AND PROTEIN CONTENTS OF SOYBEAN GENOTYPES[1]

EVERTON LUIS FINOTO[2], MARIA BEATRIZ BERNARDES SOARES[2], ALESSANDRA NEVES CORREIA[2], JOSÉ DE ANCHIETA ALVES DE ALBUQUERQUE[3], EDGLEY SOARES DA SILVA[3]*

ABSTRACT - No isolated factor influences soybean development and production more than the sowing date, but the responses of cultivars sown on different sowing dates depends on their sensitivity to environmental conditions. Thus, this study evaluated the adaptability and stability of 17 soybean genotypes in relation to yield, as well as to the grain oil and protein contents as a function of different sowing times. The experiment was designed in randomized blocks with three replications and a 17 × 5 factorial scheme. The genotypes were: Conquista, CD 223 AP, Elite, Garantia, Bioagro lineage, M-Soy 8400, M-soy 8001, Nambu, Sambaíba, Esplendor, UFVS 2006, UFVS 2005, UFVTN 102, UVF 18, UFV 16, Valiosa, Vencedora, and the five sowing dates were: SD1 = 11/3, SD2 = 11/20, SD3 = 12/07, SD4 = 12/23, and SD5 = 01/09. The M-Soy 8001, UFV 18 and Garantia genotypes showed high oil contents, with adaptation to all sowing dates and stability when sown on the most favorable dates. The Bioagro lineage, CD 223 AP, and Garantia genotypes were adapted and stable when sown on all sowing dates and had higher protein contents than the other genotypes, regardless of the sowing date. The Elite, Nambu, and Garantia genotypes were adapted and stable when sown on the most favorable sowing dates and presented high grain yields when sown in early December. The findings indicate that the Garantia genotype is the most suitable for the growing conditions of the central-north region of the state of São Paulo.

Keywords: *Glycine max*. Adaptability. Genotype-environment interaction.

ÉPOCAS DE SEMEADURA NA ADAPTAÇÃO E ESTABILIDADE QUANTO A PRODUTIVIDADE E TEORES DE ÓLEO E PROTEÍNA DE GENÓTIPOS DE SOJA

RESUMO – Nenhum outro aspecto isolado influencia tanto o desenvolvimento e produção da soja quanto a época de semeadura, porém a resposta de diferentes cultivares em datas de semeadura distintas depende de sua sensibilidade às condições ambientais às quais estão expostas. Assim, objetivou-se no presente estudo avaliar a adaptabilidade e a estabilidade de dezessete genótipos de soja na produtividade, bem como nos teores de óleo e proteína nos grãos em função de diferentes épocas de semeadura. Utilizou-se o delineamento em blocos casualizados com três repetições, em esquema fatorial com 17 genótipos (Conquista, CD 223 AP, Elite, Garantia, linhagem "Bioagro", M-Soy 8400, M-soy 8001, Nambu, Sambaíba, Esplendor, UFVS 2006, UFVS 2005, UFVTN 102, UVF 18, UFV 16, Valiosa e Vencedora) e cinco datas de semeadura (SD1 = 11/3, SD2 = 11/20, SD3 = 12/07, SD4 = 23/12 e SD5 = 09/01). Os genótipos M-Soy 8001, UFV 18 e Garantia apresentam elevados teores de óleo, com adaptação a todas as datas semeadura e estabilidade nas datas mais favoráveis. Os genótipos da linhagem "Bioagro" e os genótipos CD 223 AP e "Garantia" são adaptados e estáveis em todas as datas de semeadura e possuem maiores teores de proteína, independente das datas de semeadura. Os genótipos Elite, Nambu e Garantia estão adaptados e estáveis em nas datas mais favoráveis de semeadura e apresentam alto rendimento de grãos, nas semeaduras realizadas no início de dezembro. O Genótipo Garantia é o mais adequado às condições de cultivo da região centro-norte do estado de São Paulo.

Palavras-chave: *Glycine max*. Adaptabilidade. Interação genótipo x ambiente.

*Corresponding author
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[2]North Center Pole, Agência Paulista de Tecnologia dos Agronegócios, Pindorama, SP, Brazil; everton.finoto@sp.gov.br - ORCID: 0000-0003-1468-1428, maria.soares@sp.gov.br - ORCID: 0000-0002-0772-5325, alessandra_nc21@hotmail.com - ORCID: 0000-0002-2398-903X.
[3]Center for Agricultural Sciences, Universidade Federal de Roraima, Boa Vista, RR, Brazil; anchietaufrr@gmail.com - ORCID: 0000-0003-4391-258X, edgley_agro2008@hotmail.com - ORCID: 0000-0003-4628-1920.

INTRODUCTION

Currently, the soybean crop *Glycine max* (L.) Merr. (Leguminosae Faboideae) can be cultivated in all Brazilian regions due to the development of cultivars adapted to diverse environments. Soybean cultivation in the State of São Paulo has shown rapid expansion in the last ten years due to its contribution to the improvement of local production systems, especially in crop succession and the renewal of sugarcane areas (BÁRBARO-TORNELI et al., 2018), reaching a productive area of 1.109 million hectares in the 2019/2020 harvest (CONAB, 2021).

To express the productive potential of a soybean crop, genetic and environmental components and the interaction between them are taken into consideration. (HERRERA et al., 2020). There are different concepts of *environment*: some authors state that the term should be used for the edaphoclimatic conditions of cultivation (BORÉM; MIRANDA, 2013), whereas others argue that the cultivation environment is the result of biophysical factors, such as sowing times and cultural practices (SILVA et al., 2011).

The most influential cultivation factor is the sowing season (PRABHAKAR et al., 2018) as it relates directly to the time of flowering, maturation, and harvesting of the crop. Theoretically, the optimal sowing date for soybean is between 30 and 45 days before the summer solstice (December 21) as this enables proper plant development during the growing season (FIETZ; RANGEL, 2008). However, most soybean crops are sown outside of this ideal period due to errors in the selection of machines and agricultural implements to optimize agricultural operation, delays in the purchase of agricultural inputs, delays in the onset of rains, and, in particular, a lack of knowledge of the response of cultivars to the time of planting. Regardless of the sown cultivar, the later a soybean crop is sown, the shorter its cycle. Sowing in November is the most suitable for plant development, resulting in higher yields (VAZQUEZ et al., 2019).

Regarding the chemical composition of soybeans, according to Delarmelino-Ferraresi, Villela and Aumonde (2014), the oil and protein contents are genetically attributed, but strongly influenced by environmental factors (temperature and precipitation), mainly during the grain filling period. According to Calçado et al. (2019), there is an interaction between genotype, sowing date, and harvest date indicating that cultivars show variation in the metabolic regulation that determines oil and protein synthesis in the grains.

Adaptability and stability studies enable us to detail the changing behavior of genotypes according to environmental variation. Adaptability reflects how genotypes respond advantageously to environmental stimuli, whereas stability refers to the principle of invariance or predictability of behavior (CRUZ; CARNEIRO; REGAZZI, 2014). The Annicchiarico (1992) method estimates the risk of choosing a genotype. It uses the confidence index as a statistic and expresses the result as a percentage to relate the average performance in the evaluated environments to the performance estimated by an identity model applied to the genotypes. Studies on plant and animal development have used identity models to verify how common equations fit different groups of individuals (CARNEIRO et al., 2014).

For sustainable soybean production, it is important to obtain genotypes with superior grain quality and yield, which show adaptability and stability in different production environments. Consequently, the present study tested the adaptability and stability of 17 soybean genotypes, aiming for high oil and protein contents in the grains, as well as high productivity at different sowing dates in the north-central region of the São Paulo State, Brazil.

MATERIAL AND METHODS

The study was conducted during the 2015/2016 crop year at the North-central Regional Hub of the Agribusiness Technology Agency of São Paulo (APTA), in Pindorama, São Paulo, Brazil, (21º 13' S and 48º 55' W). The climate of the region is classified by Köppen as Aw; defined as tropical humid with a rainy season in the summer and a dry season in the winter. The average maximum temperature, annual rainfall, and annual relative humidity are 22.8 ºC, 1,390.3 mm and 71.6%, respectively (FINOTO et al., 2017). Figure 1 shows the monthly rainfall and maximum and minimum temperature averages during the experiment.

The experimental area is a rotation area, and prior to the soybean study, off-season sorghum (2014), peanuts (2014/2015) and corn (2015/2016) were cultivated in the experimental fields. The soil is classified as a moderate eutrophic Argisoil with a sandy/medium texture. The relief of the region is undulating, with altitudes ranging from 498 to 594 m above sea level. The physicochemical characteristics of the soil at the time of the study were: pH = 5,0; M.O. = 11 g.dm^{-3}; H+Al = 14 mmolc.dm^{-3}; P = 60 mg.dm^{-3}; K = 3.9 mmolc.dm^{-3}; Ca = 36 mmolc.dm^{-3}; Mg = 6 mmolc.dm^{-3}; SB = 45.9 mmolc.dm^{-3}; C.T.C = 59.9 mmolc.dm^{-3}; V% = 77%; B = 0.21 mg.dm^{-3}; Cu = 0.9 mg.dm^{-3}; Fe = 45 mg.dm^{-3}; Mn = 9.4 mg.dm^{-3}; and Zn = 1.1 mg.dm^{-3}.

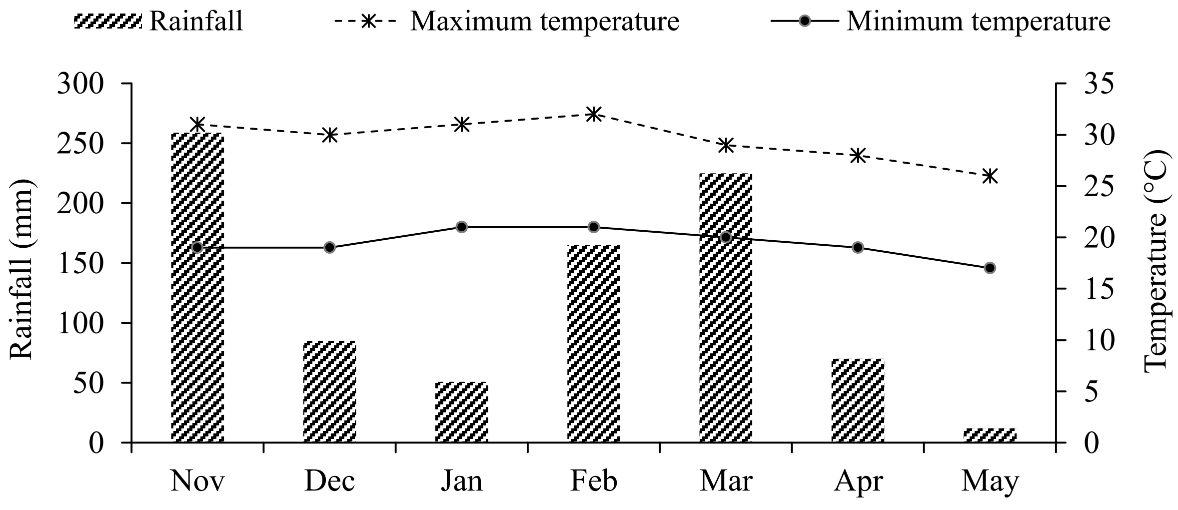

Figure 1. Monthly averages of rainfall, and maximum and minimum temperatures during the soybean experiment in Pindorama in the north-central region of the São Paulo State, Brazil.

A randomized block design was used for the experiment, with three replications arranged in a 17 × 5 factorial scheme, with factor A being 17 soybean genotypes (Conquista, CD 223 AP, Elite, Garantia, Bioagro lineage, M-Soy 8400, M-Soy 8001, Nambu, Sambaíba, Esplendor, UFVS 2006, UFVS 2005, UFVTN 102, UVF 18, UFV 16, Valiosa, and Vencedora) and factor B being five sowing dates (SD1 = 11/03, SD2 = 11/20, SD3 = 12/07, SD4 = 12/23, and SD5 = 01/09).

Each experimental plot consisted of five 5 m long rows, spaced 0.90 m apart, with a density of 14 plants per meter. The plot useful area was 3.6 m^2 because only the central portion of each row was harvested and 0.5 m at the end of each row was discarded.

The experimental area was prepared for cultivation 30 days before sowing by plowing and harrowing twice, followed by the application of 0.5 t ha^{-1} of dolomitic limestone with 80% relative power of total neutralization, as guided by the soil analysis results. The planting fertilization was conducted by applying 250 kg ha^{-1} of a 04-20-20 N-P-K formulation.

The soybean seeds were sown manually and inoculation was performed directly on the sown seeds in the planting furrows, which were sprayed with liquid inoculant (RhizomaxR), containing *Bradyrhizobium japonicum* SEMIA 5079 and 5080 strains, at a 2.0 × 109 cells mL^{-1} bacterial concentration.

Fifteen days after plant emergence, the surplus plants were thinned to reach a population density of 14 plants per linear meter. Weed control was accomplished by weeding manually twice, and pest and disease control by spraying with crop-recommended insecticides and fungicides.

Grain yield was measured after the harvest of soybean plants in each experimental plot. Thereafter, the oil and protein contents in the grains were determined based on the dry mass (DM%). The oil content was determined by extraction in petroleum ether according to the Goldfish method and the protein content by the Kjeldhal method (BRUM; ARRUDA; REGITANO-D´ARCE, 2009).

After verification of the normality and homogeneity of the data variances using the Lilliefors and Cochram methods, respectively, the data were subjected to individual and joint analysis of variance. Tukey's post-hoc test was used to compare the means at a 5% probability level; thereafter, according to data dependence, significant regressions were adjusted for each variable studied.

Analysis of the phenotypic adaptability and stability of the genotypes was performed following Annicchiarico (1992). This method estimates the reliability index of a given genotype to perform below the environmental mean estimated from the deviation of the identity regression of the behavior of the genotypes, and is based on the genotypic confidence index. The genotypic confidence index is estimated as: $W_{i(g)} = \hat{\mu}_{i(g)} - Z_{(1-\alpha)}\hat{\sigma}_{Z_{1(g)}}$ considering both favorable and unfavorable environments, where $\hat{\mu}_{i(g)}$ is the average percentage of genotypes *i*; $\hat{\sigma}_{Z_{1(g)}}$ is the standard deviation of the Z_{ij} values associated with the *i*-th genotype; and $Z_{(1-\alpha)}$ is the percentile of the standard normal distribution function. The confidence coefficient adopted was 75%, that is, α = 0.25. When the confidence index is decomposed into favorable and unfavorable environments it becomes, as well as a stability measure, a measure of adaptability to these environments. The computer application GENES, which is specialized for genetics and statistical analysis, was used (CRUZ, 2013).

RESULTS AND DISCUSSION

The variances presented normal distributions and data homogeneity, allowing the use of parametric statistical tests without the need for data transformation. In the joint analysis, the homogeneity of the residual variances of the experiments was first evaluated and verified by the ratio between the largest and smallest residual mean square, considered homogeneous when this relation is less than 7.0. In the present study, the values reached for the studied characteristics were: oil content = 2.69, protein content = 2.28, and yield = 2.57.

The coefficients of statistical variation of the studied characteristics were consistently low, ranging from 2.80% to 7.41%, indicating good precision in controlling the causes of variation of a systematic order in the experiment. The effects of the interaction: Genotypes (G) × Sowing dates (SD) were significant at the 1% probability level, as determined by the F test for all evaluated characteristics.

The average oil content in the grains ranged from 17.06% (SD5) to 19.74% (SD1), with an overall average of 18.23% between environments (Table 1). Among cultivars, the oil content varied between 22.17% for the cultivar Sambaíba for SD1 (11/03) and 15.01% for the cultivar CD223 AP sown on SD5 (01/09) (Table 1). The average percentage of oil in soybean seed is reported to be approximately 20%, ranging from 13% to 28% (FINOTO et al., 2017). Similar studies, including by Barbosa et al. (2011) and Faria et al. (2018), have revealed soybean oil content ranging from 15.52% to 22%, in line with the values obtained in the present study.

Table 1. Mean oil content values (%) in the grains of 17 soybean genotypes planted at five sowing dates (SD1–SD5) during the 2015/2016 agricultural year, in Pindorama, north-central São Paulo State, Brazil.

Genotypes	Sowing dates					
	SD1 (11/03)	SD2 (11/20)	SD3 (12/07)	SD4 (12/23)	SD5 (01/09)	Mean
M-Soy 8001	20.21Aa	20.70Aab	20.33Aa	19.23Aa	18.26Aa	19.75
UFV 18	21.11Aa	20.18ABabc	17.55Bab	18.62ABa	17.75Ba	19.04
Garantia	19.46ABa	20.74Aa	17.01Bab	19.19ABa	18.17ABa	18.91
Sambaiba	22.17Aa	17.89Babc	17.68Bab	18.47Ba	17.96Ba	18.83
UFVTN 102	20.76Aa	17.8Aabc	18.04Aab	18.26Aa	18.37Aa	18.65
UFV 16	19.82Aa	17.89Aabc	17.42Aab	18.71Aa	17.85Aa	18.34
M-Soy 8400	18.96Aa	18.67Aabc	16.86Aab	19.25Aa	17.68Aa	18.28
Esplendor	19.93Aa	18.03Aabc	17.75Aab	18.24Aa	17.08Aa	18.21
Valiosa	19.12Aa	18.55Aabc	17.91Aab	18.09Aa	16.83Aa	18.10
UFVS 2005	19.23ABa	19.71Aabc	16.60Bab	18.17ABa	16.62Ba	18.07
Conquista	19.14Aa	18.29Aabc	18.00Aab	18.32Aa	16.42Aa	18.03
Nambu	19.02Aa	18.97Aabc	16.22Ab	18.83Aa	16.26Aa	17.86
Elite	18.99Aa	18.29ABabc	15.79Bb	18.51ABa	17.41ABa	17.80
UFVS 2006	21.33Aa	16.45Bc	17.13Bab	17.79Ba	16.24Ba	17.79
CD 223 AP	19.31Aa	17.09ABabc	17.95ABab	18.49Aa	15.01Ba	17.57
Vencedora	18.41Aa	18.53Aabc	17.51Aab	16.58Aa	15.91Aa	17.39
Bioagro lineage	18.67Aa	16.87Abc	17.70Aab	17.37Aa	16.15Aa	17.35
Mean	19.74	18.51	17.50	18.36	17.06	18.23

Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by Tukey's test ($P < 0.05$).
*Tukey's HSD at 5% probability between sowing dates = 3.03 and between genotypes = 3.85.

Considering the oil content values of the cultivars averaged across all sowing dates, only the genotypes M-Soy 8001, UFV 18, and Garantia presented mean grain oil content values above 18.9%. The mean grain oil content for each sowing date, averaged across cultivars, varied between 19.74% for seeds sown in the first half of November and 17.06% for seeds sown in the first half of January (67 days later).

Of the 17 genotypes evaluated, 10 did not show significant responses to the delay in sowing, whereas the others showed a significant decrease in oil content in relation to sowing time. This finding indicates that the 10 genotypes showed superior physiological or biochemical responses to variations in temperature and water availability associated with sowing at different times. This may be due to higher photosynthetic efficiency of these genotypes, related not only to higher yields but also to higher energy availability for the plants, reducing the climatic influence on the chemical composition of the grains (NAOE et al., 2021).

It is noteworthy that the Sambaíba and UFVS 2006 genotypes showed significant reductions in oil content from SD2, with a 17-day delay. Barbosa et al. (2011) observed a trend in oil content reduction with a delay in sowing time, which was probably due to lower temperatures and higher rainfall before the grain maturation period. However, Calçado et al. (2019) observed very different behavior between the genotypes, with no clear pattern of an increase or decrease in oil content with delayed sowing.

In the present study, the earliest sowing date (SD1), produced the best oil content results for all genotypes. The sowing time-sensitive genotypes showed significant differences in oil contents only for SD2 (11/20) and SD3 (12/07), when the life cycle and, consequently, the harvesting period were decisive, in addition to the genetic sensitivity to environmental stresses in the grain-filling period. The genotypes did not differ in oil content when sown on SD4 (23/23) and SD5 (01/09).

Figure 2 shows the trends in grain oil content for the UFV 18 and UFVS 2005 genotypes with regressions that were significant for a linear model showing a decrease in oil content with a delay in sowing time, in addition to the identity curve based on these regressions after likelihood tests. These trends are likely to reflect the response of these genotypes to the low rainfall during the initial and final phases of the crop cycle (Figure 1), probably resulting in a lower nutrient transport efficiency, which may have decreased the concentration of oil in the grains, as observed in a study by Carvalho et al. (2021).

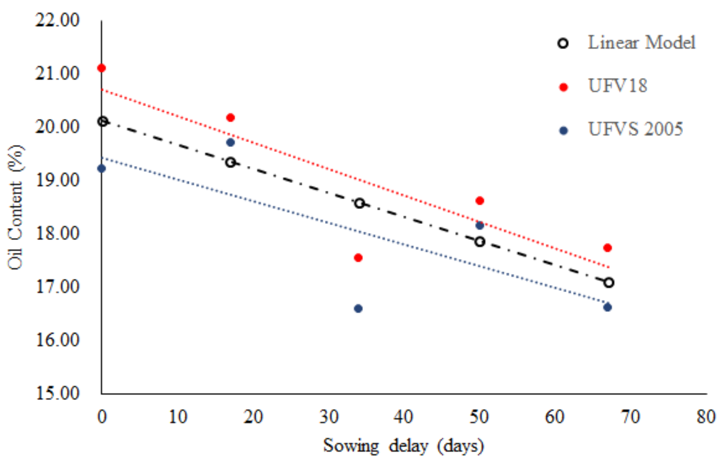

Figure 2. Relationship between the number of days of delay from the first sowing date (November 7th) and the oil content in the grains (%) of two soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Identity linear model for the oil content of these genotypes: $Y = 20.12 - 0.045x$ ($R^2 = 94.73$).

Figure 3 shows the trends in grain oil content of soybean genotypes with datasets that generated cubic model equations. There was no model identity for these genotypes due to the large number of genotypes and the discrepancy between their curves. However, Figure 3 shows that there was a tendency to a decrease in the oil content of the grains produced by these genotypes in response to delayed sowing.

There was a general tendency for the genotypes to show a decrease in oil content with a delay in sowing, although for most of them, this trend was not significant. The difference among the genotypes, as shown by the curves in Figure 3, indicates how intense is the genetic component of oil content in grains, and the observed downward trend suggests some environmental effect. In the western region of Paraná, Albrecht et al. (2008) observed different response capacities of the oil content at the sowing time with a slight tendency to decrease as the sowing time was extended. The different responses may have been due to high temperatures associated with low precipitation occurring during the reproductive stages of the crop. Calçado et al. (2019) observed the same response when evaluating sowing dates and harvest periods of soybean cultivars in Tocantins State. They found a higher oil content in grains produced from the earliest sowing date, supporting the results of the present study.

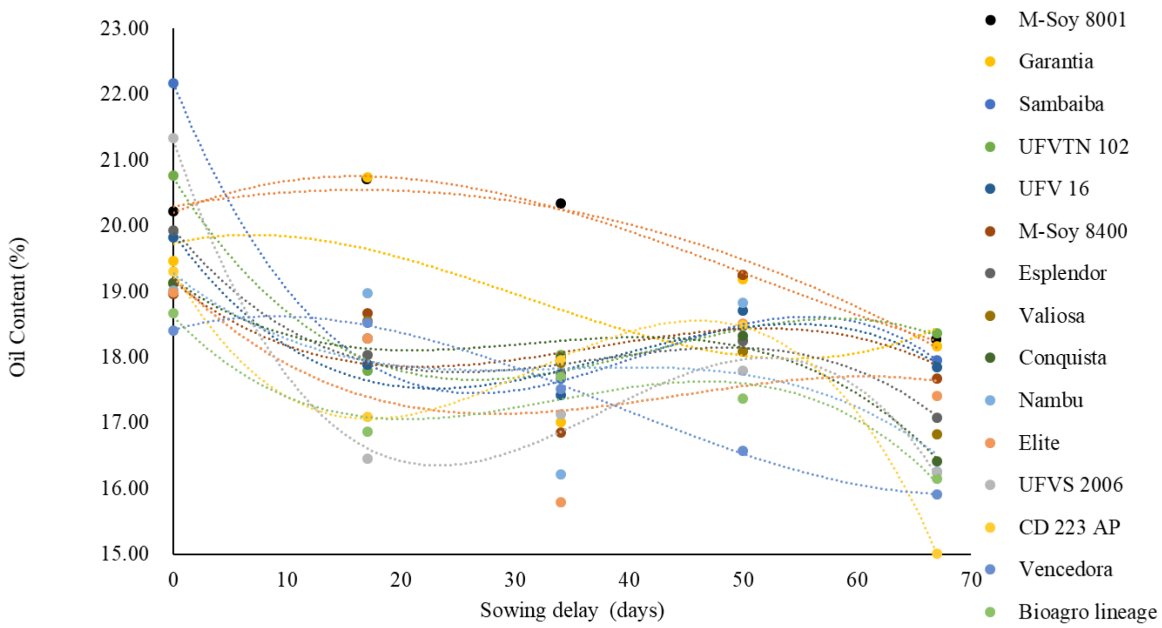

Figure 3. Relationship between the number of days of delay from the first sowing date (November 7th) and the oil content in the grains (%) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

Table 2 shows the estimates of the average oil content in soybeans and the confidence index decomposition for environments, in this case, sowing times, favorable and unfavorable according to the environmental indexes. Based on the confidence or recommendation index for the oil content in the grains (Table 2), the genotypes M-Soy 8001, UFV 18, Garantia, Sambaíba, and UFVTN 102 appeared to be the best adapted to the different sowing dates as they presented higher overall confidence indexes (106.9; 103.3; 102.1; 101.6 and 101.1, respectively) than those estimated by the identity regression of the model (100) when considering its performance on all sowing dates. The confidence index decomposed between favorable (SD1, SD2, and SD4) and unfavorable (SD3 and SD5) sowing dates presented the genotypes M-Soy 8001, UFV 18, Garantia, and Sambaíba as better than estimated by the identity model and also as the more stable genotypes.

Table 2. Estimates of the means of oil content (%)* and the confidence index (*Wi*) according to the method of Annicchiarico (1992). The confidence index was decomposed between favorable and unfavorable sowing dates. A total of 17 soybean genotypes were grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

Genotypes	General		Favorable		Unfavorable	
	Mean	*Wi*	Mean	*Wi*	Mean	*Wi*
M-Soy 8001	19.75	106.9	20.05	104.97	19.29	109.8
UFV 18	19.04	103.3	19.97	104.72	17.65	101.5
Garantia	18.91	102.1	19.80	103.20	17.59	100.1
Sambaiba	18.84	101.6	19.51	100.96	17.82	102.4
UFVTN 102	18.65	101.1	18.94	99.03	18.21	104.5
UFV 16	18.34	99.8	18.81	98.91	17.64	101.1
M-Soy 8400	18.28	99.2	18.96	99.37	17.27	98.6
Esplendor	18.21	99.4	18.73	98.75	17.41	100.5
Valiosa	18.10	98.8	18.59	98.07	17.37	99.8
UFVS 2005	18.07	97.8	19.04	99.62	16.61	95.7
Conquista	18.04	98.2	18.59	98.13	17.21	98.3
Nambu	17.86	96.7	18.94	99.49	16.24	93.5
Elite	17.80	96.3	18.60	97.97	16.60	93.9
UFVS 2006	17.79	95.5	18.53	95.32	16.69	96.1
CD 223 AP	17.57	94.6	18.30	95.77	16.48	92.5
Vencedora	17.39	94.2	17.84	93.17	16.71	95.4
Bioagro lineage	17.35	94.2	17.64	92.89	16.93	96.7

*Alfa = 0.25; Z(1-alfa) = 0.2734.

The protein content in the soybean grains ranged from 38.98% for the UFVS 2006 genotype at SD2 (11/20) to 49.51% for the Bioagro lineage at SD5 (01/09) (Table 3). Among the genotypes, the highest average grain protein content was produced by the Bioagro lineage with an overall average of 48.55%, followed by the CD 223 AP genotype with 45.27%. Genotypes that produce a high grain protein content are valuable due to the extensive use of soy protein in human food as a vegetable protein of similar quality to animal protein. Albrecht et al. (2008) found soybean grain protein contents close to 40%, whereas in the present study, all the genotypes produced higher protein content averages, with more than 49% in the Bioagro lineage. According to Bueno et al. (2017), the Soybean Quality Improvement Program/BIOAGRO-UFV has, over the years, developed productive soybean varieties with a high grain protein concentration (above 44%) from which it would be possible to produce a protein concentrate of approximately 70%.

Regarding the sowing dates, the highest protein contents were found in grains produced by plants sown on SD1 (11/03) and SD5 (01/09). Studies conducted by Albrecht et al. (2008) and Hackenhaar et al. (2019) identified an increase in protein content with delayed sowing and related it to reduced water availability during the reproductive period. However, in the present study, an increase in protein content occurred only after 67 days of delay in sowing.

In the present study, there were differences in the degree of sensitivity of the genotypes to different sowing dates, which affected the protein content of the grains. The Bioagro, Garantia, Esplendor, Conquista, and UFVS 2005 genotypes appeared to be the least sensitive to sowing delays. Calçado et al. (2019) have reported similar results. When comparing the sowing dates independently, some of the genotypes showed similar responses between the sowing times, whereas others showed a greater variation in protein content with delay in sowing.

Table 3. Mean values of grain protein content (%) of 17 soybean cultivars sown on five different sowing dates (SD1–SD5) during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

Genotypes	Sowing Dates					
	SD1 (11/03)	SD2 (11/20)	SD3 (12/07)	SD4 (12/23)	SD5 (01/09)	Mean
Bioagro lineage	48.66Aa	48.76Aa	47.01Aa	48.81Aa	49.51Aa	48.55
CD 223 AP	47.89Aab	46.92ABa	43.63Cab	43.32Cb	44.59BCb	45.27
Garantia	43.35Acd	43.04Ab	42.25Abc	43.62Ab	44.81Ab	43.41
UFVTN 102	44.54Abc	41.61Bbc	43.19ABb	42.78ABb	44.72Ab	43.37
Vencedora	43.7Acd	43.23ABb	40.84Bbc	44.04Ab	42.67ABbc	42.9
Valiosa	43.32ABcd	41.67ABbc	40.7Bbc	43.29ABb	44.17Abc	42.63
Esplendor	42.71Acd	40.8Abc	41.77Abc	43.39Ab	43.07Abc	42.35
Conquista	42.98Acd	40.71Abc	41.53Abc	41.85Ab	42.64Abc	41.94
UFVS 2006	41.45ABCcd	38.98Cc	40.72BCbc	43.18ABb	43.7Abc	41.61
M-Soy 8400	42.99Acd	41.59ABbc	39.74Bc	41.24ABb	41.95ABbc	41.5
Nambu	41.86Acd	40.76ABbc	39.01Bc	42.69Ab	42.59Abc	41.38
Elite	41.9ABcd	39.41Bc	40.35Bbc	43.45Ab	41.76ABbc	41.37
M-Soy 8001	42.61Acd	40.59ABbc	39.66Bc	41.32ABb	42.22ABbc	41.28
Sambaiba	40.78ABd	39.44Bc	40.35ABbc	42.34Ab	41.81ABbc	40.94
UFV 16	41.81ABcd	39.53Bc	39.17Bc	41.23ABb	42.65Abc	40.88
UFVS 2005	41.25Acd	41.14Abc	39.58Ac	40.71Ab	41.12Ac	40.76
UFV 18	40.36ABd	39.16Bc	39.57Bc	42.55Ab	41.73ABbc	40.67
Mean	43.07	41.61	41.12	42.93	43.28	42.4

Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by Tukey's test ($P < 0.05$).
*Tukey's HSD at 5% probability between sowing dates = 2.66 and between genotypes = 3.38.

Although some standard identity models to define the common protein content responses of the genotypes to the five sowing dates were established, none of the genotypes presented a linear equation. Figure 4 shows the trends in protein contents of the genotypes with datasets that generated significant quadratic model equations, as well as the identity model of this group of seven genotypes. The Bioagro lineage, selected for superior grain quality, outperformed the other genotypes, not being correctly represented by the identity model.

There was a decrease in protein content up to approximately 34 days of delay in sowing, followed by an increase. This trend indicates that later plantings tended to concentrate higher levels of protein in the grains, most likely due to greater environmental stresses, especially water deficit (FINOTO et al., 2017; CALÇADO et al., 2019). Lopes et al. (2016) conducted a study of the protein content of soybean cultivars in response to different sowing times and verified higher levels produced by plants sown late, probably due to low rainfall during the grain filling phase.

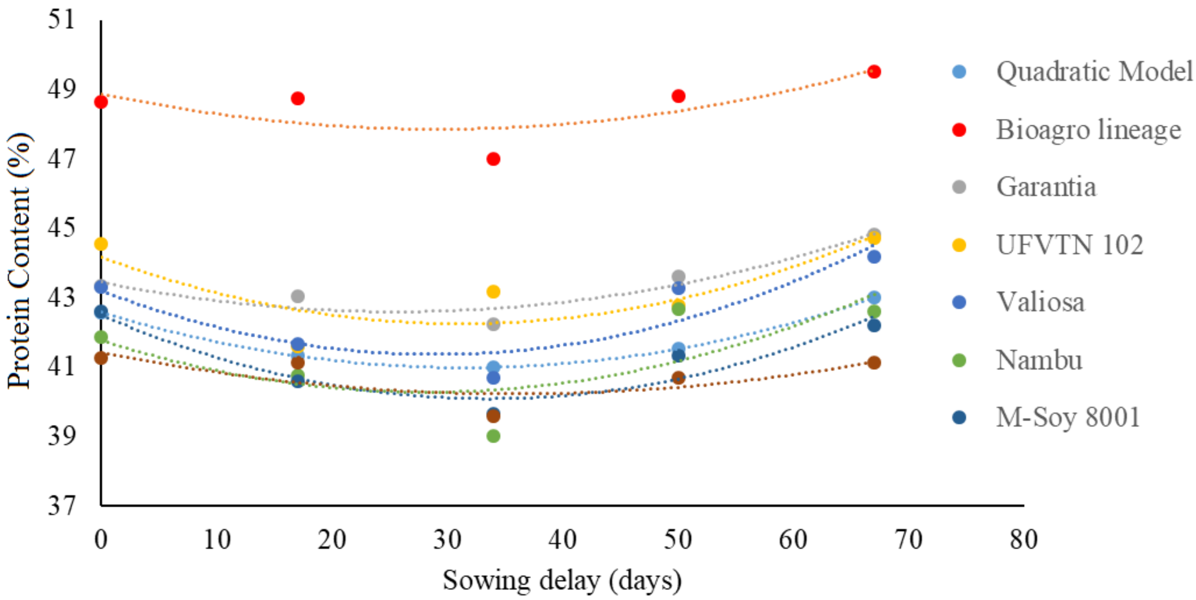

Figure 4. Relationship between the number of days of delay from the first sowing date (November 7th) and the protein content in grains (%) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Quadratic identity model for protein content of genotypes: $Y = 42.58 - 0.101x + 0.0016\ x^2$ ($R^2 = 99.92$).

Figure 5 shows the genotypes with datasets that generated cubic model equations. The CD 223 AP genotype showed a different trend in protein content from the other genotypes, not being represented by the proposed cubic identity model. The protein contents of the other genotypes, despite significantly adjusting to the cubic model, showed the same trend of an initial decrease followed by an increase in response to delay in sowing. According to Delarmelino-Ferraresi, Villela and Aumonde (2014), as it is not possible to explain the difference and variation in grain protein contents in soybean at different sowing dates on the basis of specific biotic factors; however, rainfall distribution during the grain-filling period may account for the protein content dynamics.

Table 4 presents the estimated mean grain protein contents in soybeans and the confidence index decomposition for environments, in this case, sowing times, favorable and unfavorable according to the environmental indexes. Based on the confidence or recommendation index for the protein content in the grains, the genotypes Bioagro, CD 223 AP, Garantia, UFVTN 102, Vencedora, and Valiosa appeared to be the best adapted to the different sowing dates with confidence indexes higher than that estimated by the identity model (114.1; 105.4; 102.1; 101.6; 100.6 and 100.2, respectively). The confidence index, categorized into favorable (SD1, SD4 and SD5) and unfavorable (SD2 and SD3) sowing dates, except for the Valiosa genotype, shows the genotypes that performed better than estimated by the identity model; these are also considered the more stable genotypes.

The results of the present study, showing the trends in oil and protein contents in response to sowing date, expand the framework of information regarding the behavior of the soybean genotypes used in Brazil. Although there was variation among the 17 genotypes used in this study, they were all superior to the seven commercial soybean cultivars tested by Faria et al. (2018) in terms of protein content. However, the same seven cultivars tested by these authors were superior to all the genotypes tested in the present study in terms of oil contents. These findings suggest a possible negative correlation between the grain oil and protein contents observed in this study, suggesting that the edaphoclimatic conditions during the experiment favored the increase of protein in the grains and negatively affected the oil content. Similar soybean responses have been reported by Delarmelino-Ferraresi, Villela and Aumonde (2014).

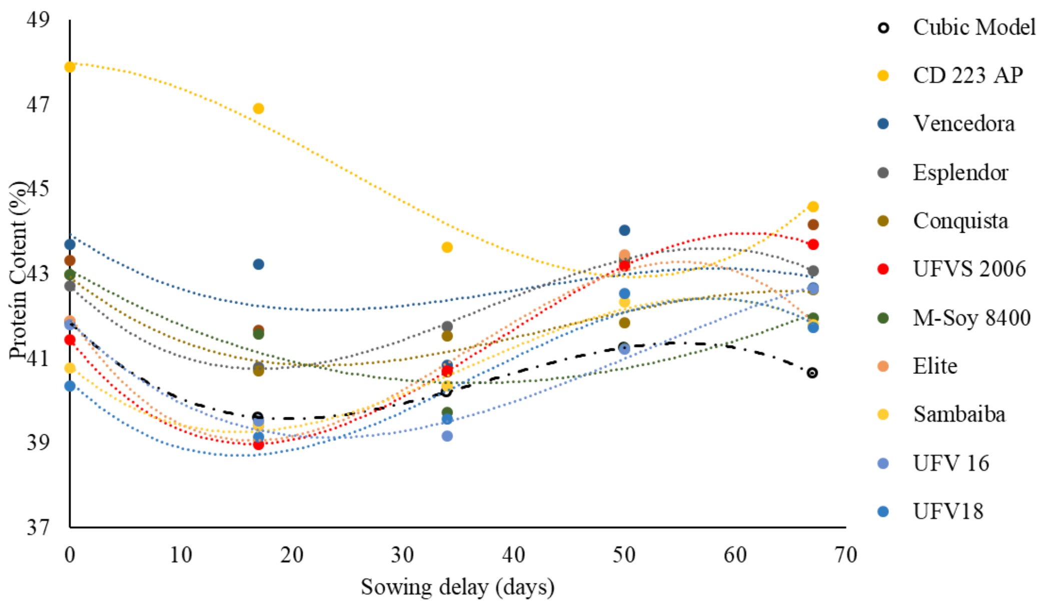

Figure 5. Relationship between the number of days of delay from the first sowing date (November 7th) and the protein content in grains (%) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Cubic identity model for protein content of genotypes: $Y = 41.86 - 0.262x + 0.009x^2 - 0.00008x^3$ ($R^2 = 99.96$).

Table 4. Estimates of the means of protein content (%)* and the confidence index (*Wi*) according to the method of Annicchiarico (1992). The confidence index was decomposed between favorable and unfavorable environments (sowing dates). A total of 17 soybean genotypes were grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

	General		Favorable		Unfavorable	
Genotypes	Mean	*Wi*	Mean	*Wi*	Mean	*Wi*
Bioagro lineage	48.55	114.1	48.99	113.5	47.89	115.2
CD 223 AP	45.27	105.4	45.27	103.6	45.28	108.1
Garantia	43.42	102.1	43.93	101.5	42.65	103.0
UFVTN 102	43.37	101.6	44.01	101.5	42.40	101.6
Vencedora	42.90	100.6	43.47	100.3	42.04	100.7
Valiosa	42.63	100.2	43.59	100.9	41.19	99.3
Esplendor	42.35	99.5	43.06	99.6	41.29	99.1
Conquista	41.94	98.5	42.49	98.3	41.12	98.8
UFVS 2006	41.61	97.3	42.78	98.5	39.85	95.3
M-Soy 8400	41.50	97.4	42.06	97.1	40.67	97.7
Nambu	41.38	97.1	42.38	98.0	39.89	95.8
Elite	41.38	96.9	42.37	97.6	39.88	95.8
M-Soy 8001	41.28	97.1	42.05	97.2	40.12	96.8
Sambaiba	40.95	96.1	41.64	96.1	39.90	95.8
UFV 16	40.88	96.0	41.90	96.9	39.35	95.1
UFVS 2005	40.76	95.7	41.03	95.1	40.36	97.1
UFV 18	40.67	95.3	41.55	95.7	39.37	94.8

*Alfa = 0.25; Z(1-alfa) = 0.2734.

The average grain yield varied from 1,494 kg ha^{-1} for the Bioagrolineage plants sown on SD5 (01/09) to 4,753 kg ha^{-1} for the Nambu genotype sown on SD3 (12/07) (Table 5). Considering the means of all sowing dates, the most productive genotypes were the cultivars: Elite, Nambu, and Garantia, which produced 3,525 kg ha^{-1}; 3,406 kg ha^{-1}; and 3,398 kg ha^{-1} of grain, respectively. The yield values of the three most productive genotypes were above the national average for the 2020/2021 crop year, which was 3,379 kg ha^{-1} (CONAB, 2021). These genotypes show promise for cultivation in the study region when the goals are not to obtain high oil and protein contents in the grains, due to the low contents shown by both. These results even surpass the average of some standard cultivars grown at different study sites, and, according to Barbosa et al. (2011) evidence possible genetic gain from genotype interaction with the cultivation environment.

Table 5. Average grain yield values (kg ha^{-1}) of 17 soybean genotypes sown at five different sowing times during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

Genotypes	Sowing dates					
	SD1 (11/03)	SD2 (11/20)	SD3 (12/07)	SD4 (12/23)	SD5 (01/09)	Mean
Elite	4444Aa	4032Bab	4512Aab	2377Ccdef	2259Cabc	3525
Nambu	3630Bbc	3954Bab	4753Aa	2370Ccdef	2321Cab	3406
Garantia	3908Ab	3843Aabc	3833Acd	3636Aa	1772Bcde	3398
Sambaiba	3333Bcde	3324Bcde	4216Abc	2870Cbc	2130Dabcd	3175
Valiosa	3458Bbcd	4315Aa	3241Befg	2685Cbcd	1864Dbcde	3113
M-Soy 8400	3236Bcdef	3222Bde	4118Abc	2648Cbcd	2111Dacd	3067
UFV 18	3185Bcdef	3153Bcdef	3741Acde	2623Cbcd	2432Ca	3027
M-Soy 8001	3356Acd	3551Abcd	3444Adef	2481Bbcde	2043Cabcd	2975
Vencedora	3065Bdefg	3764Abc	2914Bghi	2932Bb	1833Cbcde	2902
Conquista	3056Adefg	3227Ade	3408Adefg	2327Bdef	1957Babcde	2795
UFVTN 102	2815ABefgh	2810Befg	3753Acde	2457Bbcde	1883Cbcde	2744
Esplendor	2773Bfgh	3000Bef	3543Adef	2253Cdefg	2062Cabcd	2726
UFVS 2005	2583Bgh	2375BCgh	3130Afgh	2043CDefg	1963Dabcde	2419
UFV 16	2815Befgh	2463Agh	2475Aij	1741Bcde	1741Bcde	2247
UFVS 2006	2522ABh	2639Afg	2222Bj	1790Cg	1513Ce	2137
CD 223 AP	1968Bi	2407Agh	2654Ahij	1889Bfg	1691Bde	2122
Linhagem Bioagro	1991Bi	2106ABh	2167ABj	2444Abcde	1494Ce	2040
Mean	3067	3187	3419	2445	1945	2813

Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by Tukey's test ($P < 0.05$).
*Tukey's HSD at 5% probability between sowing dates = 411.30 kg ha^{-1} and between genotypes = 522.40 kg ha^{-1}.

Among the sowing dates tested, the highest average yield occurred in soybeans planted on 12/07; however there was a significant decrease when the sowing date was postponed for at least 16 days (12/23). There was substantial variability among genotypes for yield and grain quality in response to delayed sowing.

The cultivar Garantia showed a significant reduction in productivity only when sown on SD5, a delay of 67 days from SD1 (11/03), whereas the cultivars Conquista, UFVTN 102 and MSoy 8001 showed significant yield reductions from sowing on SD4 (12/23). Nine of the other genotypes had the highest crop yield when planted on SD3 (12/07); the Valiosa, Vencedora, and UFVS 2006 genotypes had the highest yield when sown on SD2 (11/20); and the Bioagro lineage had the highest yield when sown on SD4 (12/23). All genotypes had their lowest crop yield when sown on SD5 (01/09). According to Carvalho et al. (2021), a sowing delay promotes a significant reduction (25% to 19%) in grain yield associated with a lower accumulation of dry matter in the grains with the shortening of the reproductive or vegetative phases. Cultivars with indeterminate growth show continuous plant growth and development even after flowering; consequently, an increase in the duration of the vegetative phase can provide plants with the possibility of fixing carbon and accumulating nitrogen, both of which are fundamental for increasing the productive potential of soybean (SINCLAIR et al., 2005).

Figure 6 shows the curves for the three genotypes with yields that are significantly explained by linear models, as well as the identity model that represents them. All three genotypes showed a reduction in yield due to a delay in sowing. In particular, the Elite genotype showed the greatest reduction in yield and the UFV 18 genotype had the smallest yield loss with delay in sowing. Sowing soybean on a date close to that of the ideal sowing time is most indicated, and relates to more adequate climatic conditions, especially temperature and water availability (CARVALHO et al., 2021).

Figure 7 shows the genotypes with datasets that generated quadratic yield models and the identity model that represents them. These genotypes showed an initial increase in crop yield followed by a sharp reduction with delay in sowing. The derivative of the model equation revealed that for these genotypes, a sowing delay of 25 days from the earliest sowing date resulted in higher grain yields.

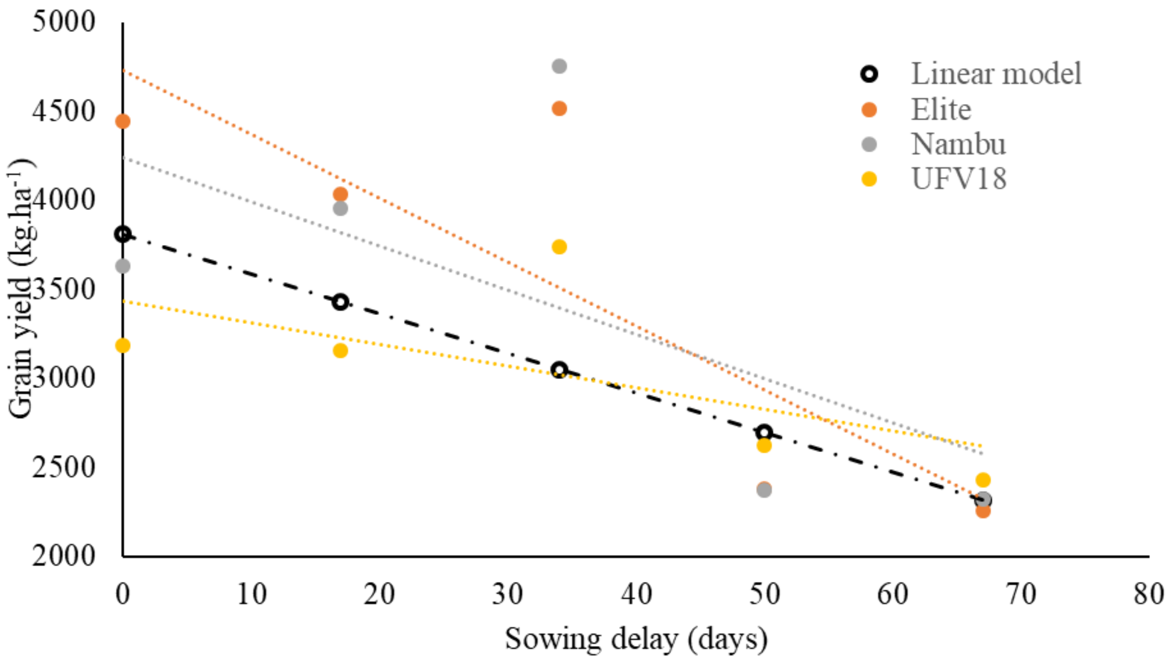

Figure 6. Relationship between the number of days of delay from the first sowing date (November 7th) and grain yield (kg ha^{-1}) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Linear identity model: Y = 3,807.67 − 22.25x (R^2 = 94.73).

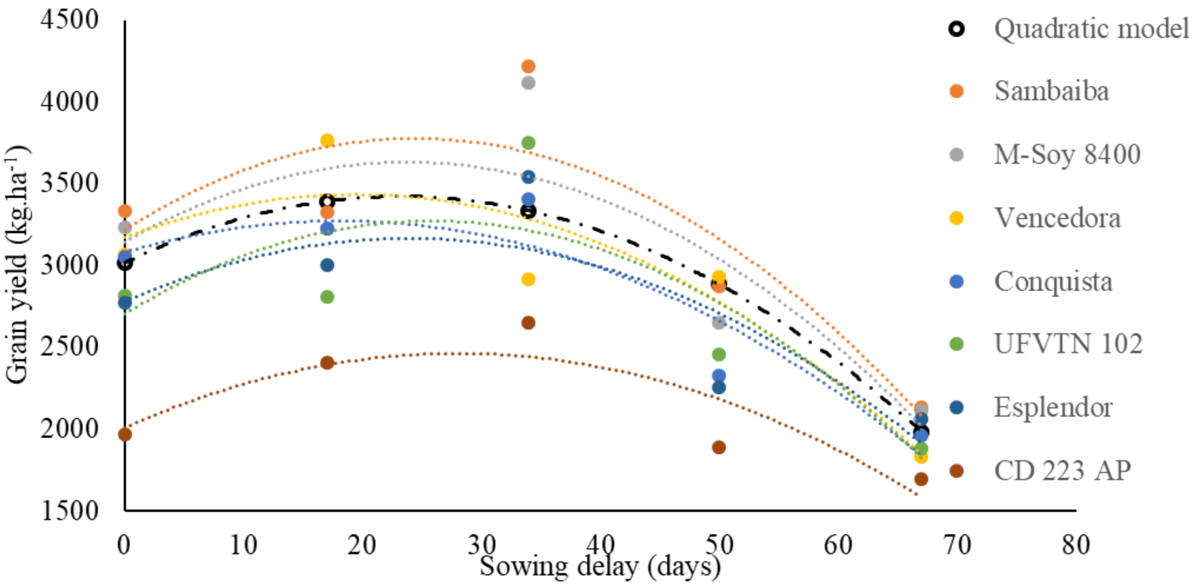

Figure 7. Relationship between the number of days of delay from the first sowing date (November 7th) and grain yield (kg ha^{-1}) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Quadratic identity model: Y = 3016.12 + 34.92X – 0.751 x^2 (R^2 = 99.01).

Genotypes with datasets that generated cubic yield models are shown in Figure 8. In this case, the Garantia and Bioagro lineage genotypes were not significantly represented by the identity model because they presented differentiated data. There was a substantial response disparity between genotypes and sowing dates for the cubic model.

Table 6 contains the average soybean yield estimates and the Annicchiarico (1992) confidence index decomposition for favorable and unfavorable sowing dates according to the environmental indexes. Based on the confidence index or recommendation index for grain yield, the Elite, Nambu, Garantia, Sambaíba, Valiosa, M-Soy 8400, UFV 18 and M-Soy 8001 genotypes showed the best adaptation to the different dates of sowing with general confidence indexes higher than those estimated by the identity model (118.4, 115.4, 114.2, 110.5, 105.5, 106.8, 106.2, and 104.3, respectively). The confidence index decomposition for favorable (SD1, SD2, and SD3) and unfavorable (SD4 and SD5) sowing dates showed that these genotypes also performed better than estimated by the identity model for both scenarios, being considered stable for different sowing dates. The Vencedora genotype, even with a poorer overall performance than expected, had a higher yield than estimated for the later sowing times that were considered unfavorable. The genotypes best adapted to late sowing were UFV 18, Sambaíba, and Garantia.

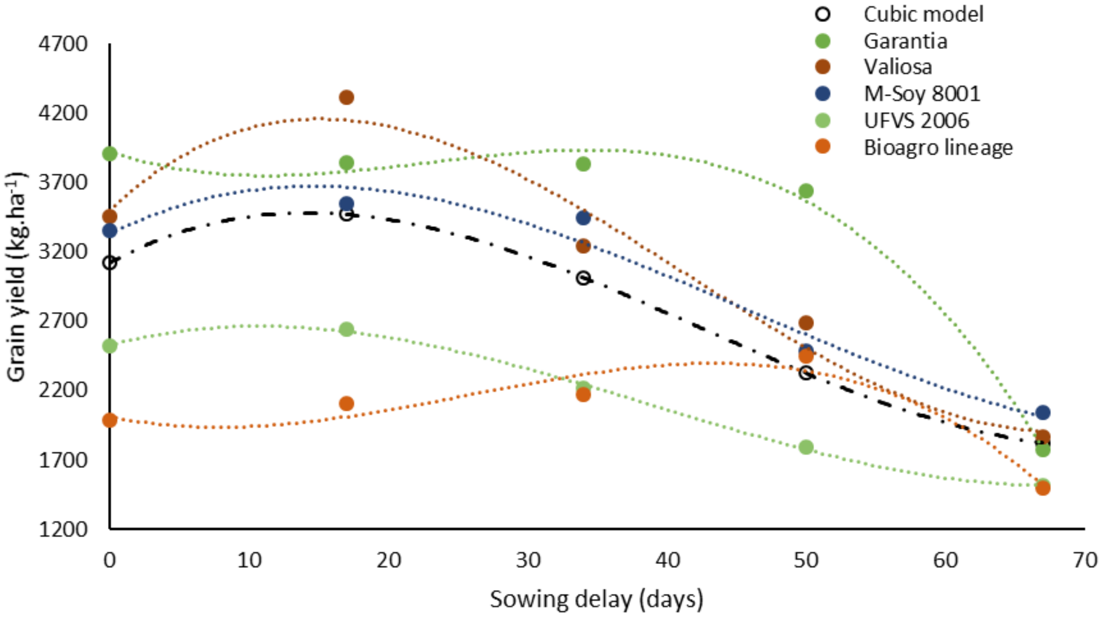

Figure 8. Relationship between the number of days of delay from the first sowing date (November 7th) and the grain yield (kg ha^{-1}) of soybean genotypes grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil. Cubic identity model for grain yield of genotypes: $Y = 3120 + 54.62x – 2.310x^2 + 0.018x^3$ ($R^2 = 97.21$).

Table 6. Estimates of the means of grain yield (kg ha^{-1})* and the confidence index (*Wi*) according to the method of Annicchiarico (1992). The confidence index was decomposed between favorable and unfavorable environments (sowing dates). A total of 17 soybean genotypes were grown during the 2015/2016 agricultural year in Pindorama, north-central São Paulo State, Brazil.

	General		Favorable		Unfavorable	
Genotypes	Mean	*Wi*	Mean	*Wi*	Mean	*Wi*
Elite	3525	118.4	4330	131.9	2318	103.0
Nambu	3406	115.4	4112	124.2	2346	103.8
Garantia	3398	114.2	3861	117.9	2704	108.8
Sambaiba	3175	110.5	3624	109.4	2500	111.9
Valiosa	3113	105.2	3671	108.7	2275	100.1
M-Soy 8400	3067	106.8	3525	106.2	2380	108.4
UFV 18	3027	106.2	3360	102.6	2528	112.7
M-Soy 8001	2975	104.3	3451	105.6	2262	102.6
Vencedora	2902	99.3	3247	96.6	2383	102.1
Conquista	2795	98.6	3230	99.9	2142	96.8
UFVTN 102	2744	95.1	3126	93.4	2170	97.9
Esplendor	2726	95.3	3106	94.2	2157	96.4
UFVS 2005	2419	84.3	2696	81.1	2003	88.9
UFV 16	2247	77.8	2584	77.7	1741	76.8
UFVS 2006	2137	74.2	2461	73.9	1651	74.6
CD 223 AP	2122	74.1	2343	70.5	1790	80.2
Linhagem Bioagro	2040	70.0	2088	64.4	1969	83.9

*Alfa = 0.25; Z(1-alfa) = 0.2734.

The results obtained for grain oil and protein contents, and grain yield of soybean genotypes in the present study agree with those of Albrecht et al. (2008) who state that sowing anticipation provides climatic conditions that tend to increase grain oil content and productivity and reduce grain protein content.

CONCLUSIONS

The M-Soy 8001, UFV 18, and Garantia genotypes have high oil contents, with adaptation to all sowing dates, and stability with good performance when sown on both favorable and unfavorable sowing dates. The Bioagro lineage, CD 223 AP, and Garantia genotypes are better adapted and more stable when sown at all sowing dates, and have higher protein contents than the other genotypes, regardless of the sowing date. The Elite, Nambu, and Garantia genotypes are the best adapted and most stable for grain yield. These genotypes are highly productive in favorable environments, and respond better to sowing dates before mid-December. Garantia is the most suitable genotype for the cultivation conditions in Pindorama, in the north-central region of São Paulo State. This genotype performs well for all three evaluated characteristics, irrespective of sowing time.

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