Edaphoclimatic Conditions of the Brazilian Semi-Arid Region Affect the Productivity and Composition of Sunflower Oil

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Abstract

It has been suggested that fatty acid balance in standard sunflower oil may be influenced by the genotype of the plant or by variation in environmental growth conditions. Therefore, this study analysed aspects of sunflower productivity and oil quality obtained from achenes of plants cultivated in a semi-arid environment, resulting from seed obtained from other regions with different edaphoclimatic characteristics. The experiment was conducted between February and May, in a Brazilian semi-arid area. At 90 days after sowing (DAS), the physiological maturation period, tissue was harvested, and the yield of plant green matter, oil and oil per hectare was evaluated. A comparative analysis of the oil content of achenes before

and after planting (parental v progeny) was performed. The experiment was conducted in a randomized block design of 4 treatments (genotypes), Embrapa122, BRSG01, Helio253 and Helio250, and 4 replications, for a total of 16 experimental plots, with each plot constituting 8 plants. In this study, sunflowers were produced in the climatic conditions of the Brazilian semi-arid region with biomasses, achenes and oil contents that were different from other crop productions in the country, providing the possibility of obtaining oil with a distinct chemical composition.

Keywords: *Helianthus annuus,* vegetable production, quality, Sertão Paraibano

1. Introduction

Sunflower (*Helianthus annuus* L.) is an oleaginous specie, which originated in North America and is a member of the Asteraceae family. It is an important commodity worldwide, providing a wide variety of raw materials (Brito et al., 2016). The crop can be used for grain production, even under adverse conditions, providing food for both humans and livestock. The oil is used as a food and for fuel, and the plants also act as a resource for the beekeeping sector (Santos et al., 2014).

According to data from the Instituto Brasileiro de Geografia e Estatística (IBGE), 61,339 thousand hectares of sunflowers were planted in Brazil in 2017, and 103,338 tons of achenes were harvested (IBGE 2018). In addition, the Companhia Nacional de Abastecimento (CONAB), reported that approximately 91% of sunflower production is destined for industrial processing, resulting in about 14.5 million tons of bran and 13.6 million tons of oil, where oil yields can exceed 600 kilograms per hectare (CONAB 2018).

Sunflower oil is considered a healthy product of excellent quality, which can be used for food or pharmaceutical purposes due to its organoleptic and functional properties, characterized by special compounds such as unsaturated fatty acids (oleic and linoleic), tocopherols (vitamin E), phytosterols, β-carotenes (pro-vitamin A) and phospholipids (Brigante 2013). In addition, it has been identified as a raw material for biodiesel production, given its high energy value, low sulphur content and acidity (Naureen et al., 2015). Oil that has a higher concentration of oleic acid and a lower linoleic content is more suitable for biodiesel production, due to the higher oxidative stability conferred by such a composition (Gondim-Tomaz et al., 2016). By contrast, the fatty acid balance in standard sunflower oil shows a preponderance of linoleic acid instead of oleic acid, which makes it more sensitive to oxidation. However, this oleic/linoleic ratio may be influenced by the genotype of the plant or by variations in environmental growth conditions (Reginato Neto et al., 2016). According to Thomaz et al. (2012), environmental conditions can negatively affect oil production of the achenes, particularly lower temperatures during the vegetative period, higher rainfall during the flowering period and higher solar radiation indices during the vegetative period or during filling of the achenes. By contrast, higher temperatures can lead to average increases of up to 35% in oleic acid content (Grunvald et al., 2013).

Based on this information, it was hypothesized that environmental changes between 2 harvests would allow significant changes in the content and composition of oil in sunflower

achenes, which could be used commercially to produce oil with a specific composition. Therefore, this study analysed aspects of sunflower productivity and oil quality obtained from achenes of plants cultivated in a semi-arid environment, produced from seed obtained from other regions with different edaphoclimatic characteristics. A comparison between the original batch of achenes and the field production showed that environmental conditions influenced the composition of oil.

2. Material and Methods

2.1 Study Area

The experiment was conducted between February and May, in an experimental field of the Centro de Ciências Humanas e Agrárias of the Universidade Estadual da Paraíba, in the municipality of Catolé do Rocha, Brazil (06°21'S; 37°43'W; 275 m above sea level). The climate of the region, according to the Köppen classification, is of the type BSw'h', characterized as hot semiarid, with 2 distinct seasons, one rainy with irregular precipitation and the other without precipitation (Alvares et al., 2013). For the experimental period, there was a mean maximum temperature of 33 ^{o}C, a mean minimum of 23 ^{o}C, mean relative air humidity of 70% and mean solar radiation of 5MJ day^{-1} (Figure 1).
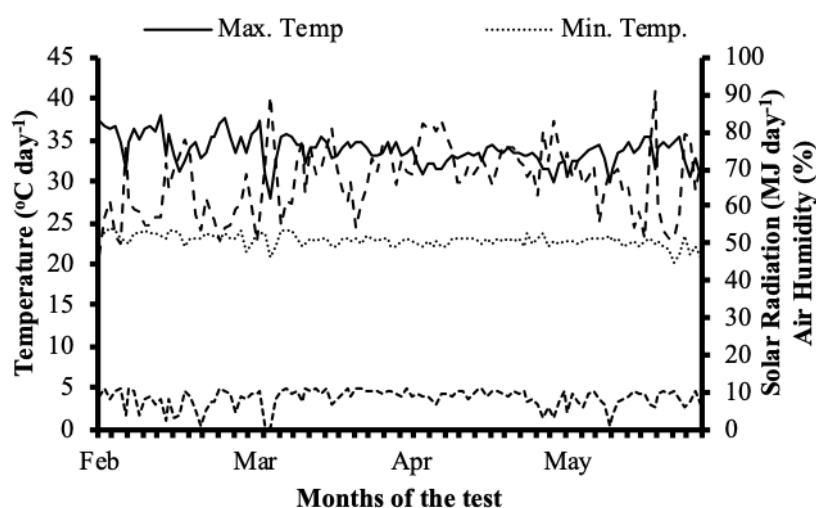

Figure 1. Monitoring of climate data for the experimental period in the region where the experiment was performed (Source: Instituto Nacional de Meteorologia -INMET 2019)

2.2 Experimental Cultivation

Seeds of 4 sunflower genotypes (*Helianthus annuus* L.) recommended by Embrapa Algodão and the Federal University of Rio Grande do Norte (Table 1) were used for the experiment. Sixty days prior to the start of the experiment, nutritional analysis of the soil was performed. In addition, fertilizer and water irrigation strategies (Table 2) were started. The nutritional and irrigation recommendations for sunflower, established in the State of Rio Grande do Norte, were used as a reference (Lira et al., 2009).

Table 1. Sunflower genotypes used in the experiment and their source

Genotype	Type	Company	Source	Climate
Embrapa122	Variety	Embrapa	Mato Grosso do Sul	Tropical
BRSG01	Variety	Embrapa Soja	Paraná	Subtropical
Helio253	Simple Hybrid	Heliagro	Minas Gerais	Tropical
Helio250	Simple Hybrid	Heliagro	Minas Gerais	Tropical

Table 2. Nutritional analysis of soil, fertilizer and irrigation water used in the cultivation of 4 sunflower genotypes in a semi-arid environment

						Soil						
pH H_2O 1:2.5	K^+	P $mgdm^{-3}$	Na^+	Mn^{2+}	Fe^{2+}	Zi^+	Ca^{+2}	Mg^{2+} ....$cmol_c dm^{-3}$...........	Al^{3+}	$H^+ + Al^{3+}$	SB $cmol_c dm^{-3}$	(T)
6.84	280	49	64	53.98	59.69	4.05	5.25	1.15	0.00	1.08	7.38	8.46

					Manure					
N	P	K^+	Ca^{+2} ....$g\,kg^{-1}$...............	Mg^{+2}	Na^+	B	Zi^{+2}	Cu^{+2} ....$mg\,kg^{-1}$...........	Fe^{+2}	Mn^{+2}
9.61	4.99	5.00	11.68	5.33	0.87	8.53	100	23	10.88	365

					Irrigation water					
EC_w $dS\,m^{-1}$	pH	K^+	Ca^{2+}	Mg^{2+} ....$(mmol_c\ L^{-1})$...............	Na^+	CO_3^{-2}	HCO_3^-	Cl^-	SAR $(mmol\ L^{-1})^{0.5}$	Water class for irrigation
6.5	1.05	0.49	2.92	1.31	5.07	0.0	4.85	4.19	4.22	$C_2S_2T_2$

SB - Sum of bases; EC - electrical conductivity; T - total cation exchange capacity.

Source: Laboratório da Empresa de Pesquisa Agropecuária do Rio Grande do Norte.

The soil was prepared with ploughing and harrowing, followed by groove lines at a depth of 0.25 m. Fertilization of foundation with bovine manure occurred 30 days before sowing, and cover 30 days after sowing (DAS). In addition, supplementation with 2 kg ha^{-1} Borax to promote the period of flowering occurred before sowing. To simulate a cropping system without the aid of an irrigation system, water was supplemented according to daily rainfall, and based on the evaporation reading of a Class A tank. Weeds were removed manually with a brush cutter in the plots and between the beds. Phytosanitary management was carried out daily to control typical pests of the region, using the recommendations of Penteado (2007).

2.3 Productivity and Oil Content

After 90 DAS, the period for physiological maturation (Lira et al., 2009), the harvest was carried out, and the yield of plant green matter, oil and oil per hectare, was evaluated. A comparative analysis of the oil content of achenes before and after planting (parental v progeny) was performed.

Oil content was determined using a commercial nuclear magnetic resonance spectrometer as described by Jambunathan et al. (1985). All readings were taken of oven-dried (110 °C, 16 h) samples, and the values were expressed on a uniform 5% seed moisture content basis.

2.4 Fatty Acids

Seed samples were taken for total fatty acid analysis, using a method modified by Wu et al. (1994). In this method seed samples were soaked in 2 ml 2% sulphuric acid in dry methanol for 16 h at room temperature, followed by 80 min at 90 °C to convert the fatty acids to fatty acid methyl esters (FAMEs). Methyl-heptadecanoate (17:0-ME) was added as an internal standard. The FAMEs were extracted in 2 ml water and 3 ml hexane and their composition was analysed using a Varian 3400 gas chromatography (GC) equipped with a Supelcovax-10 fused silica capillary column (30 m × 0.25 μm film thickness). The column's initial temperature was kept at 160 °C for 15 min, so that its temperature increased at a rate of 5 °C min^{-1}. The temperatures of the injector and the detector (FID) were 240 °C and 280 °C, respectively. The carrier gas was nitrogen with a flow rate of 1 - 2 ml min^{-1}. Split ratio was adjusted to 30 ml min^{-1}. The injected volume of the sample was 1 μl. FAMEs were identified by comparing their retention times with that of the standards. Fatty acid content was computed as a weight percentage of total fatty acids, by using the GC area counts for various FAMEs.

2.5 Experimental Design and Data Analysis

The experiment was conducted in a randomized block design, 4 treatments (genotypes) and 4 replications, totalling 16 experimental plots, with each plot constituting 8 plants. Data were submitted to ANOVA and Tukey's test. Differences were tested at a 5% confidence level using ASSISTAT 7.7 software (Silva & Azevedo 2016).

3. Results and Discussion

3.1 General Appearance of the Genotypes in the Flowering

The plants of the 4 sunflower genotypes cultivated in the semiarid environment, 60 DAS (full flowering stage), showed marked visual differences, mainly in relation to size and the capitulum (Figure 2). The genotype Embrapa122 presented with typical and single flowers per plant (Figure 2A), whereas genotype BRSG01 had smaller sized capitula and several flowers per plant (Figure 2B). The genotypes Helio253 and Helio250 had similar sized but larger capitula (Figure 2C and D).
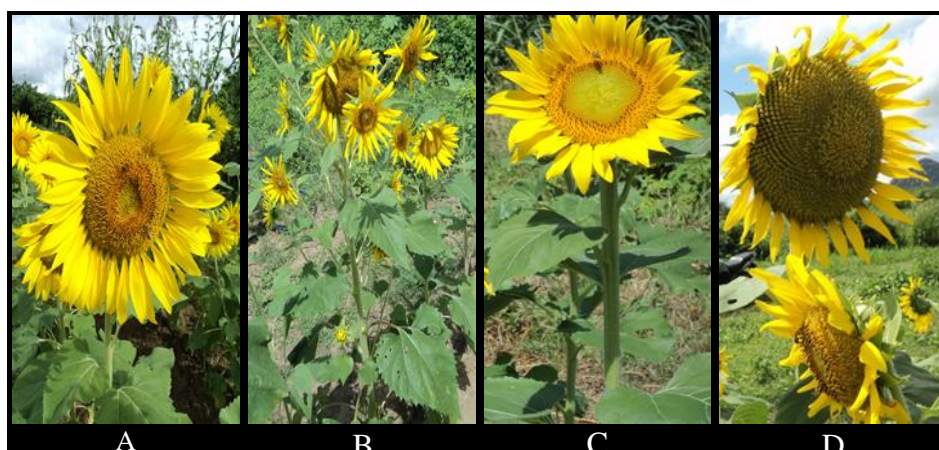
Figure 2. General appearance of the genotypes in the flowering phase at 60 days after sowing: Embrapa122 (A); BRSG01 (B); Helio253 (C); Helio250 (D); cultivated in a semi-arid environment, Catolé do Rocha, Paraíba, Brazil

Lira et al. (2017) when evaluating genetic variability among 15 sunflower genotypes found that characteristics correlated with origin, kinship and productive potential of the genotype. Voght et al. (2012) showed that genotypes Helio250 and Helio253 had similar morphological characteristics, and were closely related phylogenetically, being more productive with lower plant height than other genotypes they analysed. They also showed that Embrapa122 was a genotype with a greater height and larger number of leaves, but with lower yield, not having genetic similarity with the other genotypes.

3.2 Productivity

Of the genotypes analysed, BRSG01 produced the largest amount of green matter/hectare (4.36 t ha^{-1}), while Embrapa122 produced the least (2.29 t ha^{-1}), a difference of 47.47% between these 2 genotypes (Figure 3A). According to Santos et al. (2016), genotypes such as BRSG01 are an important option for the farmer in crop rotation and succession systems as a silage option, because they have a high protein content in their green matter. In addition they show good adaptability to adverse edaphoclimatic conditions, especially water stress (Santos et al., 2016).
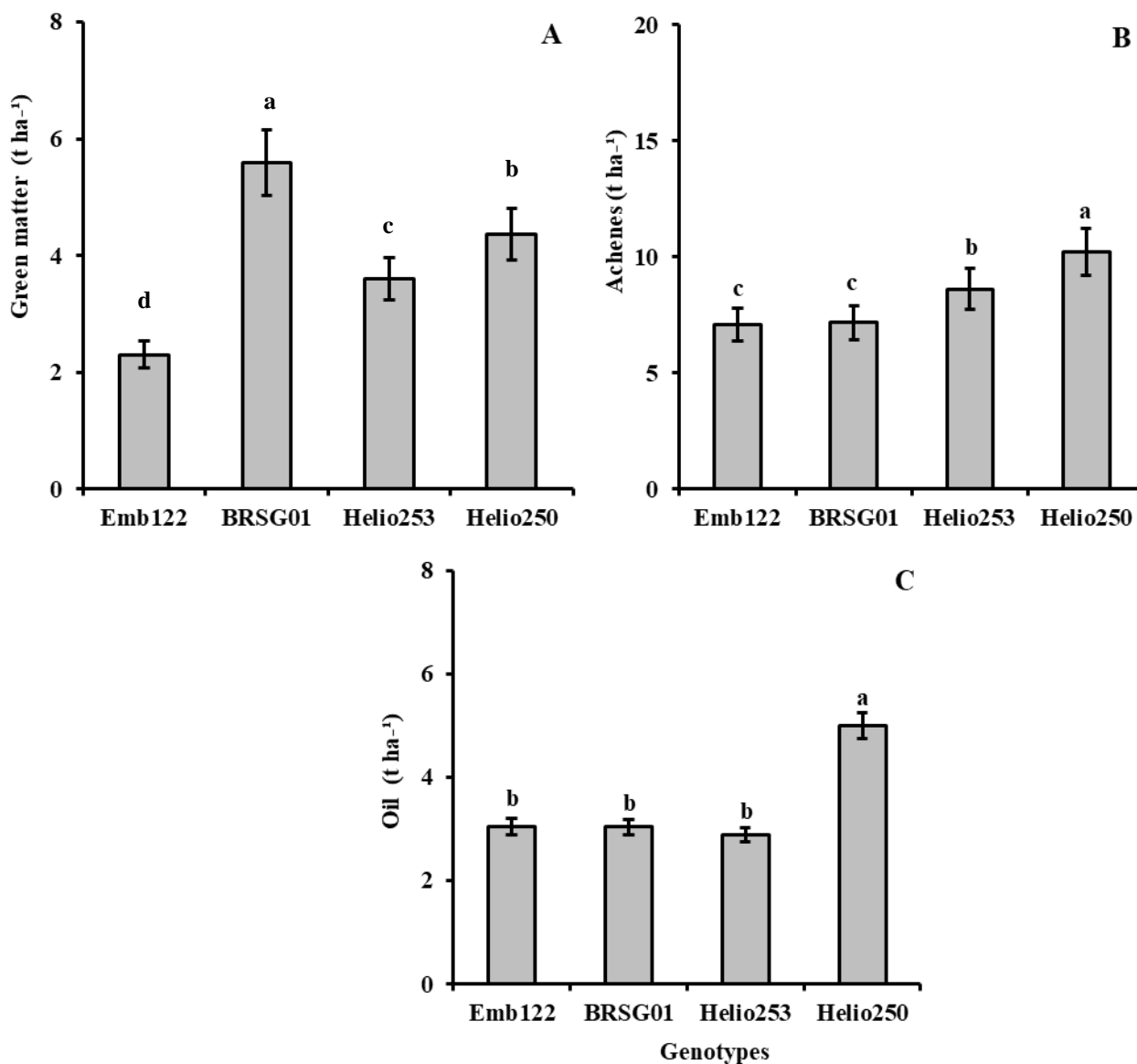
Figure 3. Green matter productivity (A), achene production (B), and oil yield (C) per hectare for 4 sunflower genotypes grown in a semi-arid environment, Catoléédo Rocha-PB. Bars represent the standard error (n = 5). Different letters indicate statistical difference (Tukey's test, $P \leq 0.05$)

However, yield of green matter is not necessarily reflected by efficiency in the productivity of achenes. Mason et al. (2017) argue that the allocation of phytomass to different plant organs depends on the physiology of each tissue, the relative abundance of available phytomass and the ecophysiology of the species. However, this multifactoral manipulation of phytomass between plant organs is important in adapting the plant to adverse edaphoclimatic conditions (Mason et al., 2017).

The genotypes Helio250 and Helio253 were the most productive in quantity of achenes with 10.20 and 8.61 t ha^{-1}, respectively. In contrast, the genotypes Embrapa122 and BRSG01

produced fewer achenes at 7.08 and 7.14 t ha^{-1}, respectively, which represented about 30% of the total produced by both Helio genotypes (Figure 3B). This reduction in yield for Embrapa122 could be explained by the low precipitation and elevated temperatures present in the region, leading to a reduction in the accumulation of phytomass and filling of for this genotype (Aquino et al., 2013). These authors also showed that hybrids such as Helio250 and Helio253 had higher productivity in relation to the openly pollinated genotypes, such as Embrapa122.

The production of achenes also reflected in oil productivity, with the genotype Helio250 being the most productive (4.99 t ha^{-1} oil), corresponding to a 39.67, 39.27 and 42.28% increase in relation to the genotypes Embrapa122, BRSG01 and Helio253, respectively, which did not differ statistically from each other, as shown in Figure 3C.

The genotype with the highest achene production of in an area does not always yield the most oil. This was observed in the current study for the genotype Helio253, which was the second most productive but had the lowest yield of oil per hectare. Clearly, the ultimate interest of industry is total oil yield, the main commercial product of the sunflower crop (Dalchiavon et al., 2016).

The results observed for the productivity of achenes were superior to those observed by Santos et al. (2012), who evaluated different sunflower cultivars in the region of Tocantins, obtaining a maximum observed productivity of 3,256 t ha^{-1} for the cultivar Helio250. These oil yield values could be considered high, since oil yield in sunflower crops without irrigation was usually in the range 400 - 1,000 kg ha^{-1}, while with irrigation yield was generally in the range 700 - 2,200 kg ha^{-1} (Force-Martinéz et al., 2015).

3.3 Oil Content

Comparison of the amount of oil in achenes before planting with those harvested as progeny was relevant in selecting genotypes that had a high oil content and maintained their productive potential when grown in the semi-arid region of Northeast Brazil. There was a significant effect of genotypes, with Helio250 and Helio253 (Figure 4) showing lower reductions of 1.37 and 0.67%, respectively, in the oil content of the achenes harvested when compared to those before cultivation, thus demonstrating their adaptation to the culture conditions of the Paraíba semi-arid region.
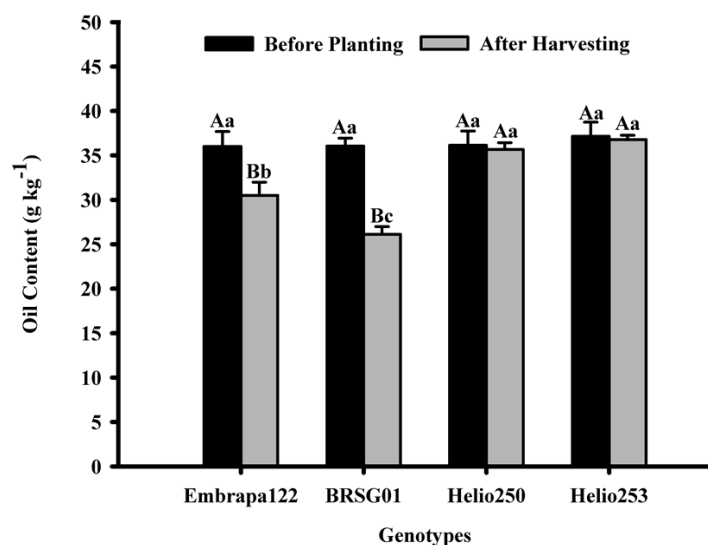
Figure 4. Oil content of achenes before planting (parental) and after harvesting (progeny) for 4 sunflower genotypes cultivated in a semi-arid environment, Catolédo Rocha, Paraḃa. Bars represent the standard error (n = 5). Different letters indicate statistical difference (Tukey's test, $P \leq 0.05$)

According to Oshundiya et al. (2014), oil content in the sunflower achenes can be reduced due to climatic conditions and cultural practices during cultivation, particularly during the phase of achenes filling. It was observed that the genotypes Embrapa122 and BRSG01 were more affected in their oil content, possibly because they suffer more from the cumulative effects of temperature, high luminosity and other environmental variables present in the region. As stated by Iqrasan et al. (2017), such environmental factors not only modified the phenology, but also caused physiological and qualitative changes, including in development, production, and accumulation of oil and fatty acids in these genotypes.

3.4 Fatty Acids

On comparing the quality of achenes before planting, no significant differences were observed in relation to the amounts of fatty acids among the genotypes, but distinctions were made regarding their chemical compositions, with the oil of these sunflower genotypes being rich in fatty acids in the following order: linoleic acid > oleic > palmitic > stearic > behenic > margaric > arachidic > lignoceric > eicosenoic > palmitoleic > myristic > linolenic > heptadecenoic (Table 3). By contrast, the chemical composition of oil from harvested progeny achenes (Table 3) showed marked differences between the sunflower genotypes, as well as the content of the fatty acids. Carvalho et al. (2018) studying fatty acid profiles of sunflower oil grown in the Brazilian semiarid region observed marked differences between the genotypes, influenced by minimum temperature during the oil synthesis phase.

Table 3. Composition of fatty acids from the oil of 4 sunflower genotypes after (progeny) and before (parental) cultivation in a semi-arid environment, Catolé do Rocha, Paraíba

Fatty acid	BRSG 01	Embrapa 122	Helio 250	Helio 253
After Harvesting				
Linoleic	21.592 Aa	21.563 Aa	21.644 Aa	22.253 Aa
Oleic	10.455 Ab	10.441 Ab	10.480 Ab	10.775 Ab
Palmitic	2.163 Ac	2.160 Ac	2.168 Ac	2.229 Ac
Stearic	1.081 Ad	1.080 Ad	1.084 Ad	1.114 Ad
Miristic	0.021 Agh	0.021 Agh	0.021 Agh	0.022 Agh
Palmitoleic	0.036 Ag	0.036 Ag	0.036 Ag	0.037 Ag
Margaric	0.144 Af	0.144 Af	0.144 Af	0.148 Af
Heptadecenoic	0.010 Ah	0.010 Ah	0.010 Ah	0.011 Ah
Linolenic	0.018 Ah	0.018 Ah	0.018 Ah	0.018 Ah
Arachidic	0.144 Af	0.144 Af	0.144 Af	0.148 Af
Eicosenoic	0.054 Ag	0.054 Ag	0.054 Ag	0.055 Ag
Behenic	0.241 Ae	0.241 Ae	0.242 Ae	0.248 Ae
Lignoceric	0.090 Afg	0.090 Afg	0.090 Afg	0.092 Afg
Before Planting				
Fatty acid	BRSG 01	Embrapa 122	Helio 250	Helio 253
Linoleic	15.927 Da	18.609 Ca	21.758 Ba	22.434 Aa
Oleic	7.571 Cb	8.847 Bb	10.344 Ab	10.665 Ab
Palmitic	1.566 Bc	1.830 Abc	2.140 Ac	2.206 Ac
Stearic	0.783 Bd	0.915 Ad	1.070 Ad	1.103 Ad
Miristic	0.015 Bj	0.018 ABj	0.021 Aj	0.022 Aj
Palmitoleic	0.026 Bi	0.030 Ai	0.035 Ai	0.036 Ai
Margaric	0.104 Bf	0.122 ABf	0.142 Af	0.147 Af
Heptadecenoic	0.007 Al	0.009 Al	0.010 Al	0.011 Al
Linolenic	0.013 Bj	0.015 ABj	0.017 Aj	0.018 Aj
Arachidic	0.104 Bf	0.122 ABf	0.142 Af	0.147 Af
Eicosenoic	0.039 Ch	0.045 Bh	0.053 Ah	0.055 Ah
Behenic	0.174 Be	0.204 Abe	0.238 Ae	0.246 Ae
Lignoceric	0.065 Bg	0.076 ABg	0.089 Ag	0.091 Ag

After harvesting and before planting samples were analysed separately. Lower and uppercase letters were used to compare the fatty acid composition within and between genotypes, respectively (Tukey's test, P ≤ 0.05).

High levels of linoleic acid (omega 6) were found at around 60% of fatty acids, and Helio253 showed statistically increased levels of 3.01, 17.05 and 29% compared to Helio250, Embrapa122 and BRSG01, respectively. The percentage of oleic acid (omega 9) in the genotypes was approximately 28%, with the Helio253 hybrid having increased levels of 3, 17.04 and 29% compared with Helio250, Embrapa122 and BRSG01, respectively.

The genotypes in this study had a higher content of linoleic acid, followed by oleic acid. Regular sunflower oil contains 69% linoleic acid, 20% oleic acid and 11% saturated fatty acids. However, these percentages vary according to the growth environment and cultivated genotype (Alberio et al., 2016, Angeloni et al., 2017). Similar results were found by Reginato Neto et al. (2016), when evaluating the effect of the environment on the quality of sunflower oil produced in Campinas, São Paulo. The current study showed that the semi-arid Paraiba had the potential to produce sunflower oil of comparable quality, with 89% of unsaturated fatty acids (Oleic and Linoleic).

The fatty acid with the third highest content was palmitic, a constituent of saturated fatty acids, corresponding to about 6% of the total oil composition in the genotypes studied. Helio253 (29%), Helio250 (26.82%) and Embrapa122 (14.42%) showed increased levels compared to BRSG01. Carvalho et al. (2018) similarly found the highest levels of palmitic acid in hybrids Helio250 and Helio251, while the hybrids CF101 and Aguará 4 exhibited the lowest levels. In our study, other saturated fatty acids were higher in the genotype BRSG01 at 5.19%, compared to 4.99% in genotypes Helio253 and Embrapa122 and 4.71% in Helio250.

According to Correia et al. (2014), the quality of vegetable oil is related to its physicochemical characteristics and fatty acid composition, which defines its use by the industry. The degree of unsaturation is considered one of the most important factors in the characterization of saturated and unsaturated fatty acids. Gondim-Tomaz et al. (2016) pointed out that saturated fatty acids, such as palmitic acid, are more stable to oxidation than unsaturated fatty acids.

4. Conclusion

It is possible to produce sunflower in the climatic conditions of the Brazilian semi-arid region with biomass, achenes and oil similar to other regions of the country, with the possibility of obtaining oil with different chemical compositions.

Helio250 and BRSG01 were the most productive genotypes. With regard to the quality of the oil, the order was Helio253 > Helio250 > Embrapa122 > BRSG01.

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