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Reproductive Components of Safflower Genotypes Submitted of Bulk Density Levels in the Brazilian Cerrado

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Abstract

Nutrient absorption in crops can decline and their development can be hindered by increased bulk density. This study aimed at assessing the manner in which bulk density levels affect the reproductive structures of the safflower genotypes in the Brazilian Cerrado. The completely randomized design was adopted with four replications for the experiment, which was conducted in a greenhouse using Oxisol collected from 0.0 to 0.2 m depth from the region supporting Cerrado vegetation. The treatments included ten safflower genotypes (PI 237538, PI 248385, PI 250196, PI 301049, PI 305173, PI 305205, PI 306520, PI 306603, PI 560202 and PI 613366) and five bulk density levels (1.0, 1.2, 1.4, 1.6 and 1.8 $Mg \cdot m^{-3}$). Evaluations were done at 90 days after emergence, in terms of the number, diameter and dry mass of the heads. The data were submitted to the analysis of variance. The means were grouped using the Scott-Knott test at 5% probability. The diameter and dry mass of the chapters were influenced by the mean bulk density of 1.10 $Mg \cdot m^{-3}$. A notable interaction was evident between the safflower genotypes and bulk density levels for the diameter and dry mass of the head alone, revealing the high degree of genetic variability that environmental changes induce among the genotypes. The PI 250196, PI 301049, PI 305173 and PI 305205 genotypes exhibited greater stability to the bulk density variations compared with the others. Mean bulk density of 1.2 $Mg \cdot m^{-3}$ was found to impair the development of the reproductive components of the safflower genotypes.

Keywords

Carthamus tinctorius L., Bulk Density, Oleaginous Crop, Safflower Genotypes, Physical Attributes of Soil

1. Introduction

The study of soil physical quality assumes great significance as it directly hinders crop yield [1]. Soil compaction can hinder the water and nutrient uptake in plants, thus inhibiting their development [2] [3] [4], besides undermining the root system aeration and obstructing the suiting development. Intensification of bulk density can curtail the macro-porosity, lower the infiltration rate and minimize the morphological changes in the roots of the cultivated plants [3] [5]. Therefore, accurate soil and crop management is vital, as soil compaction is virtually inescapable in modern [6].

As safflower (*Carthamus tinctorius* L.), belonging to family Asteraceae [7], is oleaginous, its seeds are potential raw material in the production of biodiesel and manufacture of paints and varnishes [8], with its substantial oil content (35% to 45%), being a high additional value [9].

This usually culture presents a 110 to 150 days cycle, which may be shorter or longer, based on the genotype and prevailing environmental factors [7] [10]. The rosette stage is distinguished by slow plant growth and the emergence of leaves closer to the ground. This is a three to six-week phase, contingent upon the genetic material and environment to which they are exposed, temperature in particular [7].

Stem elongation and the ramifications indicate the more intensive growth phases of the plant, and last between 6 and 8 weeks [11]. The flowering commences between 60 and 100 days, and extends outwards, with the flower stage persisting from 14 to 21 days, depending on the edaphoclimatic conditions [8] [12]. The flowers are normally in hues of yellow, orange and red but rarely white. However, they change to other colors as they wilt [13].

The plant reaches physiological maturity between 4 and 6 weeks once the flowering phase begins [14], and the ideal harvesting time is between 2 and 3 weeks post maturity [11]. This culture showed high adaptability to extreme environmental conditions, thriving in semi-arid areas as well as at altitudes ranging from sea level to 2000 m [11].

The Brazilian Cerrado is characterized by predominantly deep and well drained Oxisols. The pluviometric pattern of this region experiences two distinct seasons, a rainy season, between October and March and a dry one, from May to September. The transition periods between the seasons is between March and May, and September to October [15].

In pioneering study in the Cerrado region, researchers affirm that the Brazilian biome offers suitable conditions for the safflower culture to adapt itself for

cultivation, particularly during the off-season period [2]. Safflower is a suitable alternative for diversification in the agricultural sector during that season, once that strong rainfall during the flowering period could hinder pollination and result in a low safflower grain yield [16].

The studies conducted in Brazil focusing on the critical bulk density levels in the safflower crop continue to remain rare, particularly in terms of the reproductive constituents of the plants. However, this is fundamental to understanding the adaptation of the safflower genotypes in the Brazilian Cerrado. This study aimed at assessing the ways that the bulk density levels affect the reproductive components of the safflower genotypes in this region.

2. Material and Methods

To determine the response of the reproductive parts of the safflower genotypes to various bulk density levels, ten safflower genotypes (PI 237538, PI 248385, PI 250196, PI 301049, PI 305173, PI 305205, PI 306596, PI 306603, PI 560202 and PI 613366) were studied at five bulk density levels (1.0, 1.2, 1.4, 1.4 and 1.8 $Mg{\cdot}m^{-3}$), through artificial compaction. All the genotypes, supplied by the Mato-Grossense Cotton Institute (IMA), were reared under greenhouse conditions, adopting a completely randomized design, which included 10 safflower genotypes and 5 densities of 4 replicates, comprising 200 experimental units in total. During this period, the mean temperature and relative humidity were maintained at 28.4˚C and 67.8%, respectively.

For this study, the soil used in the experimental units was brought from an area supporting the natural vegetation of the Cerrado, taken from the layer 0.0 to 0.2 m deep and sieved through a 4.00 mm mesh. The soil was classified as Oxisol [17] and the results of the chemical and granulometric soil analysis shows in **Table 1**.

Liming was then done to increase the base saturation to 60%, and the soil was left packaged in plastic bags for continued reaction. At planting, fertilizers were added, including 200 $mg{\cdot}dm^{-3}$ of nitrogen as urea, 150 $mg{\cdot}dm^{-3}$ of phosphorus (P_2O_5) as single superphosphate and 200 $mg{\cdot}dm^{-3}$ of potassium (K_2O) as potassium chloride [2]. To meet the micronutrient demand, 15 $mg{\cdot}dm^{-3}$ of FTE BR 12 was applied with a minimum guarantee of 9% Zn, 1.8% B, 0.8% Cu, 2% Mn, 3.5% Fe, 0.1% Mo.

The experimental units included a rigid PVC pot involving three rings, each of which were 200 mm in diameter and 100 mm in height, with a volume of

Table 1. Granulometric characterization and chemical analysis of the soil collected from the layer at 0.0 to 0.2 m depth.

pH	Sand	Silt	Clay	P	K	Ca	Mg	H	Al	SB	CEC	V	O.M.
$CaCl_2$		$g{\cdot}kg^{-1}$		$mg{\cdot}md^{-3}$				$cmol_c\ dm^{-3}$				%	$g{\cdot}dm^{-3}$
4.0	423	133	444	1.4	23	0.4	0.2	5.4	0.8	0.7	6.8	9.7	27.1

SB: Base Sum; CEC: Cation Exchange Capacity; V%: Base Saturation; O.M.: Organic Matter.

9.423 $d \cdot m^{-3}$ (Figure 1), to establish the density desirable for each soil layer. These rings were attached using adhesive tape, and one end was covered with a 1 mm thick polyethylene sheet to prevent soil loss. Once the soil was filled, the experimental units were conditioned using a 300 mm plastic dish [4].

At sowing time, 20 seeds were planted per pot to ensure emergence, and superficial soil irrigation was performed until the plants were established, at around 15 days. From then on, water was supplied via capillarity to induce the plants to deepen their roots against the compacted layer to seek more water [18]. After plant emergence, the excess plants were removed at 5, 7 and 15 days after emergence, leaving ten, six and two plants in each plot, respectively, at the end of the third thinning process (Figure 2).

Data was collected at 90 DAE for the variables mentioned: Number of Heads (NH)-Diameter of Heads (DH)-which is the mean diameter of five heads per plot (mm) (Figure 3) and Dry Head Mass (DHM)-which is the dry mass of the total number of heads in each plot, dried in a forced air circulation oven at 65˚C until constant mass was achieved.

The data were submitted of ANOVA and when significant, polynomial regression analysis was done for the bulk density levels and the Scott-Knott test for the genotypes. The analyses were performed using the Sisvar program considering 5% as the error probability [19].

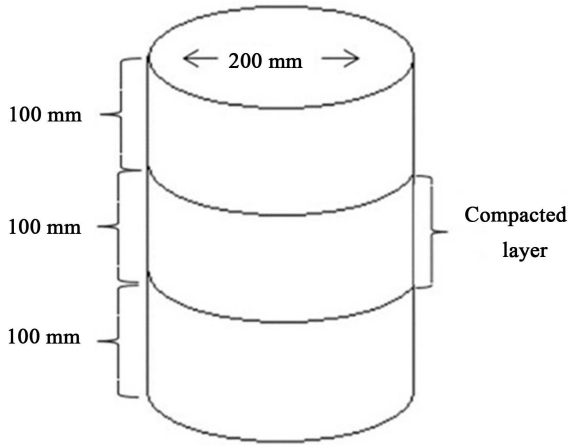

Figure 1. Representation of an experimental unit with its three soil layers.

(a) (b)

Figure 2. General view of the experiment at 37 (a) and 60 (b) days after sowing the safflower genotypes.

Figure 3. Diameter readings of the safflower heads.

3. Results and Discussion

Only the variables of head diameters (HD) and dry heads mass (DHM) revealed noteworthy interactions between the genotypes in response to the bulk density levels. The high genotypic variability was interesting from the perspective of the adaptability of the safflower crop to the different environmental conditions, as this enables the study of the adequacy of the genotypes under specific conditions, rationally using the environmental and financial resources.

3.1. Number of Heads

An isolated effect was noted for the number of heads for the genotypes and bulk densities studied (Figure 4 and Figure 5).

For the variable number of safflower heads of the genotypes can be categorized into three groups, as follows: the first group included the PI 237538, PI 248385, PI 301049, PI 305173 and PI 305205 genotypes, exhibiting the highest number of heads, (approximately 45 chapters on average per experimental unit); the second group included the PI 250196, PI 306596, PI 306603 and PI 560202 genotypes (showing an average of 28 chapters per experimental unit); and the third group included only one, (the PI 613366 genotype), bearing 8 chapters on average per experimental unit. This deficient performance is a result of the disease attack from the initial development phase, in which this genotype was less tolerant than the other genotypes.

The quadratic regression model includes the response of the number of heads to the bulk density, showing that the plant exhibited the best production of the heads for the 1.13 $Mg \cdot m^{-3}$ density with a mean of 44.34 units per pot (Figure 5).

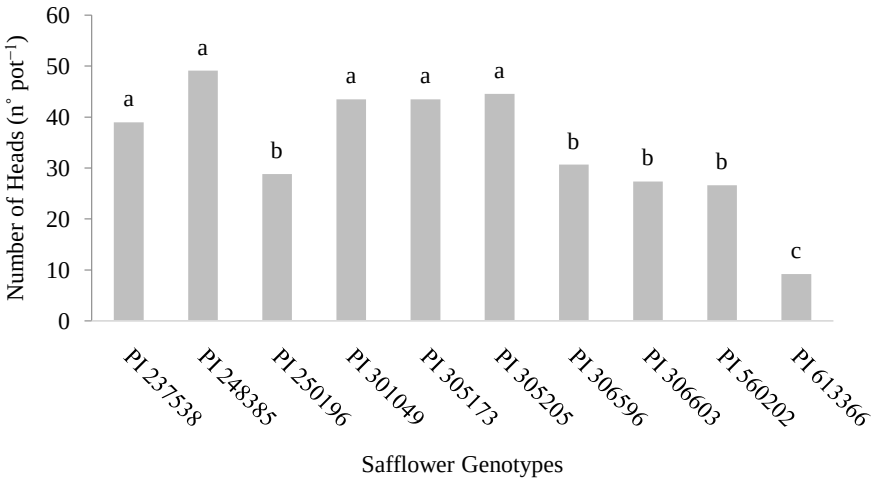

Figure 4. Number of heads of the safflower genotypes under study. Means followed by the same lowercase letter do not differ by Scott-Knott test at 5% probability.

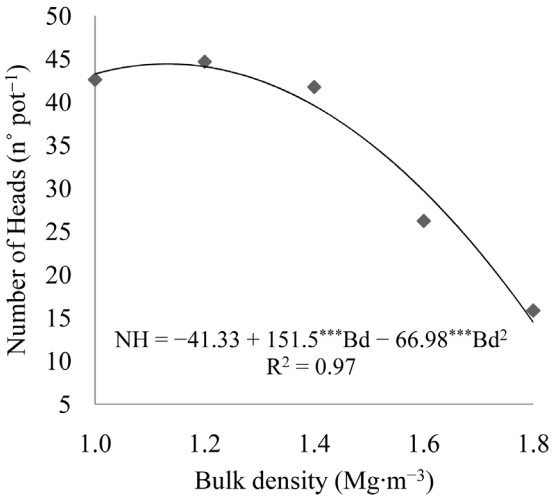

Figure 5. Number heads of safflower genotype in response to the bulk density levels. NH-Number of heads; Bd-Bulk density. ***Significant at 0.1% probability by the F test.

One of the crucial variables in the selection of the safflower genotypes is the number of heads, which is directly linked to the final crop production. In the case of the number of heads, a narrow bulk density range is recorded, while for the higher values (1.13 $Mg \cdot m^{-3}$) the number of heads drops significantly up to a density of 1.80 $Mg \cdot m^{-3}$. This action is most likely related to the stress of water and nutrient absorption by the crop, apart from the difficulties and energy expenditure in the effort to break through the compacted layer.

Confirming the findings for density, was reported developmental limitations in the morphological and productive characteristics in pig beans (*Canavalia ensiformis*) with increasing bulk density levels [20].

The root expansion into the deeper and compacted soil layers might be linked to improved exploration of the soil volume, which in turn raises the degree of water and nutrient absorption in these layers [21]. In this context, was confirmed

lower levels of soil porosity, hydraulic conductivity and soil permeability due to machine traffic [22]. The authors indicated that such changes significantly influence the capacity for flow and soil transport. Therefore, selecting safflower genotypes possessing such features will subsequently result in the best expression of the components produced and improved adaptability of the crop in the area.

The reduction of the water availability for the safflower crop can compromise the stem elongation phase, indicated as one of the most sensitive to the water deficit, which, consequently, will result in a lower vegetative development and reproductive components [23].

Thus, the genotypes exhibiting the most number of branches and heads per plant should be chosen for the selection programs to ensure enhanced grain yield [24]. In fact, study have been reported that the most important variable for improved safflower crop yield is the number of heads per plant [25].

3.2. Head Diameter

At 90 days after plant emergence, the variable head diameters revealed a strong relationship between the safflower genotypes and bulk densities (**Table 2**).

Linked to the heads diameters of the safflower genotypes, it became clear that in the bulk density containing 1.0 $Mg \cdot m^{-3}$ two groups emerged, the first had an average diameter of 22 mm produced by the PI 237538, PI 301049, PI 305173, PI 305205, PI 306596, PI 306603 and PI 560202 genotypes, while the second possessed a narrower mean diameter of 15.67 mm and was produced by the PI 248385, PI 250196 and PI 613366 varieties.

For the 1.2 $Mg \cdot m^{-3}$ density two distinct groups were visible, one possessing the greatest diameter, produced by the PI 237538, PI 301049, PI 305173 and PI 560202 genotypes and the other, showing a narrower diameter produced by the PI 248385, PI 250196, PI 305205, PI 306596, PI 306603 and PI 613366 genotypes.

Table 2. Head diameter of the safflower genotypes submitted to bulk density (Bd) levels at 90 days after emergence.

	Safflower Genotypes (PI)									
Bd ($Mg \cdot m^{-3}$)	237538	248385	250196	301049	305173	305205	306596	306603	560202	613366
	Head diameter(mm)									
1.0	22A	17B	16B	19A	19A	21A	20A	18A	21A	14B
1.2	20A	18B	18B	20A	19A	17B	17B	15B	21A	14B
1.4	19A	17B	17B	17B	18B	20A	22A	18B	22A	13B
1.6	19A	17A	15A	19A	19A	17A	19A	19A	22A	3B
1.8	20A	15B	12B	18A	18A	19A	18A	17A	19A	17A
Significant	**									
CV (%)	17.35									

Means followed by the same letter in the rows do not differ statistically by the Scott-Knott test at the 5% probability level. **Significant at 1% probability, respectively, by the F test.

At the 1.4 $Mg \cdot m^{-3}$ bulk density the expression was identical to the previous densities, revealing two groups. The greatest diameter (19 to 22 mm) was seen in the PI 237538, PI 305205, PI 306596 and PI 560202 genotypes, while the narrower one (13 to 18 mm) was evident in the PI 248385, PI 250196, PI 301049, PI 305173, PI 306603 and PI 613366 genotypes.

In the case of the 1.6 $Mg \cdot m^{-3}$ bulk density, only a single genotype, the PI 613366, was statistically different from the others, exhibiting a narrower head diameter. At the 1.8 $Mg \cdot m^{-3}$ bulk density level, the PI 248385 and PI 250196 genotypes expressed the least chapter diameter of 13.5 mm on average when compared statistically with the other genotypes. The differences in the heads diameters in the safflower genotypes are clearly seen (**Figure 6**).

In study over three years, while assessing the variability of the yield stability in 25 safflower genotypes at five research stations, was reported that spatial variability was obvious in 50% of the cases, with the most stable genotypes producing the lowest yields. It is therefore clear that the high yielding genotypes respond specifically to the intrinsic conditions of their cultivation sites, vindicating the necessity for extensive research to endorse the same [26].

Regarding bulk density, the PI 250196 genotype adjusted to the quadratic regression model revealed that soil density levels influenced this variable (**Figure 7**). The greatest leaf diameter of 17.35 mm was recorded at 1.24 $Mg \cdot m^{-3}$ bulk density; however, none of the other genotypes evaluated showed statistical difference.

The head diameter is the variable of highlighted and importance, once as the safflower culture has small heads, in which size bears a relation to the floral disk diameter [27]. The greater the head diameter, the more the number of flowers, the larger the quantity of inflorescence and, therefore, the higher the grain yield.

3.3. Dry Head Mass

An isolated effect was noted for the dry head mass for the different safflower genotypes and bulk density levels (**Figure 8**).

For the variable dry head mass, three groups emerged in which the first group including the PI 237538, PI 248385, PI 301049, PI 305173, PI 305205, PI 306596 and PI 560202 genotypes roughly produced a dry mass yield of 28 $g \cdot pot^{-1}$. The second group, including the PI 250196 and PI 306603 genotypes exhibited a dry mass yield of 18 $g \cdot pot^{-1}$, while the third group, which included only the PI 613366 genotype, showed a dry mass of 6.5 $g \cdot pot^{-1}$ (**Figure 8**).

With respect to the bulk density levels, an adjustment was made to the quadratic regression model (**Figure 9**).

For dry head mass, a yield of 34.07 $g \cdot pot^{-1}$ was noted for the 1.06 $Mg \cdot m^{-3}$ bulk density; it was evident that as the bulk density increased the dry mass production of the heads decreased. It is Known that to plant roots break through the compacted soil layers, a high metabolic energy expenditure was required [28]. This was accomplished via the transport of photosynthesized material in the shoots of the aerial parts to the roots, resulting in lower yields.

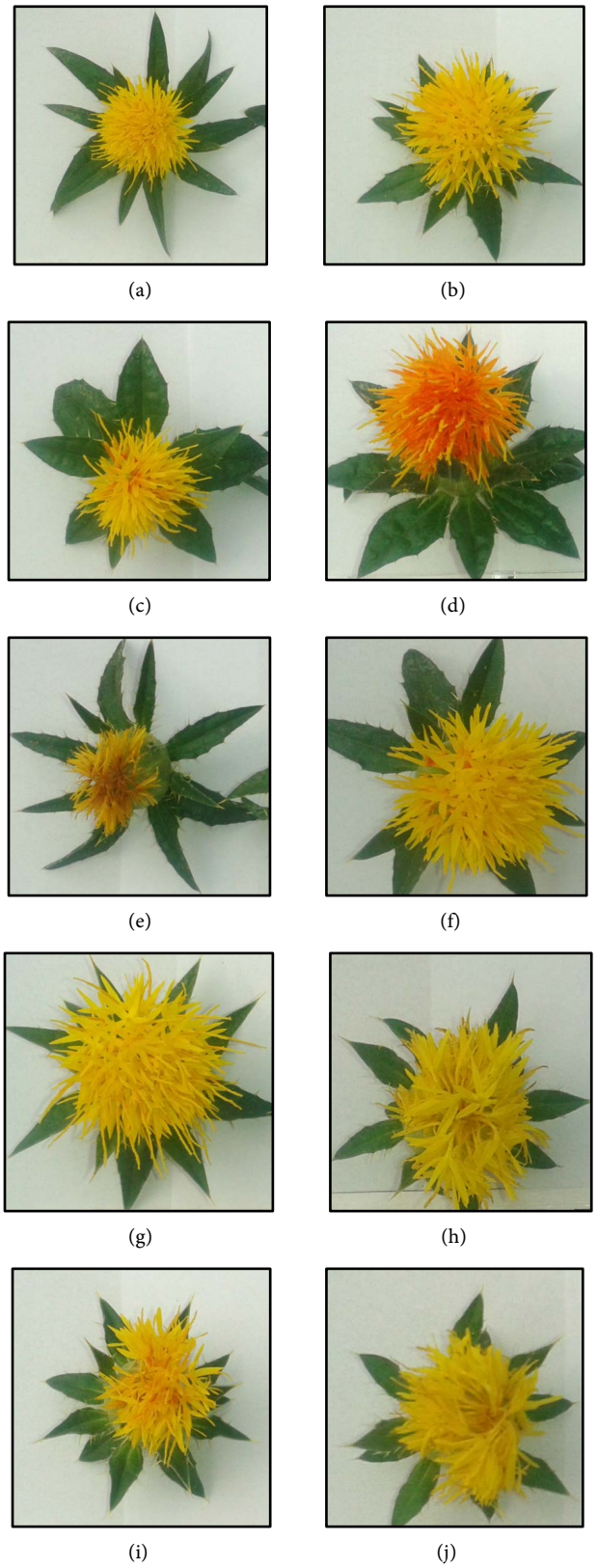

Figure 6. Variability of heads among the safflower genotypes (a) PI 237538; (b) PI 248385; (c) PI 250196; (d) PI 301049; (e) PI 305173; (f) PI 305205; (g) PI 306596; (h) PI 306603; (i) PI 560202 and (j) PI 613366.

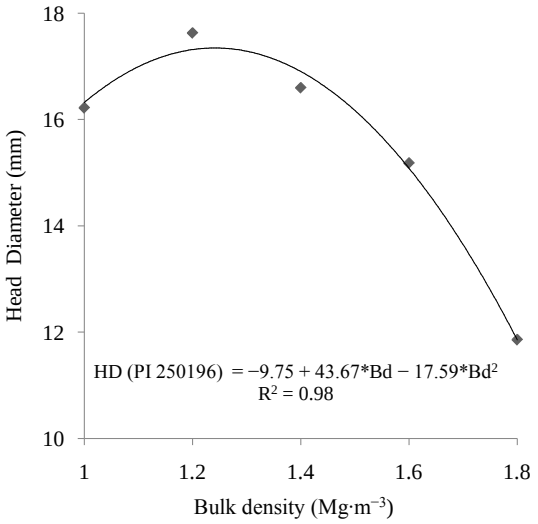

Figure 7. Head diameters of the safflower genotypes in response to the bulk density levels. HD-Head diameters; Bd-Bulk density. *Significant at 5% probability by the F test.

Figure 8. Dry head mass in the safflower genotype studied. Means followed by the same lowercase letter do not differ by the Scott-Knott test at 5% probability.

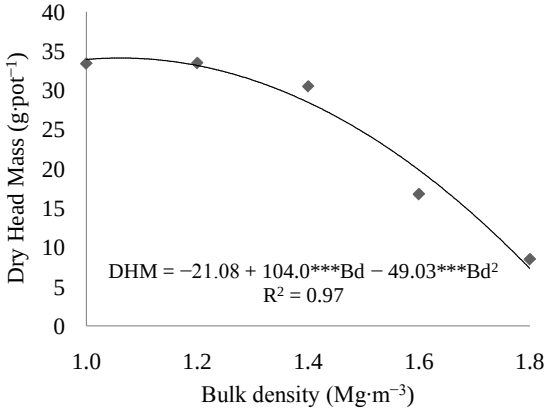

Figure 9. Dry head mass in the safflower genotype as a function of bulk density levels. DHM-Dry head mass; Bd-Bulk density. ***Significant at 0.1% probability by the F test.

The development of cover crops under soil densities and resistance to penetration, provides significant reductions in dry mass production of rapeseed (*Raphanus sativus*) and black oats (*Avena strigosa*) at soil density of 1.34 $Mg \cdot m^{-3}$ in Oxisol [29]. For maize (*Zea mays* L.) under different bulk density levels of the Oxisol, bulk densities greater than 1.21 $Mg \cdot m^{-3}$ were found to be limiting to the growth [3]. Soil penetration resistance was pointed out as the main responsible for the lower plant development, even in comparison to the availability of water and nutrients [30]. Thus, it is evident the necessity of a correct management, aiming to assure the good vegetal development.

The bulk density negatively affects the phytometric components of the safflower crop. The mass of the safflower heads declined up to 53% compared with the densities of 1.0 $Mg \cdot m^{-3}$ and 1.8 $Mg \cdot m^{-3}$, irrespective of the nitrogen dose applied [4].

Normally, safflower is regarded as a sturdy plant with the capacity to tolerate environmental stresses like aridity and altitude, which has made it popular across the world. However, it was observed that the crop, despite its rusticity, has severe restrictions on the higher bulk density levels when considering the expression of the reproductive components, number, diameter and dry head mass.

Under bulk density conditions of 1.2 $Mg \cdot m^{-3}$, all the variables analyzed showed a significant decline, which will certainly have negative repercussions in limiting the crop yield, irrespective of the genotype used. In this context, it can be established that as the bulk density intensifies, it impedes the water and nutrient absorption by the safflower plants, as well as induces a greater consumption of the photo as similates, which is expended on root growth to facilitate the search for nourishment, water and nutrients.

4. Conclusions

A notable interaction was recorded between the safflower genotypes and bulk density levels only for the variables of diameter and dry head mass, indicating a wide genetic variability among the genotypes during times of environmental alterations.

The PI 250196, PI 301049, PI 305173 and PI 305205 genotypes are found to be more stable to the bulk density variations when compared to the others.

Safflower genotypes show developmental impairments in their reproductive components under conditions of mean bulk density of 1.2 $Mg \cdot m^{-3}$.

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