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Breaking down castor seed oil content in two meaningful components

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ABSTRACT

Seed oil content is the main quality attribute in castor seed (*Ricinus communis* L.) for industrial purpose. As this characteristic has been traditionally measured as one single variable, this article proposes that castor seed oil content could be measured as two independent characteristic: the kernel oil content and the kernel percentage (i.e., the kernel weight in relation to the whole sample weight). The two separate components provide a more precise explanation on the factors influencing castor seed oil content. For instance, the kernel percentage is more influenced by the amount of residues (fruit husk, empty seeds, and contaminants), while the kernel oil content reflects the degree of seed filling and the varietal potential for storing oil. For demonstration, the two components were measured (a) in 14 castor genotypes and (b) in individual kernels sorted by weight. The kernel oil was extracted in Ankon XT15 using petroleum ether as solvent. The seed oil content was estimated from the product of kernel oil content and kernel percentage. Among varieties, the kernel oil content varied from 55.1% to 64.6%, the kernel percentage varied from 67.4% to 79.7%, and the seed oil content was estimated between 40.8% and 48.3%. The highest oil content was not found in the seed with the highest kernel oil content but with the highest kernel percentage. In the study with individual seeds, the kernel oil content was 16.8% in the lightest seeds (66 mg), it increased linearly to reach 64.8% in the seeds weighing 288 mg, and it remained stable in the seeds weighing between 323 and 476 mg (65.8% on average). This article discusses the advantages of measuring the kernel oil content and the kernel percentage separately. Kernel percentage can be a proxy for seed oil content, as it is easier to measure.

1. Introduction

Castor oil is a platform chemical used in the industry for a long list of derivatives and products. For the industry, the main quality attribute for castor seed is the oil content. Seed oil content is frequently measured in studies with castor (*Ricinus communis* L.), evaluating how it is influenced by environmental factors and agronomical management (Alexopoulou et al., 2015; Cafaro et al., 2023; Kumar et al., 2025; Severino et al., 2010, Severino and Auld, 2013a; Souza-Schlick et al., 2018), how it can be increased by genetic improvement or biotechnological tools (Chen et al., 2016a, 2018; Han et al., 2025; Huang et al., 2015a), and how it varies among wild and cultivated genotypes or among accessions in germplasm banks (Román-Figueroa et al., 2020; Vasco-Leal et al., 2018; Velasco et al., 2015; Wang et al., 2011; Yadav and Anjani, 2017).

In castor seed, the oil is stored in the kernel, although the oil stored in the endosperm and in the embryo has a slightly different composition (Sturtevant et al., 2019). There are several methods for measuring seed oil content. In the destructive methods, the seed is ground, and the oil extracted with a solvent (usually hexane or petroleum ether) in extractors such as Soxhlet or Ankon (Buthelezi et al., 2019; Huang et al., 2015a; Wang et al., 2012). As castor oil has higher solubility in ethanol than most vegetable oils, this solvent can also be employed for measuring castor seed oil content, and it was reported to result in higher oil content than measurements made with petroleum ether and hexane (Danlami et al., 2015). The main non-destructive methods are Nuclear Magnetic Resonance and Near Infrared Spectroscopy (Gislum et al., 2018; Velasco et al., 2015; Yadav and Murthy, 2016). Each method has pros and cons related to cost, processing time, and precision, and each of them is especially sensitive to specific factors such as the choice of solvent, the moisture content, the particle size, the sample or solvent temperature, and the extraction time (Buthelezi et al., 2019; Danlami et al., 2015; Silva et al., 2008; Yadav and Murthy, 2016). The oil extraction with mechanical pressure is not commonly used for measuring castor seed oil content because it has low extraction efficiency (Perdomo et al., 2013). The method of supercritical CO_2 extraction is an option (Silva et al., 2008), but it has not been commonly

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adopted for castor seed.

Seed oil content is calculated as the weight of oil stored in the kernel divided by the whole sample weight (Fig. 1). The attempts to increase seed oil content have been focused on the numerator (i.e., increasing oil content in the kernel), while the role played by the denominator (i.e., the weight of the other components in the sample) has received scarce attention. The other materials found in the sample are highly relevant, and they include residues of the plant (leaf, stem, peduncle), fruit husk, empty seeds, seed coat, caruncle, other kernel components (protein, carbohydrates, nutrients, ash), and foreign materials such as sand, rock, metal, wood, and plastic. It can also contain seeds of other plant species that grow in castor fields as weed and are unintentionally harvested (Severino et al., 2025a).

Scientific studies are predominantly conducted with samples of clean seeds, but the feedstock delivered to the castor oil extraction industry contains a relevant weight of contaminants (Severino et al., 2025a). Traditionally, seed oil content is not a quality requirement for trading between farmers and the industry because it is difficult to measure at field conditions. The seed quality for trading purposes is instead based on the content of fruit husks, which influence the amount of castor oil that can be extracted from the material.

The objective of this study is to demonstrate that castor seed oil content can be measured as two separate and independent components: kernel percentage and the kernel oil content. The method was tested in a diversity of castor genotypes (including wild and cultivated varieties) and on individual seeds classified according to the kernel weight.

2. Material and methods

2.1. Seed oil content among genotypes of castor

The study was made with 14 genotypes of castor with high morphological diversity (Fig. 2), including cultivated varieties and wild plants, and they were harvested in commercial fields, sampled in lots used for sowing, or wild plants collected in roadsides. The variety 'RS Otto 01' was harvested in two different locations, and the genotype named "local breed" refers to a strain that is planted by smallholder farmers without control of genetic purity. The seeds from wild plants were collected in two locations in Brazil.

Each seed sample weighed between 6.6 and 15.6 g (average of 8.6 g). The seed was cleaned from fruit husks and other contaminants and separated in three classes by air classification (Severino et al., 2025b) aiming to create variability in seed density. The seed in each class was oven dried (85 °C, 24 h), counted, weighed, separated in kernel and other components (fruit husk, seed coat, and contaminants) and the kernel was weighed. The mean seed weight and kernel percentage were calculated for each class.

The kernels of each class were ground in a coffee grinder to obtain a fine and uniform mash, and the oil content was measured in an extractor Ankon XT15 (Severino et al., 2025b; Wang et al., 2012), using petroleum ether as solvent, ten bags per batch, 90 min of extraction time, extraction temperature of 90 °C, and kernel samples varying from 1.2 to 1.6 g (average of 1.4 g). The measurement was made in triplicate for each class. The bags were extracted randomly among genotypes, classes, and replicates (following a Completely Randomized Design). The kernel oil content was calculated as the difference in dry mass before and after extraction divided by the initial dry mass.

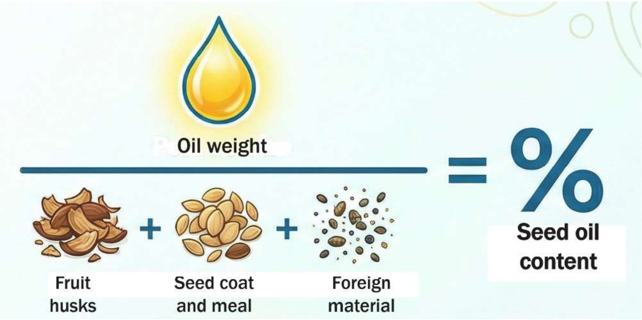

Fig. 1. Castor seed oil content is calculated as the ratio between the oil weight and the weight of all the other materials found in the sample.

The data on mean seed weight and kernel percentage were not replicated because they were not intended to test the significance of the difference among subsamples. That data was not subjected to analysis of variance, but it was presented with just a measurement of standard deviation (s.d.) to express the variability observed in the castor seed sample.

The seed oil content was calculated with the following equation:

$$\textit{Seed oil content }(\%) = \textit{Kernel percentage }(\%) \times \textit{Kernel oil content }(\%)$$

The data on both kernel and seed oil content were subjected to analysis of variance in a factorial distribution of 14 genotypes x 3 classes. Only the means of the same class were compared with test of Tukey ($p < 0.05$).

2.2. Kernel oil content according to the kernel weight

A sample of cv. 'BRS Energia' was air classified to increase the frequency of light seeds, oven dried (85 °C, 24 h), 273 seeds were individually weighed, the seed coat was removed, and the kernel was weighed. The kernel weights were sorted from the lightest to the heaviest, and the kernels were pooled in 23 groups with a size that allow the measurement of oil content. The kernels weighing up to 135 mg were pooled to reach samples of 1 g. The kernels weighing more than 135 mg were pooled in groups weighing between 1.5 and 2 g. The first group was composed by 60 kernels weighing 17 mg on average, and the last group was composed by 5 kernels with mean weight of 372 mg. The kernels were ground in a coffee grinder, and the oil content was measured as described in Section 2.1.

The seed oil content (%) was calculated for each group as the product of kernel percentage and kernel oil content (Section 2.1). The data was subjected to analysis of regression using the exponential model $y = y_0 + a(1\text{-}e^{bx})$, where y was kernel percentage, kernel oil content, or seed oil content, and x is the mean seed weight of the group. Correlations were calculated among the three variables in the results from the 14 genotypes and among the groups according to kernel weight.

3. Results

3.1. Mean seed weight and seed oil content among genotypes

The 14 castor genotypes used in this study had the mean seed weight varying from 80 mg in the wild plant 1 (class 1) to 881 mg in the local breed (class 2) (Table 1). In some genotypes, the air classification resulted in large difference in the mean seed weight, like in 'BRS Energia', which varied from 160 to 282 mg (s.d. 50.6 mg) and 'AKB 10' (from 174 to 302 mg, s.d. 57.1 mg). On the other hand, the mean seed weight of the local breed had the least difference among classes (between 855 and 881 mg, s.d. 11.6 mg). The range of mean seed weight analyzed in this study is wider than most reports on castor seed studies (Huang et al., 2015a, 2015b; Perdomo et al., 2013; Velasco et al., 2015), including the assessment of the entire USDA germplasm collection, which varied from 101 to 733 mg (Wang et al., 2011).

The kernel percentage varied from 61.4% ('BRS Energia' class 1) to 81.0% ('BRS Paraguaçu' class 3), while the kernel oil content varied from 53.3% ('BRS Paraguaçu' class 1) to 66.4% ('RS Otto 01', field 2, class 3) (Table 2). Some genotypes, such as 'AKB 10' and 'BRS Energia' had significant differences in the seed oil content among the classes that were caused by the kernel percentage, while in other genotypes, despite the significant difference in kernel oil content, the seed oil content was

Fig. 2. Illustration of the diversity of size, color, and shape among the genotypes of castor evaluated in this study of seed oil content.

Table 1
Mean seed weight of castor genotypes separated by air classification in three classes according to the density.

Genotype	Mean seed weight (mg)			Standard deviation
	Class 1	Class 2	Class 3	
AG IMA	274	275	291	7.8
AKB 10	174	287	302	57.1
BRS Energia	160	240	282	50.6
BRS Paraguaçu	552	654	785	95.4
Kariel	297	329	372	30.7
KS 2019	276	310	341	26.5
KS 2030	209	253	332	50.9
Local breed	855	881	858	11.6
Mia	253	288	300	19.9
RS Otto 01 (field 1)	183	246	262	34.1
RS Otto 01 (field 2)	254	295	285	17.5
Tamar	263	339	380	48.5
Wild plant (1)	80	99	107	11.3
Wild plant (2)	113	154	167	23.0

not different, such as ‘AG IMA’ and ‘RS Otto 01’ (field 2). For comparison, these two components were measured in 12 varieties from China by Huang et al. (2015a), and they found a smaller variability, with kernel percentage varying from 69.3% to 77.9% and kernel oil content from 24.3% to 47.0%.

3.2. *Seed oil components in a single genotype*

The individual seed weight in cv. ‘BRS Energia’ varied from 66 to 476 mg. The seed oil content was very low (4.3%) in the group with the lightest seeds, and it increased to 51.6% in the heaviest seeds (Fig. 3). A similar study was reported by Chen et al. (2016b), in which the kernel oil content was tracked along the seed development, and it evolved from 4.7% at 10 days after anthesis to 63.9% at seed maturation.

In this analysis, in which the seeds were obtained from a single genotype and harvested at the same environmental conditions, the difference among the seeds was due to the weight of reserves stored in the kernel, which influence equally the kernel percentage and the kernel oil content. Comparing the lightest and the heaviest seeds, the seed coat weight had narrow variation (from 32 to 113 mg), while the kernel weight had broad variation (from 1 to 405 mg). In this specific condition, the changes in seed oil content were equally explained by any of the components.

3.3. *Correlations among the components of seed oil content*

When the components of seed oil content were measured in different genotypes, the kernel percentage and the seed oil content were highly independent, with correlation approaching zero ($r = -0.081$), while the seed oil content had similar correlations with the kernel percentage ($r = 0.705$) and the kernel oil content ($r = 0.649$) (Table 3). For comparison, in two studies with 12 and 32 genotypes from China, the correlation between kernel percentage and kernel oil content were also low

Table 2
Kernel and seed oil content of castor genotypes separated in three classes (Cl.) by air classification and standard deviation (s.d.) of the kernel percentage among subsamples.

Genotype	Kernel percentage (%)			s.d.	Kernel oil content (%)			Seed oil content (%)		
	Cl. 1	Cl. 2	Cl. 3		Cl. 1	Cl. 2	Cl. 3	Cl. 1	Cl. 2	Cl. 3
AG IMA	71.6	71.6	72.8	0.6	64.2b	60.3ab	57.2a	46.0a	43.2a	41.7a
AKB 10	64.6	74.7	75.8	5.0	61.3a	61.5a	62.3a	39.6a	46.0b	47.2b
BRS Energia	61.4	72.4	74.5	5.7	59.3a	61.6a	60.5a	36.4a	44.6b	45.0b
BRS Paraguaçu	73.3	78.7	81.0	3.2	53.3a	54.6a	57.3a	39.1a	43.0ab	46.4b
Kariel	74.3	73.5	75.9	1.0	60.4a	61.9a	62.8a	44.9a	45.5a	47.7a
KS 2019	69.2	72.4	75.1	2.4	65.1a	64.6a	64.2a	45.0a	46.7a	48.3a
KS 2030	68.0	71.3	73.9	2.4	57.8a	59.3a	57.7a	39.3a	42.2a	42.6a
Local breed	80.1	80.0	78.9	0.5	61.0a	60.4a	60.3a	48.9a	48.3a	47.5a
Mia	67.8	70.4	69.9	1.1	63.3a	62.5a	60.4a	42.9a	44.0a	42.2a
RS Otto 01 (field 1)	65.8	72.7	72.5	3.2	59.3a	62.6a	63.4a	39.0a	45.6b	46.0b
RS Otto 01 (field 2)	69.2	71.6	72.1	1.3	62.0ab	60.9a	66.4b	43.0a	43.6a	47.8a
Tamar	68.1	74.8	76.7	3.7	60.3a	60.2a	60.5a	41.0a	45.0ab	46.4b
Wild plant (1)	64.4	66.8	70.8	2.6	59.8a	61.6a	60.3a	38.5a	41.2a	42.7a
Wild plant (2)	67.7	73.1	73.3	2.6	57.5a	56.5a	58.0a	38.9a	41.3a	42.5a

*Means followed by different letters are significantly different (test of Tukey, $p < 0.05$) in the same genotype

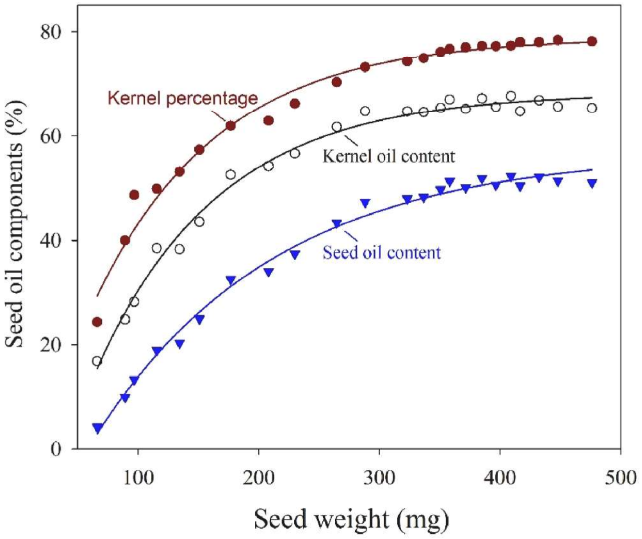

Fig. 3. Components of castor seed oil content according to the seed weight in a sample of cv. 'BRS Energia'.

Table 3
Correlations among the kernel percentage, kernel oil content, and seed oil content among the 14 genotypes and among the groups pooled by kernel weight.

	Kernel percentage	Kernel oil content
Among 14 castor genotypes		
Kernel percentage	-	−0.081
Seed oil content	0.705	0.649
Among 23 groups pooled by kernel weight		
Kernel percentage	-	0.984
Seed oil content	0.981	0.991

(r = 0.208 and r = −0.177, respectively) (Huang et al., 2015a; 2015b).

The opposite result occurred when the correlation of kernel percentage and kernel oil content was measured in the groups that were sorted by kernel weight in just one genotype. In this case, the two components varied in almost perfect association (r = 0.984), and both components were highly correlated with the seed oil content (Table 3). Similar correlations were observed in the results reported by Chen et al. (2016b) in the phases of castor seed filling and by Severino et al. (2015) on castor seeds sorted by weight. As discussed in the Section 3.2, the amount of reserves stored in the seed was the predominant difference among the groups, and they influenced equally both components. This is evidence that the kernel percentage is able to explain most of the variability in seed oil content associated with the level of seed filling inside a given genotype. This high correlation also demonstrate how the sample preparation, (i.e., the residues of light seeds and fruit husks in the sample) may influence the castor seed oil content.

Kernel percentage is easier to measure than kernel oil content. For further studies, whenever varieties are not compared, it should be considered the hypothesis that the effect of treatments on seed oil content could be measured considering only the kernel percentage, as it potentially have a high correlation with the kernel oil content. Nevertheless, before its use, the association should be validated in more studies for confirmation.

4. Discussion

4.1. The importance of sample preparation and the cleaning process

The separation of castor seeds by air classification simulates the predominant method deployed for castor seed cleaning. The anecdotal observation that air classification can create classes with contrasting seed weight and oil content has implications for experimental and harvesting procedures. An important source of variability on the kernel percentage is the presence of fruit husk residues. This study was made with clean seeds, but it is common that castor seed samples have a relevant content of husks influencing the kernel percentage. On the experimental side, when samples are prepared for measuring seed oil content, the result can be influenced by the rigor or intensity of cleaning empty seeds and other contaminants. On the farming side, there is a trade-off for adjusting the wind speed employed for air classification. If the wind speed is too low, it will increase fruit husk, empty seeds, and contaminants, which will reduce the seed oil content. If the wind speed is too high, it will trash normal seeds, reducing the seed yield.

The kernel percentage expresses the weight of internal parts of the seed in relation to the weight of the sample. The variation of kernel percentage among classes (Table 2) was coherent with the differences observed in the mean seed weight. The light seeds found in the sample were aborted seeds, in which the seed coat was formed, but the endosperm was partially filled with reserves. A detailed study of factors influencing castor seed abortion can be found in Severino and Auld (2013b). In short, castor seed weighing less than 40% of the maximum seed weight can be considered an aborted seeds. The rate of aborted seed can be influenced by both the genotype and the environmental conditions. Nevertheless, despite the variability on the seed abortion rate in the plant at field conditions, the occurrence of light seeds that potentially influence the seed oil content can be minimized in the cleaning step.

4.2. The components clarifies the factors influencing castor seed oil content

Previous studies have demonstrated how castor seed oil content is influenced by the kernel oil content (Anjani, 2014; Huang et al., 2015a; 2015b; Severino et al., 2009, 2015). This article proposes breaking down the seed oil content in two components because it allows the analysis of the specific factors influencing the oil content. Increasing the seed oil content is a key objective among castor breeding programs, cropping system researchers, and farmers (Anjani, 2014; Huang et al., 2015a), but the progress is limited when the factors influencing the main variable are confounded among many causes. For instance, the kernel percentage is prone to be influenced by the sample manipulation (light seeds and contaminants) and by morphological characteristics of the seed, such as the seed coat thickness (Severino et al., 2009, 2015). On the other side, kernel oil content is influenced by the genetic potential of each variety (Anjani, 2014; Huang et al., 2015a; 2015b; Severino et al., 2015). As most studies have presented the seed oil content without breaking these two components, the effects are confounded among the influences of genetic traits, environmental conditions, and cleaning procedures.

In some genotypes evaluated in this study, a significant difference in the kernel oil content did not cause a significant difference in the seed oil content because the kernel percentage offsets the other component (Table 2). The seed lots used in this study were carefully cleaned of contaminants, but it is very common that castor seed samples have a high content of foreign materials. In some cases, such as in the feedstock delivered to the industry, the most important reason for a reduced seed oil content can be the high content of contaminants rather than a low kernel oil content. As the contaminants content increase, the importance of the kernel oil content reduces in the calculation of the seed oil content.

The selection for castor varieties with higher oil content will be more efficient if the breeders measure the kernel oil content instead of the seed oil content. This advantage was demonstrated in the study by Peng et al. (2024) that estimated a heritability of 18.93% for the kernel oil content (which was called "crude fatty content of dehusked seed") compared with the heritability of 12.46% for the seed oil content. In other study, Chen et al. (2016a), (2018) selected castor genotypes with superior seed oil content using recurrent selection in single seeds. After three cycles of selection, the seed oil content increased from 50.33% to 54.47%. As a trade-off, the mean seed weight increased from 440 to 540 mg in the high-oil genotypes (the kernel content was not presented). Association of castor seed weight with seed oil content has been reported in several studies (Huang et al., 2015b; Velasco et al., 2015), but the discussion based on kernel percentage and kernel oil content could clarify which factor is causing the variation in seed oil content and help faster progress in castor breeding programs. As another example, Han et al. (2025) developed a tetraploid castor plant in which the seed oil content was increased from 51.24% to 55.63%, but the components were not broke down to provide more specific observations on what changed in the tetraploid plant. Sunflower (*Helianthus annuus* L.) is a case in which most of the seed oil content increase obtained through genetic improvement was explained by improving the kernel percentage rather than increasing kernel oil content (Dedio, 1982; Pereira et al., 2000).

The analysis of the components can also clarify to what extent the seed oil content can be increased by focusing on the kernel oil content. In a previous study with 40 castor genotypes, the outstanding variety reached a seed oil content of 56.6% associated with a kernel oil content of 73.9% (Severino et al., 2015). The extremely high oil content in the kernel raises concerns that it is approaching the biological limit for storing oil in the endosperm, as this tissue requires other structures to remain functional (cell wall, protein, nutrients etc), and one cannot aim to reach near 100% of kernel oil content. Therefore, further increments in seed oil content must consider increasing the kernel percentage (Severino et al., 2009).

For trading purposes between farmers and industry, the measurement of the two components clarifies the procedures required for a better seed quality. A low kernel percentage is frequently related to poor cleaning procedures during harvest (Severino et al., 2025), while a low kernel oil content can be related to genetic potential of the variety, to poor crop management, and to unsuitable growing conditions. In the study by Severino and Auld (2013a), the increased seed yield provided by irrigation was explained mostly by adjustments in the number of racemes (71%) and in the number of seeds per raceme (20%), while there was low adjustment in the seed weight (8%), and the lowest adjustment was in the seed oil content (1%). Further studies should clarify to what extent the kernel oil content can be influenced by agronomic practices such as irrigation and fertilization.

The contrast between the measurements for comparison of genotypes and for analysis inside the same genotype demonstrates the importance of breaking down the components of seed oil content. When the comparison occurred among genotypes, the sources of variability combined genetic factors (e.g., seed coat thickness and potential kernel oil content) and environmental factors (e.g. suitable conditions during seed filling and rigor of the seed cleaning procedures). When the comparison was made among seeds from the same genotype, the sources of variability were related to the seed cleaning process and to the natural variation of the seed filling degree. The present study was made with samples free of contaminants, and only the influence of seed filling (or the rate of empty seeds) was measured.

The kernel percentage could be considered a proxy to the seed oil content because it explains a large portion of the variability in the target variable. The kernel percentage explains the variability caused by many factors such as the presence of contaminants, fruit husks, empty or partially filled seeds, and seed coat thickness. The laboratorial analysis of seed oil content requires specific equipment or chemicals, and it is time and labor consuming, while the kernel percentage can be measured with just a scale.

5. Conclusions

When the components of seed oil content were employed to compare genotypes, the kernel percentage and the kernel oil content were independent, and they are useful to clarify what factors influenced the oil content in castor seeds. When the comparison was made between classes of seed in the same genotype, the two components were highly correlated, and any of the components could explain the changes in the oil content.

CRediT authorship contribution statement

Beatriz L. Oliveira: Visualization, Investigation. **Maria E.C. Esquibel:** Visualization, Investigation. **Andressa S. Rocha:** Visualization, Investigation. **Liv S. Severino:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.indcrop.2026.123704.

Data availability

Research Link Provided

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