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Oil extraction and cake bromatological properties of crambe (*Crambe abyssinica*) are affected by extraction at different temperatures and rotation speeds

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Abstract

Temperature and rotation speed are operational parameters that influence oil screw press efficiency. The objective of this study was to evaluate the oil physicochemical properties, cake bromatological properties, and oil extraction yield from crambe (*Crambe abyssinica* Hochst) seeds by mechanical pressing at different temperatures and rotation speeds in a mechanical extruder. A 4 × 5 factorial experimental design was employed to determine the effects of these parameters. The experimental design incorporated four temperature ranges (110–120, 120–130, 130–140, and 140–150°C) and five screw rotation speeds (1000, 1200, 1400, 1600, and 1800 rotations per minute, RPM), with four repetitions. The physicochemical properties of the oil and crambe cake, and the cake bromatological properties were affected by extraction at different temperatures and extruder rotation speeds. The oil density and viscosity (quality parameters), and the crambe cake bromatological factors, crude fiber, ash, lipid, and moisture content were found to be higher at extraction temperatures in the 140–150°C range. The maximum oil yield was achieved by extraction at a temperature of 140–150°C and a rotation speed of 1800 RPM. The protein and carbohydrate content of the crambe cake decreased with increasing temperature and rotation speed. The oil yield increased by 56% as temperatures increased from the 110–120°C range to the 140–150°C range, and by 41% when the rotation speed increased from 1000 to 1800 RPM. The screw configuration influenced the crambe and cake properties. These results can be used to determine the appropriate configuration of the screw.

Keywords: *Crambe abyssinica* Hoechst; Oil extraction; Screw press; Biodiesel.
Abbreviations: RPM_ rotations per minute.

Introduction

Vegetable oils constitute a valuable class of biological resources, with applications in food and non-food industries; their production has been steadily increasing over the last twenty years (Uitterhaegen and Evon, 2017). Growing concerns regarding climate change and pollution have aroused interest in the use of non-food oils for the production of biofuel, owing to their cleaner burning and renewable nature (Leite et al., 2019; Costa, Almeida et al., 2019; Bhuiya et al., 2020). Crambe (*Crambe abyssinica* Hochst) seeds contain 35–45% oil, and up to 55–60% of this oil is composed of erucic acid, which is unsuitable for human consumption, but its demand is high in industries, including the manufacture of oils, lubricants, plastics, and biodiesel (Bassegio et al., 2016; Silveira et al., 2017; Costa et al., 2019).
Mechanical extraction is the most often used method for the removal of oil from oilseeds (Sriti et al., 2011; Sriti et al., 2012; Kartika et al., 2010; Bhuiya et al., 2020). This method is highly effective and can be performed in a single step in a continuous mode (Evon et al., 2014; Evon et al., 2015). Mechanical pressing provides a simple means of processing (Singh et al., 2002).

The main parameters that influence the performance of a continuous press are the rotation speed, pressure applied to the discharge area and presses with modular screws, and screw configuration (Savoire et al., 2013). The rotation speed during continuous pressing corresponds to the speed at which the piston compresses seeds in a hydraulic press (Savoire et al., 2013). Depending on the type of oilseed used, an increase in thread rotation speed can increase (Akinoso et al., 2009) or decrease (Evangelista, 2009) the oil yield. Kartika et al. (2006) observed an increase in the yield of sunflower oil with increasing barrel temperature and rotation speed.
Temperature influences press performance in various ways (Savoire et al., 2013). High processing temperatures may significantly increase the deformability and mobility of the cellular structure of the oilseed (Bouvier and Campanella, 2014), which can increase the extraction efficiency (Karaj and Müller, 2011). Increases in press efficiency and output with concomitant heating are usually accompanied by a decrease in oil quality (Savoire et al., 2013).
Interactive effects of temperature and rotation speed on the physicochemical properties of crambe oil have not been reported in other studies. Screw pressing has been studied

for a large variety of oilseeds, including linseed, canola, crambe, and chia (Savoire et al., 2013). In addition to the operational parameters, the characteristics of the raw material also affect the screw press performance. Studies have demonstrated that factors contributing to increased pressure and temperature in the screw barrel have a major positive influence on the oil yield (Rombaut et al., 2015). However, even if the temperature increases the oil yield and press capacity, this is usually accompanied by a decrease in oil quality (Savoire et al., 2013). These factors can be modulated by optimizing the diameter of the restriction die located at the meal discharge, and by modulating the screw rotation speed (lower speeds and smaller restriction openings increase yield) (Savoire et al., 2013). Jing and Chi (2013) observed that extrusion temperature (115°C) and rotation speed (180 RPM) had a positive impact on the dietary fiber content of soybean meal. At present, there is no information in the literature regarding the effects of temperature and rotation speed on the nutritional value and chemical composition of the crambe cake. Information regarding the chemical composition and nutritional value of the cardoon press cake for ruminant nutrition is scarce and outdated. Byproducts generated during biodiesel production deserve investigation because many production chains will only be economically viable when these residues add value to the production systems (Souza et al., 2009). In addition, without a destination, the high volume of coproducts and byproducts may pose a problem due to their accumulation in the environment (Mendonça et al., 2015).

Crambe cake with high lipid content can have a deleterious effect on dietary assimilation of some nutrients (NRC, 2007), but can be a beneficial environmental factor because it can help mitigate enteric methane (Abdalla et al., 2008). The crambe seed coats are rich in lignified fiber, which remains in the cake after oil extraction. This high lignified-fiber content can reduce its usefulness in lamb feed (Canova et al., 2012).

In the present study, we hypothesized that processing conditions would influence important properties of the extracted oil as well as the crambe cake. The objective of this study was to evaluate (i) the physicochemical properties of the oil, (ii) the bromatological properties of the cake, and (iii) the yield of oil extracted by mechanically pressing seeds at different temperatures and rotation speeds in a mechanical extruder.

Results

Physicochemical properties of the crambe oil

The specific mass of the crambe oil was affected by the press temperature during extraction ($P < 0.05$; Table 1). A linear increase was observed in the specific mass of crambe oil from (0.8260 to 0.8433 g cm^{-3}) when the temperature range during extraction increased from 110–120°C to 140–150°C (Figure 2). The specific mass of crambe oil was not affected by the rotation speed ($P = 0.1747$; Table 1).

The viscosity of the crambe oil increased significantly ($P < 0.05$; Table 1) from 49.72 to 50.98 mm^2 s^{-1} as the temperature increased from 110–120°C to 140–150°C during extraction (Figure 3A). Increasing the rotation speed from 1000 to 1800 RPM increased the viscosity if the oil from 49.52 to 50.63 mm^2 s^{-1} (Figure 3B).

The temperature × RPM interaction significantly affected ($P < 0.01$; Table 1) the crambe oil yield (Figure 4), which increased with increasing temperature or RPM (Table 2; Figure 4A). At 1600 and 1800 RPM, the yield of oil was similar, regardless of the extraction temperature (Table 2). Extraction at 1600 and 1800 RPM resulted in higher oil yields compared with that at 1100 and 1200 RPM. At high temperatures (140–150°C), oil extraction at RPMs of 1400, 1600, and 1800 resulted in yields of 17.37%, 18.5%, and 19.5%, respectively. These values are statistically equal, and higher than the yield for extractions at 1000 or 1200 RPM, which provided yields of 13.75% and 15.12%, respectively (Table 2; Figure 4A and B).

Bromatological properties of crambe cake

The interaction of temperature × RPM significantly affected ($P < 0.05$; Table 1) the carbohydrate content of the crambe cake (Figure 5). Increasing temperatures and RPM decreased the carbohydrate content of the crambe cake (Table 2; Figure 5A). At high temperatures (140–150°C), oil extraction at 1600 and 1800 RPM resulted in lower carbohydrate content (41.02% and 40.85%, respectively; Table 2; Figure 5A and B).

The crude fiber content of the crambe cake was also influenced by temperature and RPM ($P < 0.05$; Table 1; Figure 6), significantly increasing from 3.30% to 4.41% with an increase in extraction temperature from 110–120°C to 140–150°C (Figure 6A). Increasing the rotation speed from 1000 to 1800 RPM also increased crude fiber from 3.79% to 4.07% (Figure 6B).

Crambe cake protein content was affected by temperature and RPM ($P < 0.05$; Table 1; Figure 6). Protein content significantly decreased from 26.55% to 24.55% with an increase in extraction temperature range from 110–120°C to 140–150°C (Figure 6C). Increasing the rotation speed from 1000 to 1800 RPM decreased protein levels from 25.57% to 25.14% (Figure 6D).

The lipid content of the crambe cake was influenced by temperature and RPM ($P < 0.05$; Table 1; Figure 6). Lipid levels significantly increased from 18.15% to 18.71% with an increase in extraction temperature from 110–120°C to 140–150°C (Figure 6E). Increasing the rotation speed from 1000 to 1800 RPM increased the crude fiber levels from 18.32% to 18.47% (Figure 6F).

The crambe cake ash content was also affected by temperature and RPM ($P < 0.05$; Table 1; Figure 7). The ash content of the crambe cake significantly increased from 6.41% to 7.49% with an increase in extraction temperature from 110–120°C to 140–150°C (Figure 7A). Increasing RPM from 1000 to 1800 increased the crambe cake ash content from 6.84% to 7.09% (Figure 7B).

The moisture content of the crambe cake was affected by temperature and RPM ($P < 0.05$; Table 1; Figure 7); it significantly increased from 4.41% to 6.16% with an increase in extraction temperature from 110–120°C to 140–150°C (Figure 7C). Increasing RPM from 1000 to 1800 increased the moisture content of the crambe cake from 5.11% to 5.58% (Figure 7D).

Discussion

Operating conditions (rotation speed and pressing temperature) exerted an important influence on both the yield and quality of the expressed oil. The specific mass of crambe oil was sensitive to variation due to treatment conditions, increasing with increasing temperature (Figure 3). Evon et al. (2013) also observed a small variation of 0.910 to 0.917 g m^{-3} in the specific mass of *Jatropha curcas* oil in response to temperature changes. Sriti et al. (2012) observed

Table 1. Physico-chemical and bromatological properties of oil on different temperatures and RPM in the extraction of crambe oil.

Sources of variation	Specific mass	Viscosity	Oil yield	Carbohydrates	Protein	Lipids	Crude fiber	Ash	Cake moisture
	g cm^{-3}	mm^2 s^{-1} 40°C	———	———	——— %	———	———		
Temperature (ºC)									
110 – 120	0.8260 c	49.72 b	10.7 a	43.41	26.45 d	18.15 d	3.30 d	6.41 d	4.41 d
120 – 130	0.8334 b	50.02 b	13.0 b	43.04	25.56 c	18.29 c	3.84 c	6.70 c	5.22 c
130 – 140	0.8338 b	50.04 b	15.1 c	42.49	24.89 b	18.46 b	4.23 b	7.22 b	5.62 b
140 – 150	0.8433 a	50.98 a	16.8 d	41.38	24.55 a	18.71 a	4.41 a	7.49 a	6.16 a
RPM (min^{-1})									
1000	0.8320	49.52 c	11.4 d	42.90	25.57 c	18.32 b	3.79 c	6.84 c	5.11 d
1200	0.8341	50.07 b	12.9 c	42.77	25.48 bc	18.37 ab	3.86 bc	6.90 bc	5.25 cd
1400	0.8343	50.30 ab	14.3 b	42.64	25.40 ab	18.39 ab	4.00 ab	6.96 b	5.36 bc
1600	0.8347	50.43ab	15.2 a	42.34	25.24 a	18.44 a	4.02 ab	6.98 b	5.46 ab
1800	0.8349	50.63 a	15.7 a	42.23	25.14 a	18.47 a	4.07 a	7.09 a	5.58 a
ANOVA	———	———	P-value	———	———				
Temperature (A)	<0.000	<0.000	<0.000	<0.000	<0.000	0.0021	<0.000	<0.000	<0.000
RPM (B)	0.1747	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
A × B	0.4908	<0.056	0.010	<0.000	0.4202	0.7305	0.9151	0.2036	0.4218

Means followed by the same letters in the column do not differ according to the Tukey test at 5% significance. P values less than 0.05 were considered statistically significant.

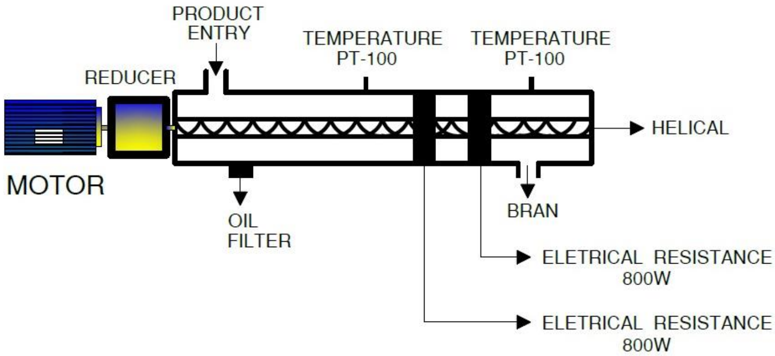

Fig 1. Schematic of extruder used in the experiment showing the main components.

Table 2. Unfolding the interaction temperature × RPM for oil yield and carbohydrates.

RPM (min^{-1})	Temperature (ºC) 110 – 120	120 – 130	130 – 140	140 – 150
	Oil yield (%)			
1000	8.37 dC	11.50 bB	12.12 cB	13.75 cA
1200	9.87 cdC	12.50 bB	14.37 bA	15.12 cA
1400	10.87 bcC	13.00 abB	16.12 aA	17.37 bA
1600	12.00 abD	14.12 aC	16.37 aB	18.50 abA
1800	12.75 aC	14.25 aC	16.50 aB	19.50 aA
	Carbohydrate (%)			
1000	43.75 aA	43.17 aB	42.77 aC	41.92 aD
1200	43.55 abA	43.25 aB	42.65 aC	41.72 aD
1400	43.25 bcA	43.15 aB	42.57 aC	41.42 bD
1600	43.22 cdA	42.82 bB	42.30 bC	41.02 cD
1800	43.12 dA	42.80 bB	42.17 bC	40.85 cD

Values followed by a different lowercase letter are significant difference between RPM under same temperature. Values followed by a different capital letter are significant difference among temperatures under same RPM (Tukey test, P <0.05).

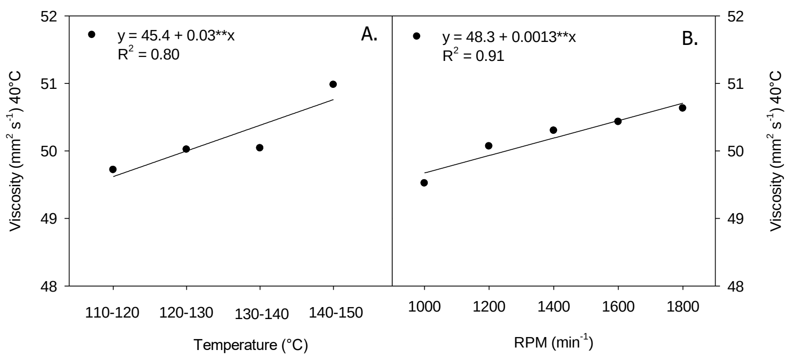

Fig 3. Viscosity at 40°C on different temperatures (A) and RPM (B) in the extraction of crambe oil. ** Significant at $P < 0.01$ probability (n=4).

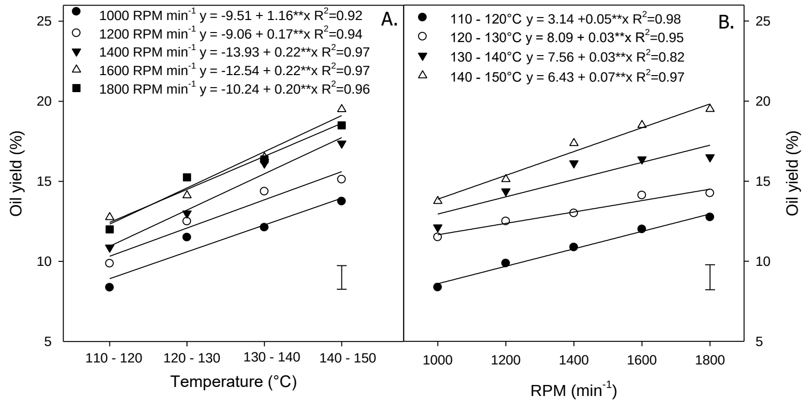

Fig 4. Interaction between temperatures (A) and RPM (B) for oil yield in the extraction of crambe oil. ** Significant at *p* < 0.01 probability. Bars indicate least significant difference (LSD) by Tukey test at *P* < 0.05 probability (n=4).

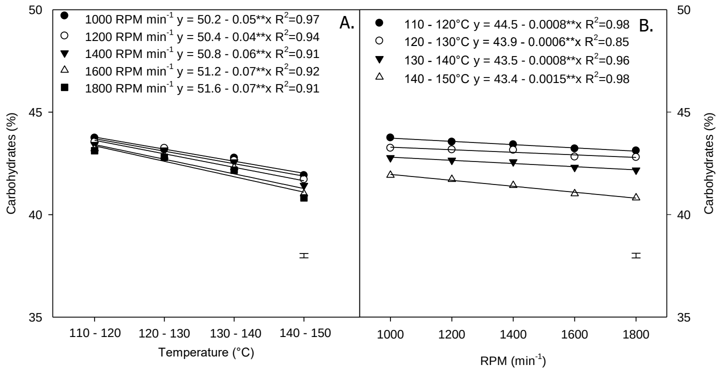

Fig 5. Interaction between temperatures (A) and RPM (B) for oil carbohydrates in the extraction of crambe oil. ** Significant at *P* < 0.01 probability. Bars indicate least significant difference (LSD) by Tukey test at *P* < 0.05 probability (n=4).

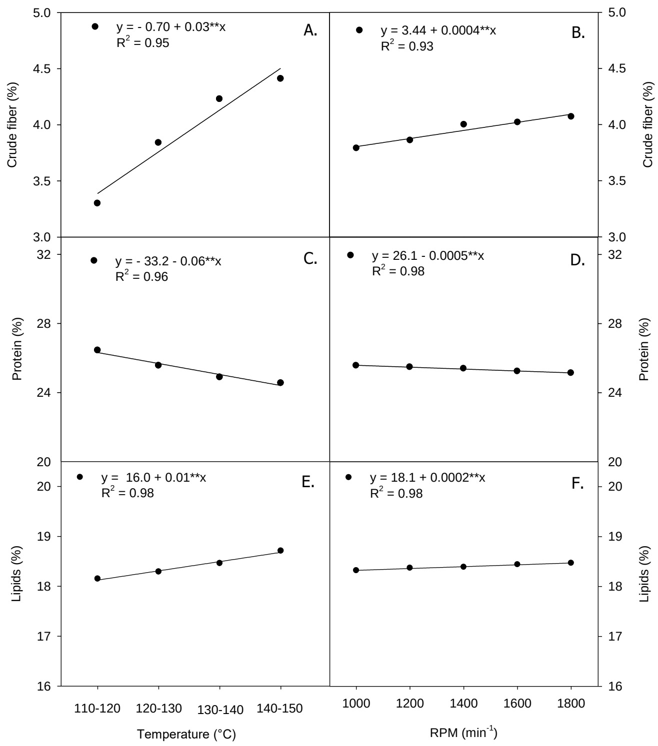

Fig 6. Crude fiber (A and B), protein (C and D) and lipids (E and F) on different temperatures and RPM in the extraction of crambe oil. ** Significant at *P* < 0.01 probability (n=4).

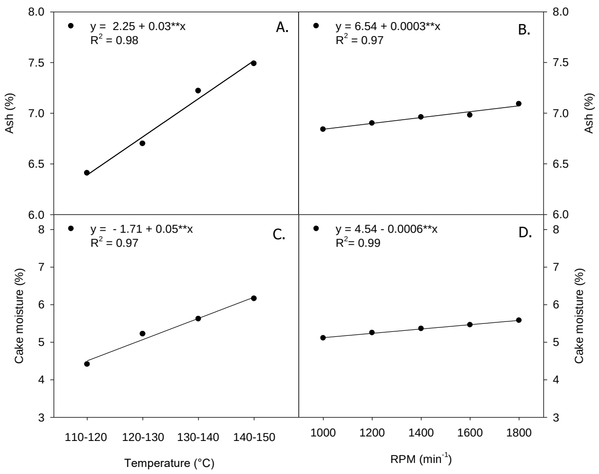

Fig 7. Ash (A and B) and cake moisture (C and D) on different temperatures and RPM in the extraction of crambe oil. ** Significant at $P < 0.01$ probability (n=4).

observed no effects on *Coriandrum sativum* oil quality with different press configurations.

The viscosity of crambe oil increased as a function of increasing temperature (Figure 4A). Pressing temperature impacts several different aspects of the output of pressing through extrusion. Increasing temperature leads to a decrease in oil viscosity and coagulation of the seeds' protein fraction, thereby increasing the capacity of the press to express the oil, thereby facilitating its release through the fibrous matrix (Dufaure et al., 1999).

Our results show that increasing the temperature favors efficient extraction of crambe oil. The crambe oil yield increased by 56% as the temperature increased from 110–120°C to 140–150°C (Figure 4A). While increasing temperature may facilitate extraction, it can distort lipoproteins, favoring the coalescence of fat globules and their subsequent exit from the plant cell (Wiesenborn et al., 2002).

High processing temperatures may approach the glass transition temperature of the cake material, causing a significant increase in the deformability and mobility of the cellular structure. This in turn leads to greater oil extraction (Bouvier and Campanella, 2014). The positive impact of high temperatures has been observed in the pressing of sunflower seeds, where an oil extraction efficiency of 66% was obtained at 80°C, whereas 70% was obtained at 120°C (Dufaure et al., 1999). Although heating may increase the press performance and oil yield, this is usually accompanied by a decrease in oil quality (Savoire et al., 2013). Increasing the extraction temperature increased the viscosity of the crambe oil. Several problems are associated with the use of vegetable oils as fuel in compression ignition engines, mainly stemming from their high viscosity. The high viscosity of these oils is due to the large molecular mass and chemical structure of vegetable oils, which can hamper effective pumping, combustion, and atomization in diesel engine injection systems (Pramanik, 2003). The viscosity of biodiesel made from crambe oil can be reduced to acceptable levels by mixing it with another type of biodiesel or producing biodiesel from a mixture of less viscous oils (Costa et al., 2018).

In the mechanical pressing of *J. curcas* oil through a double-screw extruder, Evon et al. (2013) observed yields of 56%, 41%, and 46% at temperatures of 80, 100, and 120°C, respectively, indicating generally reduced yields above a threshold of 80°C. Kartika et al. (2005) observed increases in the yield of sunflower oil as the barrel temperature and speed of rotation increased. At a screw rotation speed of 150 RPM, increasing the pressing temperature from 80 to 120°C did not improve the efficiency of oil extraction from *J. curcas* (Evon et al., 2013).

The oil yield increased by 38% when the RPM was increased from 1000 to 1800 RPM (Figure 4B). Generally, the speed of the bolt rotation affects the yield of oil. Increasing the speed of rotation of the screw increases the filling of the thread, and the pressing time in the pressing zone is increased (Kartika et al., 2010).

Bromatological properties of crambe cake

There is little information in the literature regarding the nutritional value of mechanically extruded crambe cake, indicating that this type of cake has not been intensively studied in animal nutrition research. The bromatological properties of crambe cake were influenced by extraction at different temperatures and rotation speeds (Figure 5, 6, and 7). The extrusion process is economically viable, and it is of fundamental importance that byproducts of extraction, such as the cake, have industrial applications (Uitterhaegen et al., 2015). Crambe cake in small quantities can be used in animal feed to partially replace protein from soybean meal. The use of crambe cake in animal feed is an important strategy for the allocation of crambe remains, with the potential to add value to farming and promote sustainability of the production chain (Bassegio et al., 2016). Seneviratne et al. (2011) observed how screw speed and heat interacted to affect the properties pressed canola cake. Temperature is one factor that modulates the effectiveness of the extrusion process. The dietary fiber content of soybeans increases with increasing extrusion temperature up to 110°C (Jing and Chi, 2013). Increasing temperature can also increase food degradation, thereby increasing crude fiber content (Menezes et al., 2012).

The crambe cake lipid content increased slightly with temperature and RPM (Figure 7E and F). High temperatures induce greater oil fluidity, break the walls of additional fat cells, and promote coagulation of the protein fraction. Lipid droplets are easily released through the fibrous matrix toward the surface of the material, which increases the content of residual oil in the cake flour due to a reduction in seed plasticity (Wiesenborn et al., 2001; Kartika et al., 2005). The lipid content values ranged from 18.15% to 18.47%, close to the 18.40% determined by Carrera et al. (2012) for crambe cake.

Protein content ranged from 24.55% to 25.56% (Figure 7C and D), similar to the value of 24.2% observed by Mendonça et al. (2015) for crambe cake. These values are relatively high, allowing these cakes to be classified as potential protein foods in animal diets (Abdalla et al., 2008). However, before incorporating these coproducts into a food source, studies on toxicity and anti-nutritional factors are necessary to ensure their safety (Souza et al., 2009). The protein content of the crambe cake decreased with increasing temperature and rotation speed. In addition, the protein yield decreased when the extraction temperature was higher than 77°C. According to Selling et al. (2013), it is reasonable for protein content to change with temperature, as proteins are sensitive to heat denaturation. Temperature may also affect the secondary and tertiary structure of proteins (Selling et al., 2007). Toghyani et al. (2015) observed that at high conditioning temperatures, the additional heat generated during the expulsion process at high screw torque resulted in lower digestibility. This was likely due to protein denaturation. At low or medium conditioning temperatures, the mechanical shear force under high screw torque improved the digestibility. This was likely caused by the release of encapsulated protein bodies from cell wall matrices.

Materials and methods

Characterization of the experimental area and raw material

The present study was conducted in the laboratory of the Center for the Development of Technological Diffusion of the Renewable Energy Laboratory of Unioeste (CDTER), in partnership with the Foundation for Scientific and Technological Development (FUNDETEC), Cascavel – PR, Brazil. Crambe seeds (cv. Brilhante) were supplied by the Agronomy Institute of Paraná, Brazil (IAPAR).

Automated mechanical extruders

Studies were performed with a mechanical extruder (Z-1500 Galvão Insumos Inputs, Iracema do Oeste, Brazil), wired to accept 220 V ac, with a 0.5 CV engine for feed grains, and a 7.5 CV SEW main engine (Figure 1). Extrusion procedures were performed using the latest automation technology 4.0, with a PLC S7–1200 CPU1215C, an Hmi Touch KTP900, and two inverters (model G120C), all manufactured by Siemens.

All equipment was operated using the Profinet network "Internet" This protocol allows rapid communication of commands between extruder hardware and other external hardware as needed. To measure the temperature, type PT100 sensors, model FSB–RTD–BRA–T60–U23–B03–C15–BF Novus, with a scale of –100°C to +400°C, were used to convert the electrical signal from EN100 to 4–20 m. A TxBlock (Novus) signal transducer was used.

Variation in spindle motor rotation speed (in RPM) during oil extraction was made possible by installing a Siemens model G120C frequency inverter. To control and adjust the rotation speed and temperature during an experiment, we installed a human machine interface in the equipment.

Rotation and temperature

A 4 × 5 factorial experimental design was employed to determine the effects of temperature and rotation speed in the crambe extruder. The experimental design incorporated four temperature ranges (110–120, 120–130, 130–140, and 140–150°C) and five rotation speeds (1000, 1200, 1400, 1600, and 1800 RPM), with four repetitions.

Physical and chemical analysis methods

Oil yield

After pressing, the oil was left to settle for five days, then the residue was decanted, and the oil was filtered on paper. Yield was determined by calculating the ratio between the mass of seeds that entered the process and the mass of oil obtained after filtration (Instituto Adolfo Lutz, 2008).

Specific mass

One kilogram of crambe seeds was weighed into a 1000 ± 10 mL beaker and vibrated in a Bertel Shaker for 5 s. After this operation, the volume and density (kg m^{-3}) were determined (Instituto Adolfo Lutz, 2008).

Viscosity

A Brookfield viscometer (LVDV–III+ model) was coupled to a thermostatic bath, allowing measurement of oil viscosity in the range of 40°C, with a temperature measuring accuracy of 0.5°C (Instituto Adolfo Lutz, 2008).

Bromatological analysis

Crude fiber

Extraction was performed in a Soxhlet device with 2 g of sample. Petroleum ether was used as the solvent. The extract was filtered and heated in an oven, followed by weighing and repetitive heating and cooling until the weight became constant (Instituto Adolfo Lutz, 2008).

Lipids

Samples (2–5 g) were weighed on a filter paper and set using pre-degreased wire wool. The temperature was held constant throughout an 8 (4–5 drops per s) or 16 h (2–3 drops per s) extraction period. Extracts were then placed in a desiccator at ambient temperature (Instituto Adolfo Lutz, 2008).

Protein

Organic matter was decomposed, and the nitrogen content was transformed into ammonia. As the nitrogen content of protein is approximately 16%, an empirical factor of 6.25 was used to transform g of nitrogen in an extract into g of protein (Instituto Adolfo Lutz, 2008).

Carbohydrates

A 5 g sample was repeatedly weighed in a porcelain container, then the degreased material was mixed with 100 mL of 70% alcohol and transferred to a 500 mL Erlenmeyer flask. This mixture was agitated for 1 h, centrifuged, and the residue was cooled using water. Sodium hydroxide and hydrochloric acid were heated in an autoclave. Reduced sugars in the resulting solutions were quantitated by titration using method 038/IV (Instituto Adolfo Lutz, 2008).

Ash
We performed a procedure circulated by the Adolfo Lutz Institute (2008), which involved weighing 5–10 g of sample in a pre-heated capsule, then drying in an oven until the ashes were white or slightly gray (Instituto Adolfo Lutz, 2008).

Cake moisture
The weighing plate and cover were first weighed using an analytical balance. Approximately 5 g of crambe seed sample was placed on the weighing plate. The plate was closed and weighed on a precision scale to within 1 mg. The plate and cover (with the cover removed) were then placed in an oven with an airflow and intake of air (model MA 035–MARCONI) previously maintained at 105 ± 2°C for 3 h (Instituto Adolfo Lutz, 2008).

Statistical analyses
Data were evaluated using ANOVA in a 4 × 5 factorial scheme. Temperatures and rotation speeds were adjusted by regression to 5% ($P < 0.05$) probabilities, and means were compared using the Tukey test. Differences were considered statistically significant at 5% ($P < 0.05$), using the statistical software Sisvar® (Statistical Analysis Software, UFLa, Lavras, MG, Brasil).

Conclusion

The screw configuration and operating conditions exerted prominent effects on the yield and quality of oil extracted during the extrusion of crambe. The quality parameters of oil density and viscosity, and the bromatological properties of crude fiber, lipid, ash, and moisture content of crambe cake increased with increasing temperature. The oil yield also increased with increasing temperature and rotation speed. Protein and carbohydrate levels in the crambe cake decreased with increasing temperature and rotation speed. These results can be used to improve mechanical pressing of crambe seeds and indicate the most appropriate screw configuration.

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