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Cold Hydraulic Extraction Optimization and Characterization of Balanites aegyptiaca and Ceiba pentandra Seed Oils

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ABSTRACT

Non-edible vegetable oils have a huge potential for many industrial applications. Most of them are expressed by mechanical pressing, but data on the different operating conditions to achieve optimal extraction yields and high-quality oil are scarce. Hence, the objective of this study was to optimize key hydraulic extraction parameters at ambient temperature (25 °C) of *Balanites aegyptiaca* and *Ceiba pentandra* oils by increasing the oil recovery. Optimal holding time, applied pressure, compression speed, and press cage charge were determined for whole and crushed oleaginous material. The results indicate that the *B.aegyptiaca* kernels and *C.pentandra* seeds contained 2.7 and 5.7% moisture, as well as 46.3 and 26.2% fat, respectively. Under the optimal operating conditions, the oil recovery (wt.%. d.b.) from whole (crushed) material was 73.4 (69.8) *B.aegyptiaca* kernels and 38.2 (41.2) *C.pentandra* seeds. The extracted oils have a high content of unsaturated fatty acids including of about 74 wt.% for *B. aegyptiaca* and 69 wt.% for *C.pentandra*. They were particularly rich in linoleic ω-6 acid, 45.32 and 38.77 wt.%, respectively. The chemical characteristics of cold-extracted *B. aegyptiaca* and *C.pentandra* oils were 10 and 20 ppm phosphorus, 2.8 and 3.5 ppm iron, 0.0 ppm copper, 0.06 and 0.1% water-volatile matter, respectively. These valuable material properties make the *B.aegyptiaca* and *C.pentandra* oils an ecological and renewable resource for multipurpose applications.

Keywords: *B.aegyptiaca* and *C.pentandra* oils, cold hydraulic extraction, process optimization, oil recovery, oil characteristics

1. Introduction

Vegetable oils are a complex source of valuable components such as essential fatty acids, vitamins, microelements, active phenolic and flavor compounds (Zhou et al., 2020). Due to their rich chemical composition, vegetable oils are a multifunctional and multipurpose green material utilized in food and cosmetic industries, coatings, inks, lubricants, resins, agrochemicals, plasticizers, and biofuels (Gan & Jiang, 2014; Nitièma-Yefanova et al., 2016). Moreover, vegetable oils are an excellent renewable and biodegradable bioresource to replace costly and environmentally unsafe chemical feedstock of fossil origin on a sustainable basis (Atabani et al., 2013; Yusuf, 2018).

Oil extracted from non-edible crops is an alternative raw material to overcome food versus fuel barriers. (Abdul Hakim Shaah et al., 2021). Furthermore, certain non-edible oilseeds have a higher oil content compared to that in the edible oil crops. For example, oil contents in desert date (*B.aegyptiaca*) seed kernels (39–46,7 wt%) (Chapagain et al., 2009) and kapok (*C.pentandra*) seeds (22–32 wt%) (Rashid et al., 2014; Montcho et al., 2018) are more significant than in those of soybean (18-24 wt%), corn (4-5 wt%), and cotton (15-40 wt%) (Zhou et al., 2020).

Conventional techniques for oil extracting from plant material are solvent extraction and mechanical expression using hydraulic and screw-presses. The solvent extraction method is known to be a highly effective method and is commonly applied to oilseeds with low oil content (< 20%) (Yusuf, 2018). However, the use of organic solvents (*n*-hexane, petroleum ether, chloroform, methanol) poses health, safety, and environmental issues due to their toxicity, volatility, and poor product quality caused by high processing temperatures (Yusuf, 2018; Mwaurah et al., 2019; Nde & Foncha, 2020).

Mechanical pressing is the most common process used especially at small and medium scale of oil production, it needs a lower initial investment cost and does not require highly trained technicians to operate the machines (Baldini et al., 2014). Mechanical extraction includes the production of good quality oil, the possibility of using the press cake, the low energy requirements, and the non-use of hazardous chemicals compared to solvent extraction (Nde & Foncha, 2020; Baldini et al., 2014). Moreover, the cold-pressed oil (extraction temperature below 50 °C) preserves the natural properties and valuable components like phytosterols and tocopherols and has high oxidative stability compared to hot-extracted oil (Yusuf, 2018; Al Juhaimi et al., 2018).

Although mechanical pressing is well known to produce high-quality vegetable oil from the edible oleaginous crops (sunflower, canola, soybean, palm, etc.), it is still a suboptimal process for most of the non-conventional oilseeds such as desert date, kapok, karanja, jojoba, etc. (Nde & Foncha, 2020; Karaj & Müller, 2011). The use of inappropriate processing parameters may lead to low pressing yield and high-energy consumption (Mwithiga & Moriasi, 2007; Acheheb et al., 2012; Santoso et al., 2014; Huang et al., 2019). Hence, the optimization of mechanical oil extraction for various non-conventional oilseeds should be conducted to provide the best operating parameters and to enhance the efficiency of the process. Therefore, the present study aims to optimize cold hydraulic extraction parameters such as holding time, applied pressure, compression speed, and press cage charge for the non-conventional oils of *B.aegyptiaca* and C*.pentandra* by increasing the efficiency of oil recovery.

2. Materials and Methods

2.1. Plant materials and chemicals

Plant materials used in this study was composed of mature seeds from two arid land oleaginous species (*B.aegyptiaca* and *C.pentandra*) widely represented in the West Africa area. Plant samples were collected from different regions of Burkina Faso: Nouna for *B.aegyptiaca* and Ouagadougou for *C.pentandra*. Seeds were cleaned by winnowing and sorted to remove impurities. Further, the seeds were sundried for two weeks to reduce the moisture content and avoid mold growth. The final moisture content was determined using the standard oven method at 105 °C for 24 h. After drying, the *B.aegyptiaca* seeds were decorticated, while *C.pentandra* seeds were kept unshelled. Indeed, the seeds of *B.aegyptiaca* have relatively hard shells which make pressing difficult. The plant material shown in **Figure 1** was packed in plastic bags and kept from moisture and light at room temperature before the pressing tests.

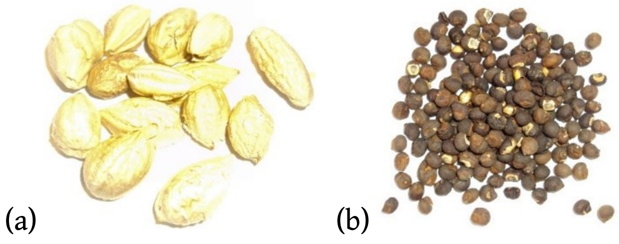
(a) (b)

Fig. 1. Plant materials: (a) *B.aegyptiaca* kernels and (b) *C.pentandra* seeds

The fat content of *B.aegyptiaca* kernels and *C.pentandra* seeds were determined from the powder (≤1 mm) of oleaginous material by using n-hexane (HPLC grade) and Soxhlet extractor at 60 °C following ISO 659:1998(F) modified method (micro-grinding and two steps extraction for eight hours full time). All chemicals used in this study were of analytical reagent (AR) grade.

2.2. Hydraulic pressing

Hydraulic pressing device (**Figure 2**) and procedure were used according to those described by Nitiema-Yefanova (Nitièma-Yefanova et al., 2022). Mechanical oil extraction was carried out using a laboratory hydraulic press (CARVER-3889CE, Wabash, Indiana, USA).

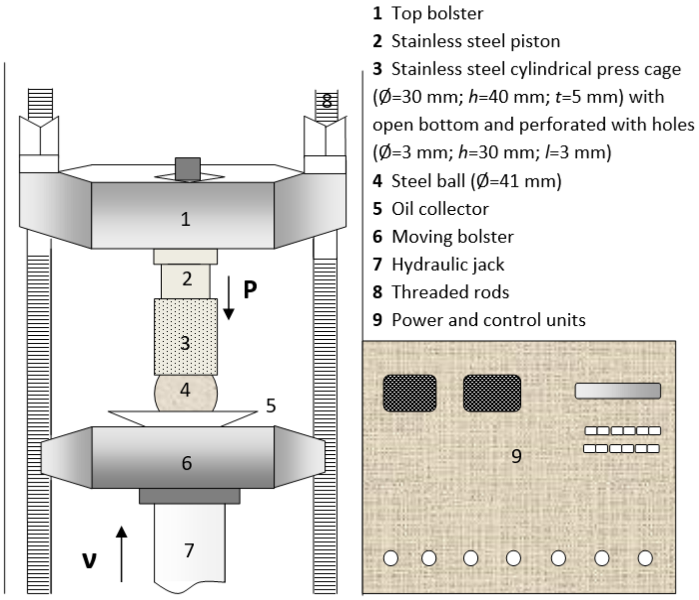

Fig. 2. Schematic representation of the hydraulic pressing setup [3]

Variables for cold press extraction were applied pressure, holding time, compression speed, and press cage charge. The optimal processing parameters were established based on the best oil recovery obtained for the different variables for whole and crushed (≤4 mm) oleaginous material processed at 25 °C. The oil recovery was evaluated as follows (**Equation 1**) (Mat Yusoff et al., 2017):

$$Oil\ recovery\ (\%) = \frac{Mass\ of\ oil\ extracted\ from\ a\ given\ mass\ of\ seeds\ or\ kernels\ (g) \times 100}{Mass\ of\ oil\ contained\ in\ the\ seeds\ or\ kernels\ initially\ taken\ (g)} \quad \textbf{(1)}$$

Table 1 presents the starting operational parameters of hydraulic pressing of oilseeds used in this study. Firstly, a reference setpoint pressure obtained from the literature was used to determine the optimal holding time determined. The pressure holding time is the interval between the end of compression and the start of the decompression (Zhang et al., 2011). The optimal holding time for each oleaginous sample was established by observing the oil flow throughout the holes of the press cage under a magnifying glass. The holding time was measured with a stopwatch from the start of compression until the oil flow stopped. The holding time was verified by a time step of ± 100 s and then used as the optimal parameter for further extraction tests. The press cage has been fully charged in each case, and the compression speed has been maximal.

Tab. 1. Starting operational parameters used in this study

Factors	*B.aegyptiaca*		*C.pentandra*	
	whole kernels	crushed kernels	whole seeds	crushed seeds
Applied pressure (MPa)	40.2[22]	40.2[22]	40.2[23]	109.6*
Optimal holding time* (s)	490	770	780	1350
Maximal compression speed* (MPa/s)	1.1	1.1	1.3	2.7
Maximal press cage charge* (g)	10.0		10.0	
Moisture* (wt.% (w.b.))	2.7		5.7	
Oil content (wt.% (d.b.))	46.3[24]		26.2*	

* Values obtained in this study.

The optimal applied pressure was determined by adjusting the reference setpoint pressure and keeping constant the optimal holding time, the maximal compression speed, and the fully loaded press cage. It was defined as an interval of applied pressures with an average pitch of 10 MPa given the best oil extraction rates.

The optimal compression speed was determined by fixing the optimal holding time, applied pressure, and the maximal press cage charge. Four speeds expressed as a percentage, i.e., 100, 75, 50, and 25%, were considered. For all types of oilseeds, the speed was expressed in MPa/s corresponding to a given percentage. "MPa" and "s" represent the optimal applied pressure and the time that elapses between the start of compression and the start of holding time, respectively.

The optimal press cage charge (100, 75, 66.7, or 50% cage capacity) for different oleaginous materials was established based on the optimal holding time, applied pressure, and compression speed. A flow chart for optimization of cold extraction parameters to enhance the oil recovery from non-conventional oilseeds is shown in **Figure 3**.

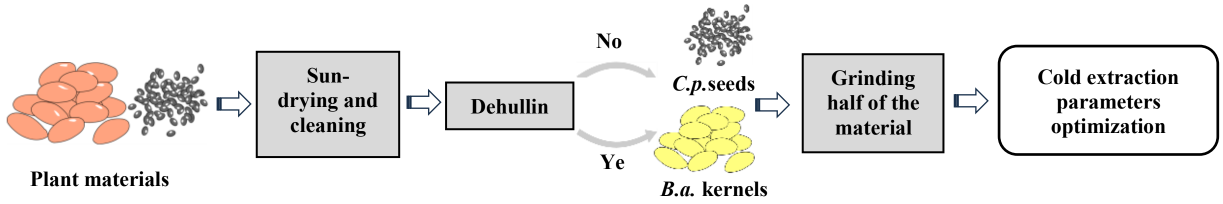

Fig. 3. Flow diagram

2.3. Analysis

2.3.1. GC analysis

The fatty acid composition was determined as methyl esters after transesterification [(Rashid et al., 2014; MOHIBBEAZAM et al., 2005). All chemicals and solvents used are the analytical quality. 150 µL of the methyl esters were mixed with 1 mL of 0.75 mg/mL internal standard solution (undecanoic acid C11:0 dissolved in n-hexane) and diluted to 20 mL with n-hexane. Each sample was performed by dissolving 400 µL of methyl esters sample into 400 µL of n-hexane.

The fatty acid profile of each oil was determined using a Thermo Finnigan type Trace (20090 Rodano (MI), Italy) gas chromatograph equipped with a flame-ionization detector. GC conditions were as follows: 1 µL of sample is inserted on column (100 m, 0.25 mm i.d., and 0.2 µm film thickness). The operational conditions were as follow: injector temperature, 225 °C; column flow, 200 kPa; detector temperature, 255 °C; H_2 flow, 35 mL/min; airflow, 350 mL/min. The oven temperature was initially 80 and raised to 175 °C at a rate of 25 °C/min (25 min hold), raised to 205 °C at a rate of 10 °C/min (4 min hold) and finally raised to 225 °C at a rate of 10 °C/min (20 min hold). The instrument was controlled with ChromQuest (Thermo Finnigan) software.

2.3.2. Physicochemical characterization

Physical and chemical parameters of oils were determined according to standard methods: acid value (ISO 660:2009(F)), moisture and volatile matter (ISO 662), relative density (ASTM D-4052-96), kinematic viscosity (ASTM D-445), pour (ASTM D97-93) and cloud (ASTM D2500-91) points. Iron and copper contents in plant materials, oils, and press cakes were determined by flame atomic absorption spectrometry (AA-7000 Atomic Absorption Spectrophotometer SHIMADZU, Japon) at 248.3 and 324.8 nm, respectively. Samples were calcined at 550 °C (CARBOLITE, BWF 11/13, England) for 10 h, after which ashes were wholly dissolved in 5% HNO_3. The phosphor content of oils was determined colorimetrically at 460 nm (T70 UV/VIS Spectrophotometer, PG Instruments Ltd, England) using the mixed solution of ammonium vanadate and ammonium molybdate. The moisture content of plant materials was measured according to ISO 665 method. All analytical tests were performed in duplicate.

2.4. Statistical analysis

A two-way analysis of variance (ANOVA) was performed by using R software for Windows (Version 4.0.0). Applied pressure, compression speed, and press cage charge were the main factors with a confidence interval of 95%. Statistical significance of the differences observed among mean values was assessed using Scheffe's test. A probability of $p \le 0.05$ was considered significant. All analyses were carried out at least three times and the results are mean ± SD.

3. Results and discussion

3.1. Moisture and oil contents of oilseeds

Table 2 reports the moisture and oil contents of oilseeds subjected to mechanical extraction. *C.pentadra* seeds and *B.aegyptiaca* kernels contain 5.7 and 2.7 wt.% (w.b.) moisture, respectively. Indeed, the kernel is composed of more than 50% of hydrophobic compounds (lipidic fractions), while the hydrophilic compounds as lignocellulose, fibres, and mucilage are mostly present in the hull (Willems et al., 2008; Subroto et al., 2015; Lazouk et al., 2015). The oil contents in *C.pentadra* seeds and *B.aegyptiaca* kernels determined by n-hexane extraction were 26.2 and 46.3 wt.% (d.b.), respectively, which agrees with the literature (Chapagain et al., 2009; Kaimal & Lakshminarayana, 1970; Muhammad, 2018).

3.2. Influence of hydraulic extraction parameters on oil recovery

Processing parameters (holding time, applied pressure, compression speed, and press cage charge) influence the oil recovery during hydraulic extraction of seed oils. **Table 2** summarizes the optimal cold extraction parameters for whole and crushed *B.aegyptiaca* kernels and *C.pentandra* seeds.

3.2.1. Holding time

The pressing time depends on the extraction temperature, oil content, applied pressure, particle size, and the thickness of the press cake (Lanoisellé & Bouvier, 1994; Subroto et al., 2015). The results presented in **Table 2** show that the optimal holding time is specific to each oleaginous material. The crushed seeds and kernels require more time to release the oil than the whole ones. That can be linked to significant compaction of the small size material and, consequently, to the difficulties of draining the oil. The optimal holding time measured at reference pressure was 780 and 1350 s for and crushed *C.pentandra* seeds, respectively. The same trend was observed for *B.aegyptiaca* kernels for which the optimal values were 540 (whole) and 770 s (crushed).

3.2.2. Applied pressure

The applied pressure is the most significant parameter in the hydraulic pressing of oilseeds (Santoso et al., 2014). This statement agreed with the results ($p<0.0001$) of variance analysis obtained for applied pressure in this study. In general, a higher oil recovery would be obtained at higher operating pressure (Mwithiga & Moriasi, 2007; Acheheb et al., 2012; Santoso et al., 2014; Lanoisellé & Bouvier, 1994; Willems et al., 2008; Lazouk et al., 2015). **Figure 4** shows the variation in oil recovery with applied pressure for the oilseeds and kernels used in this study. The fixed parameters were the previously determined optimum holding time and the maximum compression speed and press cage charge. As can be seen from the graph, the maximum oil recovery is within an optimum pressure range limited to about ±10 MPa. Increasing the pressure beyond this range results in lower oil recovery due to the compaction of the pressing cake. **Table 2** gives the optimum applied pressure established in this experiment for different oleaginous materials.

The oil recovery as well as the optimal applied pressure are positively or negatively affected by the size reduction. In the case of *C.pentandra*, the size reduction of oilseeds allows to achieve the best oil recovery of 41.2 wt.% (d.b.) at lower applied pressure of 71.9 MPa compared to 38.5 wt.% (d.b.) oil recovery at 120.1 MPa for whole seeds. That could be explained by high rigidity and small size of *C.pentandra* oilseeds. Grinding *B.aegyptiaca* kernels slightly reduced oil recovery from 72.4 wt.% (d.b.) for whole kernels to 69.3 wt.% (d.b.) for crushed kernels. However, the optimal applied pressure was higher for whole kernels (56.1 MPa) than for the crushed (40.2 MPa).

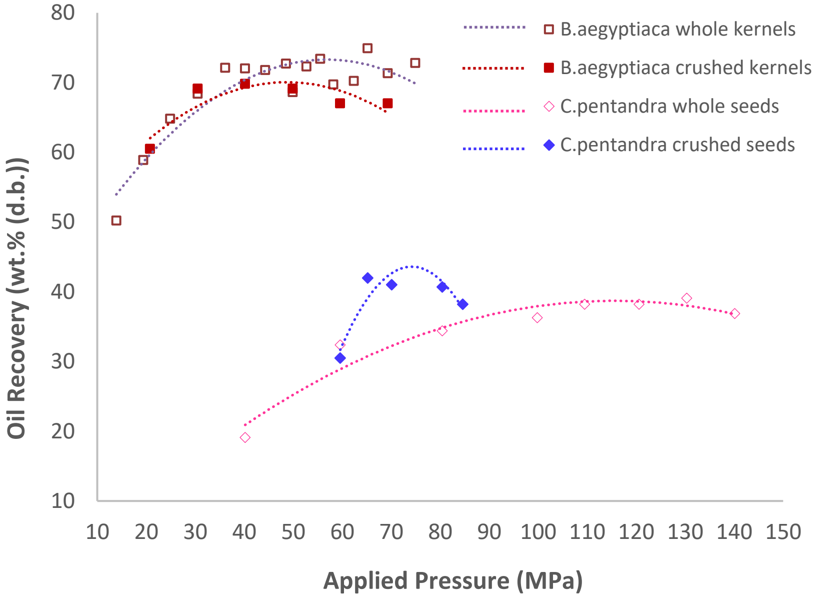

Fig. 4. Influence of applied pressure on oil recovery for *B.aegyptiaca* and *C.pentandra* oilseeds

3.2.3. Compression speed

Compression speed was studied at four levels: maximal speed (100%), minimal speed (25%), and two intermediate speeds (50 and 75%). All tests were carried out at optimum applied pressure and holding time determined previously. The press cage charge was maximal. **Figure 5** shows the relationship between oil recovery and compression speed for different oleaginous materials. It has been established that an average speed (50%) of compression of the oilseeds favors oil extraction. The best oil recovery for whole and crushed *B.aegyptiaca* kernels was obtained at 1 MPa/s, while for whole *C.pentadra* seeds the optimum compression speed was 1.7 MPa/s.

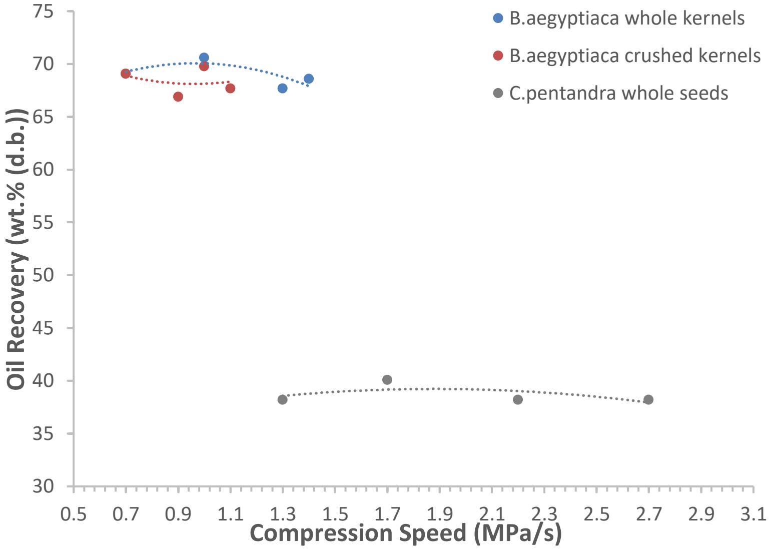

Fig. 5. Influence of compression speed on oil recovery for *B.aegyptiaca* and *C.pentandra* oilseeds

3.2.4. Press cage charge

In this study, four filling levels (100, 75, 66.7, and 50%) of pressing cage capacity were expected. The fixed parameters were the optimal holding time, applied pressure, and compression speed determined previously. It should be noted that the maximum load of the pressing cage corresponded to individual weight depending on the type of oleaginous material (**Table 1**).

Figure 6 illustrates the effect of press cage charge on the oil recovery from the oilseeds used in this study. Under the experiment conditions, a significant improvement in oil recovery ($p<0.05$) with increasing press cage charge was observed for *C.pentandra* whole seeds while for *B.aegyptiaca* kernels the oil recovery does not vary significantly ($p>0.05$).

The reduction in oil recovery with the low press cage charge could be explained by the more significant compaction of the pressing cake due to the reduced specific strength of the oleaginous material when its amount decreases. Consequently, a higher compactness of pressing cake restricts the flow of the oil. The hardness of certain oilseeds should also be considered for appreciation of the compactness of the pressing cake. Furthermore, the specific design of the pressing device (steel ball replacing the bottom of the pressing cage) used in this study might also influence the thickness and compactness of the pressing cake. In general, the results presented here were obtained for small quantities of oilseeds using small size pressing cage positioned on a steel ball and need to be confirmed with more replications and a larger press cage. Also, for comparison, the steel ball should be replaced by a conventional plate at the pressing cage's bottom. Moreover, scaling up using more significant amounts of oleaginous material would require special consideration concerning the configuration of the pressing device (i.e., with or without a steel ball at the bottom of the press cage).

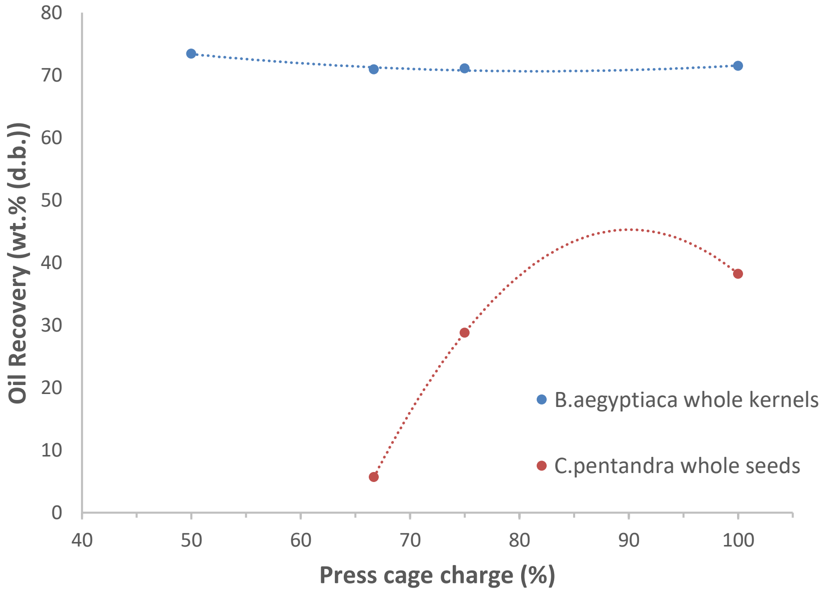

Fig. 6. Influence of press cage charge on oil recovery for *B.aegyptiaca* and *C.pentandra* oilseeds

Tab. 2. Optimal cold hydraulic extraction parameters for *B.aegyptiaca* and *C.pentandra* oilseeds

	Parameters				Oil recovery (wt.% (d.b.)) ± SD
	Holding time (s)	Applied pressure (MPa) ± SD	Compression speed (MPa/s)	Press cage charge (%)	
B.aegyptiaca					
whole kernels	489	56.1 ± 12.2	1	50	73.4 ± 4.3
crushed kernels	770	40.2 ± 9.7	1	ND	69.8 ± 1.2
C.pentandra					
whole seeds	780	120.1 ± 10.0	1.7	100	38.2 ± 0.0
crushed seeds	1350	71.9 ± 7.8	ND	ND	41.2 ± 0.7

* ND: non determined

No significant relationship ($p>0.05$) was found between oil recovery and some combined parameters such as shell removal and applied pressure or size reduction and applied pressure. However, the individual effects of applied pressure, size reduction, shell removal, and press cage charge significantly affected oil recovery in some cases. The most influential sources of variation ($p<0.001$) are the applied pressure, the press cage charge, and the shelling of oilseeds.

3.3. Oil quality parameters

3.3.1. Fatty acid composition

Table 3 presents the fatty acid composition of the hexane extracted oils. The most abundant fatty acid was linoleic (45.32 and 38.77 wt.%) for *B.aegyptiaca* and *C.pendandra* oils, respectively. In addition, *C.pentandra* oil has a high palmitic acid content (25.93 wt.%), while the oil of *B.aegyptiaca* contains more stearic acid (11.0 wt.%). The fatty acid compositions of these oils were in good agreement with those reported in the literature (Chapagain et al., 2009; Rashid et al., 2014).

Tab. 3. Fatty acid composition of *B.aegyptiaca* and *C.pentandra* oils

Fatty acid composition (wt.%)	*B.aegyptiaca* (kernels)[24]	*C.pentandra* (seeds)	Crude Cottonseed oil [31-33] (References)
Capric (C10:0)	0.05	0.06	≤0.05
Lauric (C12:0)	0.02	0.02	≤0.2
Tridecylic (C13:0)	0.02	0.03	-
Myristic (C14:0)	0.06	0.14	0.5-2.0
Pentadecylic (C15:0)	-	0.02	-
Palmitic (C16:0)	13.79	25.93	17.0-29.0
Palmitoleic (C16:1 cis-Δ9) ω-7	0.14	0.36	0.5-1.5
Margaric (C17:0)	0.11	0.16	≤0.1

Stearic (C18:0)	11.07	3.69	1.0-4.0
Oleic (C18:1 cis-Δ9) ω-9	28.25	27.87	13.0-44.0
Vaccenic (C18:1cis-Δ11)	0.72	1.17	-
Linoleic (C18:2 cis, cis-Δ9, Δ12) ω-6	45.32	38.77	33.0-58.0
Linolenic (C18:3 cis, cis, cis-Δ9, Δ12, Δ15) ω-3	0.06	0.66	0.1-2.1
Arachidic (C20:0)	0.33	0.73	0.2-0.5
Eicosatrienoic (C20:3 cis, cis, cis-Δ11, Δ14, Δ17) ω-3	-	-	
Docosapentaenoic (C22:5 cis, cis, cis, cis, cis-Δ7, Δ10, Δ13, Δ16, Δ19) ω-3	0.06	-	
Clupanodonic (C22:6 cis, cis, cis, cis, cis, cis-Δ4, Δ7, Δ10, Δ13, Δ16, Δ19) ω-3	-	0.33	
Total saturated	25.45	30.78	26-35
Total unsaturated	74.55	69.22	65-70
Mono-unsaturated	29.11	29.46	
Poly-unsaturated	45.44	39.76	

3.3.2. Physicochemical properties

Table 4 summarizes some physicochemical parameters of the oils obtained by hexane extraction and cold pressing. The comparison of their quality was based on the oil extraction procedure. The quality of crude oil varies with processing (Crapiste et al., 2000).

The acid values of hexane-extracted oils were 0.70 for *B.aegyptiaca* and 4.38 mgKOH/g for *C.pentandra*. The oil of *B.aegyptiaca* showed the lower proportions of free fatty acids in respect to the maximal concentration fixed at 2.00 mgKOH/g for plant oil-based fuel in the DIN 51605 2010-10 standard. In contrast, the *C.pentandra* oil exhibited high acid values which means a certain degree of deterioration in the quality of the oil due to the hydrolysis of the triglycerides.

Moisture and volatile matter contents of the oils extracted by solvent were higher than those of cold-pressed oils and exceeded the stipulated DIN 51605 standard (0.075%). Their contents were ranged from 0.89 (*C.pentandra*) to 2.00 wt.% (*B.aegyptiaca*). In contrast, the cold-pressed oils displayed relatively low moisture and volatile matter values of 0.06 (*B.aegyptiaca*) and 0.10 wt.% (*C.pentandra*).

The phosphorus content was higher for hexane-extracted NEVOs compared to those of cold-pressed oils. This result agrees with the data reported by (Crapiste et al., 2000), showing that the solvent extraction produces high phospholipid (gums) content in the oil, while the cold-pressed oils contain small amounts of phosphatides. The highest phosphorus content of 80 ppm was obtained for *C.pentandra* hexane extracted oil, while for *B.aegyptiaca* oil it was 30 ppm. The phosphorus content of cold-pressed oils was low and do not exceed 20 ppm (*C.pentandra*). Subroto et al. found that increasing the moisture content of the kernel increases the phosphorus content of the oil (Subroto et al., 2015).

This statement can be applied to *C.pentandra*, whose seeds have the highest moisture content compared to other oilseeds used in this study.

The viscosities of the hexane extracted oils measured at 37.8 °C were 29.49 (*C.pentandra*) and 30.92 cSt (*B.aegyptiaca*). For vegetable oils, viscosity decreases as saturation of fatty acids decreases and with shorter chain lengths (O'Brien, 2002). Indeed, *B.aegyptiaca* and *C.pentandra* oils contain a significant quantity of polyunsaturated acids 45.38 and 39.43%, respectively. The cold-pressed *B.aegyptiaca* oil has a relatively higher viscosity than solvent extracted oil i.e., 38.05 and 30.92 cSt (at 37.8 °C), respectively. The same tendency in variations in the viscosity of oils extracted by solvent and cold pressing was observed in other works [(Acheheb et al., 2012; Yilmaz & Güneşer, 2017).

The density of hexane extracted oils measured at 25 °C was 0.908 (B.aegyptiaca) and 0.904 (C.pentandra). Also, the difference of densities was observed for the oils extracted by solvent and cold pressing. The density of cold-pressed B.aegyptiaca oil measured at 25 °C was higher (0.913) than that of hexane-extracted oil. This result agrees with the work carried out by (Acheheb et al., 2012).

Determination of cloud and pour points revealed that *C.pentandra* oil has attractive cold flow properties with a low cloud point of 0°C and a pour point of -6°C. Regarding the degree of unsaturation of fatty acid, Moser and Sajjadi et *al.* noticed that the number of double bonds has a significant effect on the crystallization of vegetable oil (Moser, 2011; Sajjadi et al., 2016). Thus, methyl linoleate is solid at -35 °C, while unsaturated methyl oleate melts at -19 °C (Sajjadi et al., 2016). This observation agrees with our results. No differences in cold flow characteristics were noted for hexane-extracted and cold-pressed *B.aegyptiaca* oils. The cloud and pour points of *B.aegyptiaca* hexane extracted and cold-pressed oils were 0 and +1 °C, respectively.

Tab. 4. Quality parameters of extracted *B.aegyptiaca* and *C.pentandra* oils

	B.aegyptiaca (kernels)	*C.pentandra* (seeds)	Crude Cottonseed oil [31-33] Rapeseed oil [c]
Quality parameters			
Acid value (mgKOH/g)	0.70 [a]	4.38 [a]	1.0-10.0[31-33] and 2.0 [c]
Moisture and volatile content (wt.% (d.b.))	2.00 [a] 0.06 [b]	0.89 [a] 0.10 [b]	0.075 [c]
Relative density (15 °C)	0.915 [a] 0.920 [b]	0.911[a] ND [b]	0.910-0.925 [c]
(25 °C)	0.908 [a] 0.913 [b]	0.904 [a] ND [b]	0.916-0.918[31-33]
Kinematic viscosity, cSt (37.8 °C)	30.92 [a] 38.05 [b]	29.49 [a] ND [b]	36 (40 °C) [c]

(50.0 °C)	21.27[a]	20.27[a]	
	25.59[b]	ND[b]	
Cloud point (°C)	+1[a]	0[a]	-1.1-3.3[31-33]
	+1[b]	ND[b]	
Pour point (°C)	0[a]	-6[a]	-3.9-0[31-33]
	0[b]	ND[b]	
Phosphorus (ppm)	30[a]	80[a]	10.0[31-33]
	10[b]	20[b]	3[c]
Iron (ppm)	3.8[a]	1.7[a]	5.0[31-33]
	2.8[b]	3.5[b]	
Copper (ppm)	0.1[a]	0.0[a]	0.4[31-33]
	0.0[b]	0.0[b]	

[a] Hexane-extracted oil; [b] Cold-pressed oil; ND : non determined; [c] DIN 51605: 2010-10;

A low level of iron (<4 ppm) and copper (0-0.1 ppm) was observed in the oils (Table 4). The metals in vegetable oils derived from raw materials or transported by contact with the manufacturing or storage equipment reduce the oxidation stability of the oils involved in rancidity processes (O'Brien, 2002; Agarwal et al., 2003; Garrido et al., 1994). The presence of iron and copper in hexane extracted oils indicates their natural origin. The metal contents were assessed in the starting oleaginous material (seeds and kernels) and the press cakes (**Table 5**). *C.pentandra* seeds contain more iron (53.8 ppm) and copper (17.0 ppm) than the kernels of *B.aegyptiaca*, 49.5 and 4.6 ppm, respectively. It was the same for its press cake. The results show that the iron and copper concentrations in the press cakes are higher than those in the seeds or kernels, suggesting that the oil drives only a negligible amount of these metals. The results generally show that the concentrations of iron and copper in the press cakes are higher than those present in the oilseeds, suggesting that the oil carries only a negligible amount of these metals.

Tab. 5. Iron and copper concentrations in oilseeds and press cakes

	Iron (ppm)	Copper (ppm)
B.aegyptiaca		
kernels	49.5	4.6
press cake	70.9	8.1
C.pentandra		
seeds	53.8	17.0
press cake	71.8	26.3

4. Conclusion

In this work, the optimum processing parameters were established on a laboratory scale for a cold hydraulic extraction of the *B.aegyptiaca* and *C.pentandra* oils. The parameters studied within the study were the holding time, the applied pressure, the compression speed, and the press cage charge. The individual effect of four key parameters on the oil recovery was assessed for whole and crushed oleaginous materials. It was found that the applied pressure is the most significant factor affecting the oil recovery. Under the optimal conditions and at 25 °C, the oil recovery (wt.% d.b.) for whole (crushed) oleaginous material was 73.4 (69.8) *B.aegyptiaca* kernels and 38.2 (41.2) *C.pentandra* seeds.

The quality of the extracted oils complies with the DIN 51605: 2010-10 standard for vegetable oil fuels with regard to the phosphorus and moisture contents, density and kinematic viscosity. Moreover, the extracted oils were characterized by a high content of unsaturated fatty acids (oleic, linoleic, and linolenic). These characteristics attribute to the *B.aegyptiaca* and *C.pentandra* oils valuable material properties which can be used for multipurpose applications.

Conflict of interest: The authors have declared no conflict of interest on the financial or commercial application of this study.

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References

Abdul Hakim Shaah, M., Hossain, Md. S., Salem Allafi, F. A., Alsaedi, A., Ismail, N., Ab Kadir, M. O., & Ahmad, M. I. (2021). A review on non-edible oil as a potential feedstock for biodiesel: physicochemical properties and production technologies. *RSC Advances*, *11*(40), 25018–25037. https://doi.org/10.1039/d1ra04311k

Acheheb, H., Aliouane, R., & Ferradji, A. (2012). Optimization of Oil Extraction from Pistacia atlantica Desf. Seeds Using Hydraulic Press. *Asian Journal of Agricultural Research*, *6*(2), 73–82. https://doi.org/10.3923/ajar.2012.73.82

Agarwal, D. K., Singh, P., Chakrabarty. M., Shaikh, A. J., Gayal, S. G. (2003). Cottonseed oil quality, utilization, and processing. Central Institute for Cotton Research Nagpur, *CICR Technical bulletin*, 25, p.4.

Al Juhaimi, F., Özcan, M. M., Ghafoor, K., Babiker, E. E., & Hussain, S. (2018). Comparison of cold-pressing and soxhlet extraction systems for bioactive compounds, antioxidant properties, polyphenols, fatty acids and tocopherols in eight nut oils. *Journal of Food Science and Technology*, *55*(8), 3163–3173. https://doi.org/10.1007/s13197-018-3244-5

Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Fayaz, H. (2013). Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renewable and Sustainable Energy Reviews*, *18*, 211–245. https://doi.org/10.1016/j.rser.2012.10.013

Baldini, M., Bulfoni, E., & Ferfuia, C. (2014). *Seed processing and oil quality of Jatropha curcas L. on farm scale: A comparison with other energy crops*. *19*, 7–14. https://doi.org/10.1016/j.esd.2013.12.005

Chapagain, B. P., Yehoshua, Y., & Wiesman, Z. (2009). Desert date (Balanites aegyptiaca) as an arid lands sustainable bioresource for biodiesel. *Bioresource Technology*, *100*(3), 1221–1226. https://doi.org/10.1016/j.biortech.2008.09.005

Codex Alimentarius Commission. (1999). Standard for Named Vegetable Oils. CODEX STAN 210-1999, Rev. 2019, FAO/WHO, Rome, Italy.

Crapiste, G. H., Brevedan, M. I. V., & Carelli, A. A. (2000). Changes in composition and quality of sunflower oils during extraction and degumming. *Grasas Y Aceites*, *51*(6). https://doi.org/10.3989/gya.2000.v51.i6.460

Gan, Y., & Jiang, X. (2014). Photo-cured Materials from Vegetable Oils. *Books.rsc.org*. https://doi.org/10.1039/9781782621850-00001

Garrido, M. D., Frías, I., Díaz, C., & Hardisson, A. (1994). Concentrations of metals in vegetable edible oils. *Food Chemistry*, *50*(3), 237–243. https://doi.org/10.1016/0308-8146(94)90127-9

Huang, S., Hu, Y., Li, F., Jin, W., Vikas Godara, & Wu, B. (2019). Optimization of mechanical oil extraction process from *Camellia oleifera* seeds regarding oil yield and energy consumption. *Journal of Food Process Engineering*, *42*(6). https://doi.org/10.1111/jfpe.13157

Kaimal, T. N. B., & Lakshminarayana, G. (1970). Fatty acid compositions of lipids isolated from different parts of ceiba pentandra, sterculia foetida and hydnocarpus wightiana. *Phytochemistry*, *9*(10), 2225–2229. https://doi.org/10.1016/s0031-9422(00)85389-3

Karaj, S., & Müller, J. (2011). Optimizing mechanical oil extraction of Jatropha curcas L. seeds with respect to press capacity, oil recovery and energy efficiency. *Industrial Crops and Products*, *34*(1), 1010–1016. https://doi.org/10.1016/j.indcrop.2011.03.009

Lanoisellé, J. L., & Bouvier, J. M. (1994). Le pressage hydraulique des oléagineux : mise au point. *Revue Française de Corps Gras*, 41(3-4), 61-72.

Lazouk, M.-A., Savoire, R., Kaddour, A., Castello, J., Lanoisellé, J.-L., Van Hecke, E., & Thomasset, B. (2015). Oilseeds sorption isoterms, mechanical properties and pressing: Global view of water impact. *Journal of Food Engineering*, *153*, 73–80. https://doi.org/10.1016/j.jfoodeng.2014.12.008

Mat Yusoff, M., Gordon, M. H., Ezeh, O., & Niranjan, K. (2017). High pressure pre-treatment of Moringa oleifera seed kernels prior to aqueous enzymatic oil extraction. *Innovative Food Science & Emerging Technologies*, *39*, 129–136. https://doi.org/10.1016/j.ifset.2016.11.014

Mohamed, A. M., Wolf, W., & Spieß, W. E. L. (2002). Physical, morphological, and chemical characteristics, oil recovery and fatty acid composition of Balanites aegyptiaca Del. kernels. *Plant Foods for Human Nutrition*, *57*(2), 179–189. https://doi.org/10.1023/a:1015237612018

MOHIBBEAZAM, M., WARIS, A., & NAHAR, N. (2005). Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy*, *29*(4), 293–302. https://doi.org/10.1016/j.biombioe.2005.05.001

Montcho, P. S., Tchiakpe, L., Nonviho, G., Bothon, D., Sidohounde, A., Pascal, C., Bessieres, D., Chrostowska, A., & Codjo, D. (2018). Fatty acid profile and quality parameters of Ceiba pentandra (L.) seed oil: A potential source of biodiesel. *Journal of Petroleum Technology and Alternative Fuels*, *9*(3). https://doi.org/10.5897/jptaf2018.0141

Moser, B. R. (2011). Influence of extended storage on fuel properties of methyl esters prepared from canola, palm, soybean and sunflower oils. *Renewable Energy*, *36*(4), 1221–1226. https://doi.org/10.1016/j.renene.2010.10.009

Muhammad, C. (2018). Biodiesel Production from *Ceiba pentandra* Seed Oil Using CaO Derived from Snail Shell as Catalyst. *Petroleum Science and Engineering*, *2*(1), 7. https://doi.org/10.11648/j.pse.20180201.12

Mwaurah, P. W., Kumar, S., Kumar, N., Attkan, A. K., Panghal, A., Singh, V. K., & Garg, M. K. (2019). Novel oil extraction technologies: Process conditions, quality parameters, and optimization. *Comprehensive Reviews in Food Science and Food Safety*, *19*(1), 3–20. https://doi.org/10.1111/1541-4337.12507

Mwithiga, G., & Moriasi, L. (2007). A study of yield characteristics during mechanical oil extraction of preheated and ground soybeans. *Journal of Applied Sciences and Research*, 3(10), 1146-1151.

Nde, D., & Foncha, A. (2020). Optimization Methods for the Extraction of Vegetable Oils: A Review. *Processes*, *8*(2), 209. https://doi.org/10.3390/pr8020209

Nitièma-Yefanova, S., Coniglio, L., Schneider, R., Nébié, R. H. C., & Bonzi-Coulibaly, Y. L. (2016). Ethyl biodiesel production from non-edible oils of Balanites aegyptiaca, Azadirachta indica, and Jatropha curcas seeds – Laboratory scale development. *Renewable Energy*, *96*, 881–890. https://doi.org/10.1016/j.renene.2016.04.100

Nitièma-Yefanova, S., Georges Yé, S., Son, G., Nébié, R., & Bonzi-Coulibaly, Y. L. (2022). Hydraulic pressing optimization and physicochemical characterization of Jatropha curcas seed oil. *IRA - International Journal of Applied Sciences*, *17*(4), 31–40. https://doi.org/10.21013/jas.v17.n4.p1

Nitièma-Yefanova, S., Poupaert, J.H., Mignolet, E., Nébié, R.H., & Coulibaly, L.Y. (2012). Characterization of some nonconventional oils from Burkina Faso. *J. Soc. Ouest-Afr. Chim*. 033, 67 – 71.

O'Brien, R.D. (2002). Cottonseed oil, In *Gunstone F.D. (Ed.), Vegetable oils in food technology–Composition, Properties and Uses*. Blackwell Publishing, Oxford, pp. 202–230.

Rashid, U., Knothe, G., Yunus, R., & Evangelista, R. L. (2014). Kapok oil methyl esters. *Biomass and Bioenergy*, *66*, 419–425. https://doi.org/10.1016/j.biombioe.2014.02.019

Sajjadi, B., Raman, A. A. A., & Arandiyan, H. (2016). A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models. *Renewable and Sustainable Energy Reviews*, *63*, 62–92. https://doi.org/10.1016/j.rser.2016.05.035

Santoso, H., Iryanto, & Inggrid, M. (2014). Effects of Temperature, Pressure, Preheating Time and Pressing Time on Rubber Seed Oil Extraction Using Hydraulic Press. *Procedia Chemistry*, *9*, 248–256. https://doi.org/10.1016/j.proche.2014.05.030

Subroto, E., Manurung, R., Heeres, H. J., & Broekhuis, A. A. (2015). Mechanical extraction of oil from Jatropha curcas L. kernel: Effect of processing parameters. *Industrial Crops and Products*, *63*, 303–310. https://doi.org/10.1016/j.indcrop.2014.06.018

Willems, P., Kuipers, N. J. M., & De Haan, A. B. (2008). Hydraulic pressing of oilseeds: Experimental determination and modeling of yield and pressing rates. *Journal of Food Engineering*, *89*(1), 8–16. https://doi.org/10.1016/j.jfoodeng.2008.03.023

Yilmaz, E., & Güneşer, B. A. (2017). Cold pressed versus solvent extracted lemon (Citrus limon L.) seed oils: yield and properties. *Journal of Food Science and Technology*, *54*(7), 1891–1900. https://doi.org/10.1007/s13197-017-2622-8

Yusuf, A.K. (2018). A Review of Methods Used for Seed Oil Extraction. *IJSR*. 7(12), 233-238.

Zhang, H. Q., Barbosa-Cánovas, G. V., Balasubramaniam , M. B., Dunne, C. P., Farkas, D. F., & Yuan, J. T. C. (2011). *Nonthermal Processing Technologies for Food*. John Wiley & Sons.

Zhou, Y., Zhao, W., Lai, Y., Zhang, B., & Zhang, D. (2020). Edible Plant Oil: Global Status, Health Issues, and Perspectives. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.01315