Dehulling of Cuphea PSR23 seeds to reduce color of the extracted oil

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A B S T R A C T

Oil extracted by screw pressing seeds of Cuphea PSR23 contained 200–360 ppm of chlorophyll. A high amount of bleaching clay was needed during refining to remove the chlorophyll in the oil. In this paper, we investigated the dehulling of the seed as a method of reducing the chlorophyll content in oil extracted from cuphea seeds. The effects of seed moisture content, huller's impeller speed, and feed rate to the huller on dehulling of the seeds were determined. The hulls were separated from the cotyledons by screening and using a vacuum gravity separator. The oils extracted from the cotyledon-rich fraction were analyzed for chlorophyll content and color. The hulls accounted for 44.6% (w/w) of the whole cuphea seed. When seeds were dried to 3.5% moisture content (MC) before dehulling, 37% of the dehulled seed (containing 8.8% oil) can be removed by screening. This discard fraction has similar oil content to those of press cakes. The remaining cotyledon-rich fraction contained 39.2% oil, which is 38% greater than that of whole cuphea seeds. Hexane-extracted oil from the cotyledon-rich fraction contained 70% less chlorophyll content compared with similarly extracted whole seed oil. The minimum chlorophyll content achievable was 15 ppm from almost pure cotyledons and extracted by hydraulic pressing. Dehulling cuphea seed before oil extraction effectively reduced chlorophyll content in the oil, which can greatly decrease the amount of bleaching clay in oil refining and the cost associated with its handling and disposal.

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1. Introduction

Cuphea, of the family *Lythraceae*, is a large genus of over 200 species of herbs and shrubs growing in the tropics and subtropics of the Americas. Several cuphea species contain saturated medium-chain fatty acids (MCFAs) (Miller et al., 1964; Graham et al., 1981; Wolf et al., 1983). MCFAs (C8:0–C12:0) are used in soaps, detergents, cosmetics, lubricants, and food applications. A semi-domesticated, high-capric-acid variety with partial seed retention (PSR) was reported by Knapp (1993). Cuphea PSR23 is a hybrid between *Cuphea viscosissima* (a species native to the United States) and *Cuphea lanceolata* (a species native to Mexico). The seeds contain up to 35% oil and greater than 70% of the fatty acids are capric (C10:0). Cuphea PSR23 has been the subject of field studies in west central Minnesota and central Illinois to establish the best agronomic management practices in preparation for commercial production (Gesch et al., 2002; Sharratt and Gesch, 2004; Gesch et al., 2005; Forcella et al., 2005; Behle and Isbell, 2005).

Oil extracted by screw pressing whole cuphea seeds produced dark green colored oil. Evangelista and Cermak (2007) reported that chlorophyll content of the oil ranged from 200 to 260 ppm, but levels of up to 326 ppm were also observed. About 6.5–8% bleaching clay had been used in the bleaching step to bring the chlorophyll level in the refined oil to 0.5 ppm. Aside from the added cost of bleaching clay, more oil is also lost as these adsorbents also retain between 50 and 75% their weight of oil.

Seed dehulling is usually performed before oil extraction to reduce the amount of material to be processed, thus increasing the throughput of the downstream processing equipment. Dehulling also reduces maintenance cost associated with the wear of the lining bars and shaft of the screw press. Furthermore, dehulling increases the protein content of the meal and reduces the amount of wax that gets extracted with the oil (Buhr, 1990; Williams and Hron, 1996). In this study, we explored the feasibility of mechanical dehulling of cuphea seed and determined its impact on the color of the oil obtained from dehulled seeds.

2. Materials and methods

2.1. Materials

Cuphea PSR23 seeds were harvested using a John Deere 6600 concave cylinder combine in late September from field plots in central Illinois in 2006 and 2007. The seeds were immediately dried

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Fig. 1. Photograph of Cuphea PSR23 seeds.

using a Grain Technology 245XL Grain Dryer (GT Mfg., Inc., Clay City, Kansas). The seeds from these harvests were mixed and then density-graded using a vacuum gravity separator (Model TKV-25, Forsberg, Inc., Thief River Falls, MN) to remove light and unfilled seeds. The seed had 7.1% moisture content (MC) and 28.4% oil (dry basis, db). The seed weighed 3.06 ± 0.04 g/1000 seeds. The seed measured 2.73 ± 0.14 mm wide and 0.83 ± 0.07 mm thick (Fig. 1).

2.2. Seed dehulling

2.2.1. Effects of seed moisture, huller speed, and feed rate on dehulling

Four levels of starting seed moisture (3.5, 7.1 (as is), 11.4, and 14.0%) were employed in 1-kg batch dehulling. To obtain seeds with 11.4 and 14.0% MC, seeds (10 kg) were sprayed with predetermined amount of water as the seeds were scooped into a 20-L bucket. The seeds in the bucket were tumbled for 5 min and allowed to stand overnight. The seeds were tumbled again and allowed to equilibrate for at least 24 h. The 3.5% MC seed was obtained by drying the seeds in a vacuum oven (60 °C) until the target weight was attained. The tempered seeds were then divided into 1-kg batches, placed in resealable polyethylene bags, and stored in an airtight 20-L bucket.

The huller used in this study was a Forsberg Impact Huller Model 15-D (Forsbergs Inc., Thief River Falls, MN). Details of this huller were described previously by Evangelista (2007). The feed control was set to dispense 1 kg of seed per min into the hulling chamber. Three huller impeller speed settings (1250, 1400, and 1700 rpm) were employed. The 1250 and 1700 rpm represent the minimum and maximum attainable impeller speeds of the huller. Three replicates were run for each moisture and huller speed combination. The seeds from the huller were fractioned into five particle sizes using standard testing sieve Nos. 12, 16, 25, and 35 (Table 1) that were stacked on a RO-TAP sieve shaker (Model RX 29, W.S. Tyler, Mentor, OH). Fraction number was assigned to correspond with the sieve number that retained the material. Material that passed through sieve No. 35 was designated as fraction −35 (Figs. 2 and 4; Tables 2 and 3). Each fraction was weighed, and moisture and oil contents were determined.
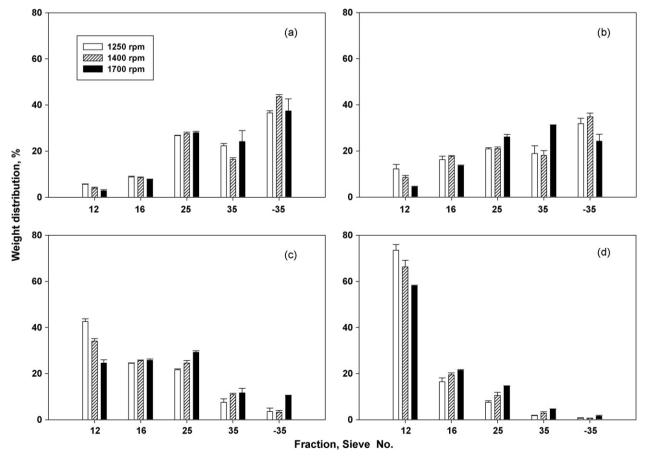

Fig. 2. Weight distribution of fractions from dehulled 1-kg seed with (a) 3.5%, (b) 7.1% (as is), (c) 11.4%, and (d) 14.0% moisture content.

Table 1
Ro-Tap and Rotex screens used in fractionating dehulled cuphea seeds.

Screener	U.S. standard sieve No.	Mill grade screen mesh No.	Opening (mm)
Ro-Tap	12	–	1.70
	16	–	1.18
	25	–	0.71
	35	–	0.50
Rotex	–	12	1.65
	–	16	1.18
	–	18	1.03
	–	22	0.81
	–	34	0.52

After a suitable seed moisture and huller speed combination was determined, seeds (50 kg/batch) were tempered as described above using a baffled 200-L stainless steel drum. The tempered seeds were placed in a bin lined with polyethylene bag. Tempered seeds (20 kg/run) were dehulled at different feed rates ranging from 0.7 to 8.7 kg/min (42–522 kg/h). Each feed rate was performed in triplicate. The feed rate to the huller was varied using the feed control lever. The dehulled seeds from the huller were screened using a two-deck Rotex Model 12A screener (Rotex Inc., Cincinnati, OH) fitted with a 12-mesh (12M) top screen and a 16-mesh (16M) bottom screen (Table 1). Dehulled seeds smaller than 16-mesh (−16M)

Table 4
Combined fractions from 20-kg batches of cuphea seeds dehulled at different feed rates.

Fraction	Weight (kg)	Weight (%)	Oil content[a] (%, dry basis)	Cotyledons (%)
16M	95.5	55.6	25.1 ± 2.2	49.6
22M	38.2	22.2	40.6 ± 0.4	81.9
34M	32.3	18.8	39.2 ± 0.5	78.9
−34M	5.7	3.3	39.3 ± 0.7	79.3

[a] Mean ± standard deviation of triplicate determinations.

were partitioned further using 22- and 34-mesh (22M and 34M) screens. A 22M screen was used because it is the screen size available in our facility that is closest to sieve number 25. Fraction number was assigned to correspond with the screen mesh number that retained the material. Material that passed through 34M screen was designated as fraction −34M (Fig. 5; Tables 4–6). Weights of the fractions were obtained and samples were taken for oil and moisture content determination.

2.2.2. Separation of hulls from cotyledons

All similar fractions in the feed rate study were combined. Fractions 34M and −34M were set aside for oil extraction. Fractions 16M and 22M were density-graded using a vacuum gravity separator (Forsberg Model TKV-25) to separate the hulls. The gravity separa-

Table 2
Analysis of variance of the effect of starting seed moisture and the huller's impeller speed on the weight distribution of fractions.

Fraction	Source	DF	Type I SS	Mean square	F value	p > F
12	Seed moisture	3	20705.3858	6901.7953	3028.23	<0.0001
	Impeller's speed	2	731.2029	365.6014	160.41	<0.0001
	Moisture × speed[a]	6	196.2500	32.7083	14.35	<0.0001
16	Seed moisture	3	1201.8426	400.6142	633.95	<0.0001
	Impeller's speed	2	11.4283	5.7141	9.04	0.0015
	Moisture × speed	6	49.7230	8.2872	13.11	<0.0001
25	Seed moisture	3	1410.9979	470.3326	989.77	<0.0001
	Impeller's speed	2	168.7294	84.3647	177.54	<0.0001
	Moisture × speed	6	41.9042	6.9840	14.70	<0.0001
35	Seed moisture	3	2030.4762	676.8254	148.55	<0.0001
	Impeller's speed	2	207.1285	103.5643	22.73	<0.0001
	Moisture × speed	6	176.0366	29.3394	6.44	0.0006
−35	Seed moisture	3	8916.3477	2972.1159	568.42	<0.0001
	Impeller's speed	2	47.2908	23.6454	4.52	0.0233
	Moisture × speed	6	224.0224	37.3371	7.14	0.0003

[a] Interaction between seed moisture and huller's impeller speed.

Table 3
Analysis of variance of the effect of starting seed moisture and the huller's impeller speed on the oil contents of fractions.

Fraction	Source	DF	Type I SS	Mean square	F value	p > F
12	Seed moisture	3	87.3991	29.1330	22.45	<0.0001
	Impeller's speed	2	26.6407	13.3204	10.27	0.0008
	Moisture × speed[a]	6	6.0421	1.0070	0.78	0.5976
16	Seed moisture	3	2556.5821	852.1940	428.14	<0.0001
	Impeller's speed	2	5.9644	2.9822	1.50	0.2485
	Moisture × speed	6	38.5409	6.4235	3.23	0.0209
25	Seed moisture	3	6259.3944	2086.4648	1853.46	<0.0001
	Impeller's speed	2	23.5518	11.7759	10.46	0.0007
	Moisture × speed	6	32.4110	5.4018	4.80	0.0032
35	Seed moisture	3	846.9909	282.3303	234.14	<0.0001
	Impeller's speed	2	3.5870	1.7935	1.49	0.2488
	Moisture × speed	6	27.9813	4.6636	3.87	0.0093
−35	Seed moisture	3	873.2592	291.0863	229.66	<0.0001
	Impeller's speed	2	912.5974	456.2987	360.00	<0.0001
	Moisture × speed	6	2713.9854	452.3309	356.87	<0.0001

[a] Interaction between seed moisture and huller's impeller speed.

Table 5
Chlorophyll content of hexane-extracted and hydraulic-pressed oils from whole seed and dehulled seed fractions.

Oil source	Oil content (%, db)	Cotyledons %	Chlorophyll content (ppm)[a]	
			Hexane-extracted oil	Hydraulic-pressed oil
Whole seed	28.4	56.4	163a	103b
16M CRF[b]	46.4	93.8	23i	25h
18M CRF[b]	49.2	99.5	19j	15k
22M[c]	43.4	87.6	46d	41g
34M	39.2	85.8	43f	43f
−34M	39.3	86.2	49c	45e

[a] Values with different letters are significantly different ($p < 0.05$).
[b] Cotyledon-rich fraction.
[c] Aspirated and density-graded.

tor was fitted with a 40-mesh corrugated stainless steel rectangular (61.0 cm × 91.4 cm) deck. The deck elevation, the inclination from the light to the heavy discharge end, was set at 4.5°. The thrust or the travel distance of the deck as it shook side to side was adjusted to 1 cm. A feed rate of 3 kg/min was needed to maintain a fully covered deck. For stratification of the dehulled seed to occur, a "bubbly" bed must be maintained. This was achieved by adjusting the deck oscillation (450 cycles/min) and the air flow through the deck. The heavier cotyledons stayed close to the deck surface and moved up the slope, while the lighter hulls floated and moved towards the light discharge end. The density grading was carried out in such a way that a light hull-rich fraction (HRF) was removed from every pass through the gravity table. The heavier fraction was subjected to further density grading as needed to improve the purity of the cotyledon-rich fraction (CRF). The movable dividers at the discharge end were used to make the desired cut for HRF and CRF. Samples of CRF, HRF, and middle fractions were analyzed for oil and moisture contents.

2.3. Oil extraction

Oil samples from whole seed and dehulled seed fractions were obtained by solvent extraction and mechanical pressing. For solvent extraction, a 60 mm diameter × 180 mm cellulose extraction thimble was filled with sample and extracted with hexane (600 mL) for 4 h using a Soxhlet apparatus. Mechanically pressed oil was obtained using a hydraulic press (Model C, Carver, Inc., Wabash, IN) fitted with a cage equipment (Carver catalog No. 2094) consisting of a stainless steel cylinder (8.9 cm internal diameter × 19 cm), plunger, stainless steel separator discs, cloth pads, and an oil pan. The sample was loaded in the cylinder in 1 in. (2.54 cm) layers separated by separator disks and cloth pads. The extracted oils were filtered before they were analyzed for chlorophyll content and color.

Table 6
CIE $L^*a^*b^*$ color (10 mm) of hexane-extracted and hydraulic-pressed oil from whole seed and dehulled seed fractions.

Oil source	Hexane-extracted oil				Hydraulic-pressed oil			
	L^{*a}	a^{*b}	b^{*c}	ΔE^*	L^{*a}	a^{*b}	b^{*c}	ΔE^*
Whole seed	24.2	−1.6	41.4	–	38.7	−0.7	65.6	–
16M CRF[d]	72.6	−11.0	86.7	67.0	71.5	−7.9	99.0	47.4
18M CRF[d]	76.1	−12.4	81.2	66.3	75.1	−10.1	90.3	45.0
22M[e]	56.4	−9.1	80.6	51.3	59.8	−4.6	95.0	36.4
34M	58.8	−7.9	75.7	49.1	56.6	−4.3	89.4	30.0
−34M	54.0	−4.3	84.9	52.8	56.3	−4.2	88.5	29.1

[a] 0 = black, 100 = white.
[b] (−) green, (+) red.
[c] (−) blue, (+) yellow.
[d] Cotyledon-rich fraction.
[e] Aspirated and density-graded.

2.4. Analytical methods

The moisture contents of the seed and dehulled seed samples were obtained following AOCS official method Ba 2a-38 (AOCS, 1997). The oil contents of the seed and dehulled seeds were determined using pulsed NMR spectrometer (The Minispec, Bruker Optics Inc., Billerica, MA). Whole cuphea seeds with known oil content were used to calibrate the spectrometer. The chlorophyll content of the oil was determined following AOCS official method Cc 13d-55 (AOCS, 1997). Oil color was measured on the Lovibond PFX995 Tintometer (The Tintometer Ltd., Amesbury, Wiltshire, UK) using the CIE $L^*a^*b^*$ color scale and cell path length of 10 mm. The total color difference (ΔE^*) between the whole seed and dehulled seed oils were calculated using the following equations (HunterLab Application Notes, 1996):

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

where $\Delta L^* = L^*_{\text{dehulled seed}} - L^*_{\text{whole seed}}$; $\Delta a^* = a^*_{\text{dehulled seed}} - a^*_{\text{whole seed}}$; $\Delta b^* = b^*_{\text{dehulled seed}} - b^*_{\text{whole seed}}$.

2.5. Statistical analysis

Statistical analysis was performed using PROC GLM in SAS Version 9.1 for PC (SAS Institute Inc., Cary, NC). Analysis of variance was performed to determine significant effects of seed moisture, huller's impeller speed, and feed rate on the weight distribution and oil content of the fractions. Duncan multiple range test was conducted to determine significant differences among treatment means at $p \leq 0.05$.
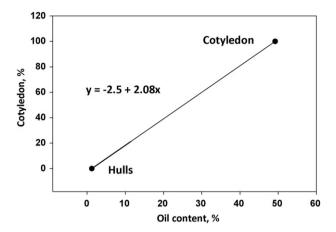
3. Results and discussion

The 2006 and 2007 crops of cuphea experienced relatively dry growing periods between May and September, and the seeds were slightly smaller than the 3 mm reported by Cermak et al. (2005). The cuphea seed had an oil content of 28.4% (db), which is within the 28–30% range of typical clean bulk seed. Cuphea has an indeterminate growth habit resulting in seeds with different degrees of maturity when harvested. Mature cuphea seeds have 35% oil and weigh 3.3 g/1000 seeds (Evangelista and Manthey, 2004).

3.1. Effects of moisture, huller's impeller speed, and feed rate on dehulling

The particle size distribution of the dehulled seed was strongly influenced by the seed's moisture content and by the huller's impeller speed as indicated by p values < 0.05 (Table 2). The driest seeds (3.5% MC) had the highest amounts of 35 and −35 fractions (Fig. 2a). As the moisture content of the seeds increased, the weight distribution of fractions shifted towards the larger particle sizes. Most of the increase in the amounts of fractions 12 and 16 came from fractions 35 and −35. On the other hand, increasing the huller's impeller speed shifted the weight distribution towards the smaller particle size. This trend was more consistent at higher seed moisture (Fig. 2c and d).

Upon close examination of the dehulled seed fractions, it was observed that the hulls were practically free of adhering cotyledons. This showed that the hulls did not bind strongly to the cotyledon and, hence, can be separated readily by an impact huller. Hulls and cotyledons hand-picked from fraction 16 contained 1.2% and 49.2% (db) oil, respectively. Using these values, a linear plot (Fig. 3) was made to estimate the amounts of hulls and cotyledons in whole seed and dehulled seed fractions. Whole seeds with 28.4% oil (db) would have about 44.6% hulls. This weight ratio is within the range of that of sunflower (40–55%) but much higher than those of rape-

Fig. 3. Linear plot for estimating cotyledon content of dehulled seed based on its oil content.

seed (18%) and soybeans (7%). The oil content of the cotyledon is comparable to that of peanuts (Williams and Hron, 1996).

The seed moisture content also had a very significant effect on the oil contents of the fractions (Table 3 and Fig. 4). The cotyledons of the seeds with 3.5% MC were more susceptible to breakage than the hulls, as indicated by the higher oil contents of the 35 and −35 fractions than that of whole seeds (Fig. 4a). Fractions 16 and 25 were mostly hulls and had oil contents ranging from 6.7 to 10%. These oil contents were already within the range of the residual oil in the press cake, and, therefore, may be considered for discard. Residual oil content of 5.6–6.8% in press cake was achieved by full

pressing cuphea seeds (Evangelista and Cermak, 2007). Press cakes from commercial presses have residual oil ranging from 3 to 10% (Williams and Hron, 1996; O'Brien, 2004). As the seed moisture increased, the cotyledons were not as prone to breakage; thus, the oil content in fractions 16 and 25 were higher (Fig. 4b, c and d). Fractions with oil content ≥40% had more than 50% of the hulls already removed. However, as shown in Fig. 2c and d, their fraction weights had decreased considerably.

It appears that there are two ways cuphea seed dehulling can be conducted: (1) dehull dry seeds (3.5% MC), discard fractions 16–25, and keep fractions smaller than fraction 25 for oil extraction. The discard fraction accounted for 37% of dehulled seeds from the huller (excluding fraction 12, which will be recycled) and contained about 8.8% oil (15.8% cotyledons). The combined fractions smaller than fraction 25 accounted for 63% of the dehulled seed and contained 39% oil (79.2% cotyledons); and (2) temper the seeds to about 11.5% MC before dehulling, separate the hulls from 16 and 25 fractions, and then combine with fractions smaller than fraction 25 for oil extraction. The combined fractions smaller than fraction 25 accounted for 24% of the dehulled seed and contained 44.8% oil (90.8% cotyledons). The overall purity of the dehulled seed can be improved if fractions 16–25, which account for 76% of the dehulled seed, can be enriched to contain about 45% oil (>90% cotyledons). The amount of oil lost in the discard will depend on the efficiency of the hull separation process.

To maximize the throughput of the huller for dehulling larger amounts of seeds, higher feed rates were also performed. The seeds (20 kg) have MC of around 11.5% and the huller's impeller speed was set at medium speed (1400 rpm). As shown in Fig. 5, increasing the feed rate had no significant effect on the weight distribution of
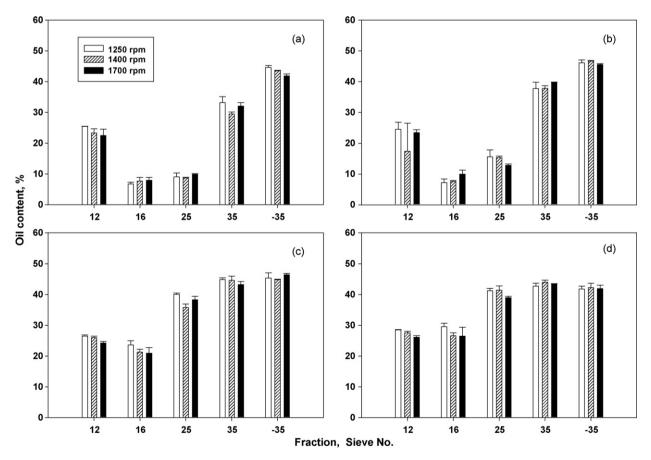

Fig. 4. Oil contents of fractions from dehulled 1-kg seed with (a) 3.5%, (b) 7.1% (as is), (c) 11.4%, and (d) 14.0% moisture content.
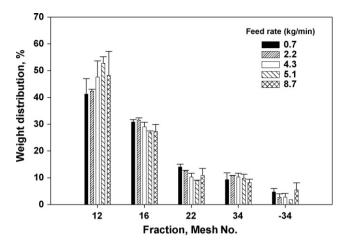
Fig. 5. Weight distribution of fractions from 20-kg seeds dehulled at different feed rates.

the fractions. Therefore, higher feed rates within the range tested may be used in future dehulling runs. The weight distribution was different from that of the 1-kg dehulling (Fig. 2c). This could be due to the slightly bigger opening for 22M screen used in Rotex compared to the No. 25 Ro-Tap screen (Table 1).

3.2. Removing hulls by density grading

To evaluate the impact of dehulling on chlorophyll content and color of the oil, a relatively pure cotyledon sample was produced. This was done by employing Scheme 2 as described in the preceding section. The combined 16M fraction accounted for 55.6% of the total dehulled seed and had oil content less than that of whole seed (Table 4). This fraction contained about 50% hulls. The hulls and cotyledons were loose and free flowing and appeared to be amenable to density grading using a gravity table. Fractions 34M and −34M had about the same oil content and close to 80% cotyledons. Because of the high oil contents and smaller particle size of these fractions, the hulls and cotyledons tend to stick together, making them difficult to separate. Samples of these fractions were set aside for oil extraction.

The CRF obtained from 16M had an oil content of 46.4% or about 94% cotyledons (Table 5). The HRF removed had an oil content of 6.2%. These fractions represented the best cut obtained from the gravity table. Most of the remaining 16M fraction had oil contents ranging from 21 to 35%. Upon rescreening this fraction using an 18-mesh (18M) screen, a CRF with 99.5% cotyledons was obtained. It appears that density grading alone cannot effectively remove most of the hulls from fraction 16M. Density grading of 22M fraction resulted in only slight improvement in its purity. Although this particle size is still suitable for density grading, the poor hull separation was due to the hulls becoming sticky as they absorbed oil from the cotyledons. Higher cotyledon purity could have been achieved if this fraction was processed immediately. In a continuous process, the chance of hulls absorbing oil is greatly reduced because its contact time with the cotyledons after dehulling is relatively short.

3.3. Chlorophyll content and oil color

The chlorophyll contents of the oil from whole seeds were much lower than the 200–260 ppm in screw-pressed oil we reported previously (Table 5). This could be another effect of the relatively dry conditions during the 2006 and 2007 growing seasons. Nevertheless, the 100–160 ppm of chlorophyll in the extracted oil obtained in this study is still about 10 times higher than that of rapeseed oil

(Niewiadomski, 1990). The hexane-extracted oil from whole seeds contained 58% more chlorophyll than the hydraulic-pressed oil, while the chlorophyll contents of the respective oils from dehulled seed fractions were practically the same. Although chlorophyll has limited solubility in hexane, the repeated extraction of whole seeds with fresh (distilled) hexane over 4 h could have extracted more of the pigment. In hydraulic pressing, the extraction time was short (about 30 min per load) and no heat was employed. The amount of chlorophyll varies directly with the amount of hulls in the fractions. However, even with almost pure cotyledons (like fraction 18M CRF), the extracted oil still contained 15–19 ppm of chlorophyll. Therefore, complete dehulling will achieve an 80 and 87% reduction in chlorophyll for hydraulic-pressed and hexane-extracted oil, respectively. For fractions with cotyledon purity of 86%, the chlorophyll content in the hexane-extracted oil was reduced by 72%, while that in hydraulic-pressed oil went down by 57%. The lower reduction in hydraulic-pressed oil was due to the lower chlorophyll content of its whole seed oil, the basis of the calculation.

The CIE $L^*a^*b^*$ color scale was utilized to make use of the green $(-a^*)$ and yellow $(+b^*)$ color values of its three dimensional color space, which is more appropriate for cuphea oil. The L^* value represents lightness (100 being white and 0 as black) and runs from top to bottom of the color space. The a^* and b^* coordinates run perpendicular to L^*. The L^* values were inversely proportional to the chlorophyll content of the oils (Table 5). The L^* values for oils from whole seeds were the darkest as indicated by their lower L^* values (Table 6). The lightest oils were from the 16M and 18M CRFs which have greater than 90% cotyledons. By comparing oil with very close L^* values, i.e., the a^*b^* coordinates are approximately on the same plane, the hexane-extracted oils tend to be greener (more negative a^*) and the hydraulic-pressed oils were more yellow (higher b^* values). This is also consistent with the chlorophyll contents of these oils. In terms of total color difference (ΔE^*) between the whole seed oil and the dehulled seed oil, the oils that were hexane-extracted from 16M and 18M CRFs showed the highest values while those from 22M, 34M, and −34M were basically the same. A similar trend was observed in hydraulic-pressed oils, except for 22M which was slightly lighter than the oils from 34M and −34M.

4. Conclusions

The hulls in cuphea seeds, which contain high amount of chlorophyll, account for 44.6% by weight of the whole seed. The seeds can be dehulled using an impact huller and a screener. If seeds were dried to 3.5% MC before dehulling, 37% of the dehulled seed (containing 8.8%) oil can be removed by screening. The amount of oil lost in the process is similar to those in press cakes obtained by full pressing. The remaining cotyledon-rich fraction contained 39.2% oil, which was 38% higher than that of whole seeds. Hexane-extracted oil contained 70% less chlorophyll content. Seeds with 11.4% MC may also be dehulled to generate 78% of the dehulled seed between 12M and 22M fractions. There is a potential for even higher reduction in chlorophyll in the extracted oil if a cotyledon-rich fraction with ≥44% oil content can be obtained from fractions 16M and 22M of dehulled seeds. The minimum chlorophyll content achievable was 15 ppm from almost pure cotyledons and extracted by hydraulic pressing. Therefore, dehulling cuphea seed can greatly decrease the amount of bleaching clay needed for reducing oil color and the cost associated with its handling and disposal.

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