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ORIGINAL ARTICLE

Effect of moisture content and residence time on dehulling of flaxseed

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Abstract Effects of moisture content and residence time on various dehulling parameters of flaxseed including yield, hull, hullability, extraction rate and embryo (dehulled flaxseed) recovery were studied. A laboratory model rice polisher/ dehulling machine and a laboratory model aspirator were used for dehulling and aspiration (hull separation), respectively. The dehulling experiments were carried out for moisture contents ranging from 1.9 to 7.8% wb and residence times from 20 to 50 sec in dehulling machine at 2000 rpm of abrasive disc (rotor) of the polisher. Both moisture content and residence time played an important role in dehulling of flaxseed. The optimum moisture range and residence time for dehulling of flaxseed were 1.9 to 4.5% wb and 40 sec, respectively.

Keywords Flaxseed · Dehulling · Embryo · Hull · Moisture · Residence time

Flaxseed (*Linum usitatissimum*) is grown for its seeds, fibre and also as an ornamental plant in gardens. It contains high level of lignans and omega-3 fatty acids. The studies on mice have shown that it has helped to reduce growth in some specific types of tumours (Chen et al. 2006). Sahu et al. (2009) reported a simple technique for removal of toxic substance from linseed (flaxseed) meal which can be used to enrich the wheat flour chapatti.

Flaxseed comprises of three layers viz. cotyledon, endosperm and spermoderm from inside to outside. Its oil is distributed mainly in the cotyledon and endosperm while the mucilage and lignans exist in the spermoderm (Oomah and Mazza 1998; Madhusudhan et al. 2000; Zhang et al. 2009). Traditionally, flaxseed has been processed into oil and meal and it has not been dehulled prior to oil extraction. This resulted in deterioration of the oil quality due to gum residue in the oil fraction (Zheng et al. 2003; Zhang et al. 2009).

Dehulling is essentially used to improve the seed meal obtained after oil extraction and to obtain high quality edible oil. During this process, a major part of the fibre and certain pigments are removed which otherwise pass into the meal and lower its quality. About 99% of the oil is stored in kernels and the hulls contain up to 1.1% oil. So, if the hulls are not removed, they may reduce the total yield of oil by absorbing or retaining oil in the pressed cake. For most of the oilseeds, dehulling is not used prior to oil extraction. In case of flaxseed, dehulling is required to recover the hulls for its use as lignan concentrate, a health improving compound.

There are two kinds of dehulling processes, reported for flaxseed, viz. dry process and wet process. Bhatty and Cherdkiatgumchai (1990) used a liquid cyclone process for separation of flaxseed hull which contains less than 10 g/kg oil, about 200 g/kg protein and 330 g/kg total monosaccharide. The wet process is not economical because it involves multiple steps of operations. Use of mechanical means for dry dehulling of seeds to remove flax mucilage has been reported. The fractionation of ground flaxseed with graded sieves and also using air separation method has been investigated by Smith et al. (1946). A similar process of crushing flaxseed into a coarse meal followed by extracting with isopropanol at room temperature and screening the meal on a 0.25 mm sieve to obtain low and high mucilage protein products has been studied by Dev and Quensel (1988).

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Abrasive dehulling is a front-end method to remove the outer layers of flaxseed (Oomah et al. 1996). A novel, multi-sample, tangential abrasive dehulling device (TADD) was designed and tested by Oomah et al. (1981). The design of TADD was further refined by Reichert et al. (1986) and tested for the dehulling of wheat and sorghum. Lawton and Faubion (1989) used TADD to measure kernel hardness in sorghum, wheat and corn. Oomah et al. (1996) used the TADD process of dehulling of flaxseed and reported that best dehulling was achieved when moisture content was reduced to 35–20 g/kg and stored for at least 24 h and dehulled at a speed of 2000 rpm for 25 sec. Some works on dehulling of flaxseeds are reported in literature (Oomah et al. 1996; Oomah and Mazza 1997, 1998; Madhusudhan et al. 2000; Zhang et al. 2009).

The moisture content of the seed generally affects the dehulling operation since wet seed is difficult to split and may clog the huller. If the seeds are dried suitably, the kernels may disintegrate cleanly and excessively. Therefore, an attempt has been made to study the effect of moisture content and residence time on the dehulling parameters of flaxseed using a laboratory model rice polisher using a constant speed for optimum dehulling.

Materials and methods

The flaxseed (*Linum usitatissimum*) was procured from local market. The seeds were cleaned and graded by sieves to remove broken seeds and other foreign materials.

A laboratory model rice polisher (STE–08, Cadence Electronics Systems, Ambala, Haryana, India) was used for dehulling of flaxseed. The hull was separated from dehulled mixture by using a batch type laboratory aspirator (6726, M/s Osaw Industrial Products Pvt Ltd, Ambala, Haryana, India). A small recirculatory tray dryer (batch type) was used to dry the flaxseed to lower moisture content. Two ASTM sieves (ASTM Nr 10 and 20 with size of openings as 1.651 mm and 0.833 mm, respectively) were used for cleaning and separation of undesired material from raw and dehulled materials.

Moisture conditioning of flaxseed The initial moisture content of flaxseed was determined by hot air oven method at 105°C for the period until the constant weight reached (AOAC 1984). The flaxseed was conditioned for different moisture content levels (2, 4, 6 and 8% wb) e.g. (i) if desired moisture content was less than the initial moisture content, the seeds were dried in a small recirculatory tray dryer (batch type) and stored in a cool place at 5°C in self sealable polyethylene bags for experimentation and (ii) to achieve moisture content more than the initial moisture content, the distilled water (desired quantity) was added and mixed thoroughly by hand and stored in a cool place at 5°C in refrigerator for over-night / 24 h.

The desired quantity of distilled water to be added, or moisture to be evaporated (seed to be dried), was calculated using following formula (Chakraverty 1988):

$$W_m = \mathrm{W}_1 \left[\frac{\Delta \mathrm{M}}{100 - M_2} \right] \tag{1}$$

where, $\mathrm{W_m}$ is moisture to be added or removed (g), $\mathrm{W_1}$ is initial weight of the seed at $\mathrm{M_1}$(g), $\Delta M = M_2 - M_1$ (for $\mathrm{M_2 > M_1}$) and $\Delta M = M_1 - M_2$ (for $\mathrm{M_1 > M_2}$), $\mathrm{M_1}$ is initial moisture content (wb) and $\mathrm{M_2}$ is final or desired moisture content (wb).

Table 1 Analysis of variance for hull, yield, extraction rate, hullability and embryo recovery of flaxseed at various moisture contents and residence time

Source	Degrees of freedom	Mean square	F-value	*p*-value
Hull				
Moisture content	3	144.49	7.39[a]	0.01
Time	3	48.06	2.46[NS]	0.13
Yield				
Moisture content	3	168.83	5.89[a]	0.02
Time	3	120.75	4.21[a]	0.04
Extration rate				
Moisture content	3	168.83	5.89[a]	0.02
Time	3	120.75	4.21[a]	0.04
Hullability				
Moisture content	3	884.90	5.89[a]	0.02
Time	3	632.86	4.21[a]	0.04
Embryo recovery				
Moisture content	3	953.41	41.97[a]	0.00
Time	3	353.47	15.56[a]	0.00

$F_{3,3,0.05}$=3.86; [a] Significant at $p \leq 0.05$; *NS* Not significant

Though vacuum oven or microwave oven methods are less time consuming process to achieve lower moisture contents (i.e. 2% wb), the small recirculatory tray dryer (batch type) available in our laboratory was used.

Experimental procedure The experiments were conducted at various moisture contents as well as residence times using laboratory rice polisher.

The flaxseed was conditioned to obtain moisture contents of 2, 4, 6 and 8% wb. The samples were allowed to equilibrate at room temperature 30±2°C prior to dehulling and its moisture contents were determined in triplicate and the average values have been found as 1.9, 4.5, 6.2 and 7.8%, respectively. The different residence times selected were 20, 30, 40 and 50 sec.

The flaxseed samples were dehulled in the laboratory model rice polisher. In the polisher, there is a provision for speed variation (1120, 1460 and 2000 rpm) of abrasive disc (rotor) through cone pulleys attached to motor and rotor shafts. During preliminary trials, the lower speeds were not sufficient to dehull the flaxseed; therefore, the dehulling experiments were performed at 2000 rpm of the rotor at different moisture contents and residence times of flaxseed as stated above.

The effect of independent variables namely, the moisture content of seed and residence time at constant speed were studied using 100 g seed in duplicate samples.

The raw flaxseed was sieved by ASTM Nr 10 sieve and the flaxseed retained on the sieve was used for dehulling experiments. The ASTM Nr 20 sieve was used to separate the powder from the mixture of the dehulled fraction. The powder was weighed and the fraction retained on ASTM Nr 20 sieve was fed in the laboratory aspirator for separation of hull. The hulls and dehulled mixture (unhulled and dehulled seeds) were obtained after aspiration and weighed. The dehulled mixture was manually separated which gave the embryo recovery. It is to mention here that in the above process almost no brokens were formed.

Calculations of dehulling parameters The various dehulling parameters were calculated using equations as shown below:

Yield of hull (%): It is defined as weight loss of the seed after dehulling and expressed as (Oomah et al. 1996):

$$Y_{hull}(\text{fraction}) = \frac{\Delta W}{W_{in}} \tag{2a}$$

and,

$$Y_{hull}(\%) = \left(\frac{\Delta W}{W_{in}}\right) \times 100 \tag{2b}$$

where, ΔW = weight loss of seed = weight of (powder + broken) + machine loss, Machine loss = (feed input – products output) from the machine, and W_{in} = initial sample weight (prior to dehulling), 100 g in present case.

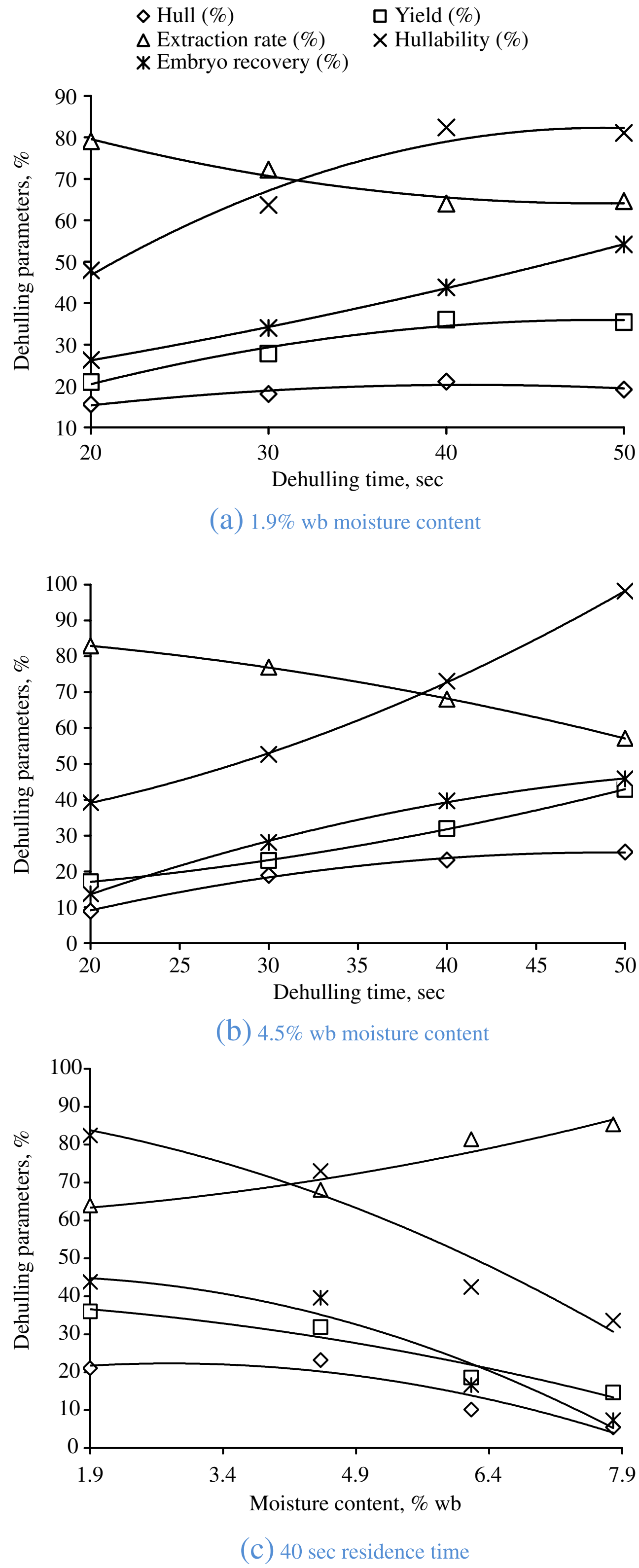

Fig. 1 Effect of residence time and moisture content of flaxseed on various dehulling parameters

Table 2 Second order (quadratic) equations and R^2 - values of various dehulling parameters in terms of residence time (range: 20 to 50 sec)

Moisture content (%, wb)	Dehulling parameters, %	Second order equation	R^2
1.9	Hull	$y = -0.011\,T^2 + 0.9087\,T + 1.545$	0.904
	Yield	$y = -0.0187T^2 + 1.8253\,T - 8.6151$	0.967
	Extraction rate	$y = 0.0187\,T^2 - 1.8253\,T + 108.62$	0.967
	Hullability	$y = -0.0428\,T^2 + 4.1788\,T - 19.723$	0.967
	Embryo recovery	$y = 0.0065\,T^2 + 0.483\,T + 13.945$	1.000
4.5	Hull	$y = -0.0193\,T^2 + 1.887\,T - 20.923$	0.996
	Yield	$y = 0.0127\,T^2 - 0.0278\,T + 12.548$	1.000
	Extraction rate	$y = -0.0127\,T^2 + 0.0278\,T + 87.452$	1.000
	Hullability	$y = 0.0291\,T^2 - 0.0636\,T + 28.727$	1.000
	Embryo recovery	$y = -0.0205\,T^2 + 2.5162\,T - 28.505$	0.999

Hullability (%): It is defined as the ratio of hull removed by the dehulling machine to the total quantity of hull in the seed (Oomah et al. 1996) and written as:

$$H(\text{fraction}) = \frac{\Delta W}{W_{m-hull}} \tag{3a}$$

and,

$$H(\%) = \left(\frac{\Delta W}{W_{m-hull}}\right) \times 100 \tag{3b}$$

where, $W_{m\text{-hull}}$ = total quantity of hull in raw flaxseed (per 100 g seed) obtained by manual hulling of 50 seeds.

Extraction rate (ER)(%): It is an indication of endosperm recovery and calculated as (Oomah et al. 1996):

$$ER(fraction) = \frac{W_{\text{dehulled mix}}}{W_{in}} = \frac{W_{in} - \Delta W}{W_{in}} = 1 - Y_{hull}(fraction) \tag{4a}$$

and,

$$ER(\%) = 100 - Y_{hull}(\%) \tag{4b}$$

where, $W_{\text{dehulled mix}}$ is weight of (dehulled + un-hulled) seed mixture after dehulling.

Hull (%): It is defined as the ratio of hull recovered to the total quantity of hull present in the seed. It is written as (Oomah et al. 1996):

$$R_{hull}(fraction) = \frac{W_{r-hull}}{W_{m-hull}} \tag{5a}$$

and,

$$R_{hull}(\%) = \left(\frac{W_{r-hull}}{W_{m-hull}}\right) \times 100 \tag{5b}$$

where, R_{hull} is hull recovered (fraction or %); $W_{r\text{-hull}}$ is weight of recovered hull by aspirator (per 100 g seed) and $W_{m\text{-hull}}$ is weight of hull (per 100 g seed) obtained by manual hulling of 50 seeds.

Embryo recovery (%): It is defined as the ratio of dehulled whole flaxseed (embryo), obtained after dehulling to the actually embryo present in the seed. It may be expressed as:

$$R_{embryo}(fraction) = \frac{W_{r-embryo}}{W_{m-embryo}} \tag{6a}$$

and,

$$R_{embryo}(\%) = \left(\frac{W_{r-embryo}}{W_{m-embryo}}\right) \times 100 \tag{6b}$$

where, R_{embryo} is embryo recovery (fraction or %); $W_{r\text{-embryo}}$ is weight of recovered embryo (per 100 g seed) and $W_{m\text{-embryo}}$ is the weight of embryo in the seed obtained by manual hulling of 50 seeds (per 100 g seed).

Statistical analysis Equations 2 to 6 were used to calculate the various dehulling parameters and to test the effect of moisture content and residence time on the dehulling parameters, a two way analysis of variance was performed using MS-Excel 2003 software.

Table 3 Second order (quadratic) equations and R^2 - values of various dehulling parameters in terms of moisture content (range: 1.9% wb to 7.8% wb) (Residence time=40 sec)

Dehulling parameters, %	Second order equation	R^2
Hull	$y = -0.7648M^2 + 4.4375M + 15.945$	0.892
Yield	$y = -0.3534M^2 - 0.5216M + 38.961$	0.938
Extraction rate	$y = 0.3534M^2 + 0.5216M + 61.039$	0.938
Hullability	$y = -0.809M^2 - 1.1941M + 89.197$	0.938
Embryo	$y = -0.9611M^2 + 2.6197M + 43.304$	0.944

Results and discussion

Table 1 indicates that all dehulling parameters were significantly ($P \leq 0.05$) affected by moisture content and residence time except percent hull, which was not significantly affected by residence time.

It is observed from Fig. 1 that embryo recovery increased with decrease in moisture content of flaxseed. The values of various dehulling parameters were favourable at 1.9% and 4.5% wb moisture content and not encouraging at 6.2% and 7.8% wb moisture contents. These results are in agreement with 20 to 35 g/kg (Oomah et al. 1996, Oomah and Mazza 1997, 1998) and 54 g/kg wet basis (Madhusudhan et al. 2000) of moisture content required for dry dehulling of flaxseed. At 1.9% wb moisture content, hull, yield, extraction rate and hullability ranged from 15.6 to 21.1%, 20.9 to 36%, 64 to 79.1% and 47.9 to 82.4%, respectively. The values of hull, yield, extraction rate and hullability varied from 8.9 to 25.4%, 17.1 to 42.9%, 57.1 to 82.9% and 39.2 to 98%, respectively at 4.5% moisture content of flaxseed. Similar values of hull, yield, extraction rate and hullability as 17.4 to 27.5%, 20.3 to 27.1%, 72.9 to 79.7% and 50.3 to 90.9% respectively had been reported by Oomah et al. (1996) for 20 to 35 g/kg moisture content for seven cultivars of flaxseed. The embryo recovery varied from 26.3 to 54.2% and 13.7 to 45.8% for 1.9% and 4.5% moisture content of flaxseed, respectively.

It is also seen from Fig. 1(a–b) that yield of hull, hullability, hull and embryo recovery have increased as the residence time increased. The extraction rate decreased with increase in residence time. The decrease in extraction rate was due to more powder formation at higher residence times for abrasion. The various dehulling parameters were best fitted for second order (quadratic) equations using MS-Excel 2003 software. Various regression equations along with the R^2- values for moisture contents of 1.9% wb and 4.5% wb are presented in Table 2, which would be helpful in prediction of the variation of dehulling parameters with residence time at the above indicated moisture contents.

During experiments, it was observed that when residence time was increased from 40 to 50 sec, the oil released from the seed got mixed up with dehulled output from the polisher and hence it was very difficult to properly separate the hull by using the aspirator. Hence, variation of various dehulling parameters with moisture contents has been plotted for 40 sec residence time (Fig. 1c). The hull, yield, extraction rate and hullability varied from 5.4 to 23.2%, 14.7 to 36%, 64 to 85.3% and 42.5 to 82.4%, respectively. The embryo recovery varied from 7.4 to 43.8% for 40 sec residence time. It is clear from Fig. 1(c) that extraction rate was more for higher moisture content and hence the more un-hulled seed was found in the dehulled mixture (dehulled + un-hulled). Therefore, less embryo recovery was found at the higher moisture contents. It is also seen that for moisture range (1.9% wb to 4.5% wb), the dehulling parameters have better value and little variation as well. Various dehulling parameters were best fitted for second order (quadratic) equations using MS-Excel 2003 software. Table 3 gives various equations along with R^2-values with respect to moisture contents for residence time of 40 sec. These regression equations may provide the prediction of dehulling parameters with moisture content at 40 sec residence time.

From above discussion, it is inferred that for proper dehulling of flaxseed, the moisture content should be lower (2 to 4% wb) and residence time should be optimized as per the type of dehulling equipment used. The dehulling of flaxseed, used for separation of hulls and embryo, prior to crushing is of economic importance as it improves the feed value of flaxseed meal (Oomah et al. 1996). The hulls and embryo, thus separated, may be used either as such or for further processing. The flaxseed hulls may be further processed to remove flaxseed gum and oil. This process results in a lignan-rich component of flaxseed, a flaxseed gum extract and the flaxseed oil. These separated components of flaxseed may be used in products such as feed and personal care products or nutraceuticals.

Conclusion

It was found that moisture content of flaxseed plays an important role in its dehulling performance. The dehulling performance was favourable at lower moisture content (1.9% wb and 4.5% wb) for 40 sec residence time and 2000 rpm of abrasive disc (rotor) of the polisher.

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