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Optimizing the debranning of wheat for incorporation in animal feed production

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ABSTRACT. Wheat, the predominant feedstock for ethanol production in Canada may be debranned prior to the milling, fermentation and downstream processes. Experiments were carried out using two the Satake mill and tangential abrasive dehulling device (TADD) to remove the bran layer of wheat to optimize the debranning process. Two hundred gram samples of wheat grains were debranned in the Satake mill at grit sizes of 30, 36 and 40, retention time of 30, 60 and 90 s and rotational speed of 1215, 1412 and 1515 rpm or in the TADD at grit sizes of 30, 36, 50 and 80, retention time of 2, 3, 4 and 5 min and rotational speed of 900 rpm. The statistical analysis indicated that rotational speed and retention time were the most significant factors in Satake mill and grit size and retention time affected debranning efficiency in TADD. Using abrasive rollers of higher grit size (fine grit) resulted in a decrease in the percentage removal of bran whereas long retention time caused a high amount of bran to be removed. This, in turn, results in an undesirable loss in starch content of the kernel. . The results indicate that rotation speed of 1412 rpm, 40 grit size and 60 s retention time are the optimum condition for bran production for the Satake mill. Similarly, 900 rpm rotation speed, 50 grit size and 300 s retention time are the optimum conditions for the TADD mill though bran obtained from debranning in TADD was low. Based upon starch separation efficiency, the optimized conditions for the Satake was more desirable compared to TADD.

Keywords: Debranning, Satake mill, tangential abrasive dehulling device, grit size, retention time, rotational speed, starch separation efficiency.

INTRODUCTION. The production and consumption of animal-based food products derived from cattle, swine, sheep and poultry has increased tremendously in developing countries due to population growth and increase in affluence in many countries. According to a study by the IFPRI, "global production and consumption of meat will continue to rise, from 233 million tonnes (t) in the year 2000 to 300 million t in 2020, as will that of milk, from 568 to 700 million t over the same period" (Delgado *et al.* 1999). Animal-production researchers have demonstrated that the quality of these products is directly related to animal feeding practices (Capucille *et al.* 2004; Gatlin *et al.* 2003; Zaghini *et al.* 2005). Feed ingredients nutritionally enhance and improve the production capabilities of the animals. Therefore, the animal feed ingredients affect the quality of the resulting products and the potential human health associated with consumption of animal- based food.

The animal feeds presently available in the markets contain mixtures of plant-based products, as well as other ingredients. Most compounded feeds contain limited amount of grains and oilseed cakes. During the production, over- heating of soybean during roasting and oil removing steps could reduce the nutritional quality and the steam treatment could increase the moisture and rancidity in dehusked rice (Uppal *et al.*, UNAPCAEM). Among the above mentioned grain- based feeds, our investigation primarily deals with wheat bran- based animal feeds. According to previous researches, desired levels of livestock performance are not always achieved when forage is consumed alone. Improving weight gain of cattle consuming forages with moderately high protein contents may require the use of energy supplements. But the "use of the most common energy supplement, cereal grains, can decrease forage intake and digestibility" (Hoover 1986). Wheat bran, on the other hand, increases energy intake when cattle consume roughage without the negative effects often associated with cereal grain supplementation (Horn and McCollum 1987). These negative effects include inadequate nutrient supply to cattle and horses. Similar findings have been reported by studies conducted on mature pigs, especially breeding sows (Noblet *et al.* 2001).

Since wheat bran is a byproduct of milling, technological developments in milling operations and the advantages associated with them are equally important (Scudamore 2008) and should be investigated. Debranning allows uniform removal of bran layers all around the dorsal part of grain ensuring that the endosperm region remains intact (Bottega *et al.* 2009). Debranning of grains can be carried out by friction (peeling), by abrasion (pearling), or by a combination of these two operations. Numerous studies have evaluated the benefits of abrasion as a means of improving wheat flour milling. Some commonly abrasive dehulling equipment include a Satake grain testing mill (Wang *et al* 1997), a modified Udy grinding mill (Shepherd 1979) and a tangential abrasive dehulling device (TADD). In the present investigation, the Satake mill and TADD have been taken into consideration. TADD works on the principle of tangential abrasion and is preferred over other roller mills and attrition mills because it tends to permit more controlled removal of successive layers of grains with less breakage of residual kernels (Reichert and Youngs 1976).

Thus the objective of this study was to optimize the debranning of wheat using two milling equipment, Satake mill and TADD before the bran was incorporated in animal feed production.

MATERIAL AND METHODS. Terra Grain Fuels, an ethanol plant located in Belle Plaine, SK, supplied the wheat grains which were stored in large plastic bins to prevent rodent infestation. The dockage tester and aspirator (optional) were used to clean the grain off weeds, stones, broken kernels and other grains before the wheat was subjected to debranning.

Satake mill. The Satake mill is a unique roller mill, developed by Satake, which can be utilised in the cereal milling industry for applications such as debranning wheat, dehulling barley and degerming maize. The mill sequentially removes the outer kernel bran layers prior to milling or subsequent processing, which optimizes the yield and reduces the amount of bran contamination in the finished product (Cheli *et al.* 2010). The equipment used is able to sequentially strip the bran layers, giving the degree of control that the commercial flour miller demands. The mill comprises of an abrasive roller (50 grit size rough surface) made up of carborandum or emery, which is placed on a shaft within the milling chamber of the machine and is surrounded by a metallic casting. The mill has a smooth peripheral surface on which 2-3 angularly spaced, raised hulling portions are present which extend in the longitudinal direction of the roller. Another advantage of the Stake mill is its flexibility. The ability to adjust the amount of bran removed is ideal for mills required to produce a range of products such as wholemeals, browns and white flours.

Two hundred grams of wheat grain was used as the batch size. The grains enter at the top of the machine and move into the abrasion section. They are abraded between the roller and the metallic casting before they moved to the bottom of the friction section where a series of lifters moved the grains towards the discharge end causing friction between the kernels and the screen. The process is fully automated and features a control system that adjusts for variations in the nature of the raw product being fed into the system. The debranning process also has important applications in starch and ethanol product systems, where the removal of bran prior to milling can substantially improve the efficiency and performance of subsequent processes. After milling, the husk and bran are collected together in the wooden box located below the milling chamber, whereas the grain and husk plus bran get collected separately (Opoku *et al.* 2003). The degree of debranning was controlled by a number of factors like the stone surface grit size, screen slots, the revolutions per minute (rpm) and airflow through the materials. The Satake mill has high efficiency in debranning because the grains are forced outwardly by the rotor and then get rubbed against the metallic casting surrounding the rotor. During the experiment, the grit size of the rollers, the retention time of feed material and the speed of rotation of the rollers were varied in order to optimize the debranning process. Grit sizes of 30, 36 and 40, retention time of 30, 60 and 90 s and rotational speed of 1215, 1412 and 1515 rpm were used for the experiment. Three replications for each condition were conducted.

Tangential abrasive dehulling device (TADD). The tangential abrasive dehulling device is used for rapidly and reproducibly debranning grains. The machined aluminium head plate holds eight stainless steel open-bottomed sample cups mounted vertically over the horizontally rotating disk. The cups are mounted vertically with their centers equally spaced around a circle. Each batch of wheat grains comprised of 200 g of sample. A cover plate with a rubberized material attached to it was used to cover the cups when the machine was in operation. A digital electronic timer (Model 8683-10, ColeParmer Instrument Company, Chicago, IL) was used to adjust the residence time during a test. The sample-cup plate was positioned so that the bottom edges of the cups are very close to the rotating disk. The device simultaneously collects and cleans the dehulled grain, removing any residual fine material that had not escaped under the sample cups (Mwasaru *et al.* 1988). After debranning, the debranned grains are collected using a vacuum aspirating collector device (Oomah *et al.* 1981), and the husk and bran are collected through a cyclone separator device, connected to the TADD (Opoku *et al.* 2003). The mesh screen on the air outlet from the collector retained the dehulled grains but allowed the fines to be removed. The operating variables, namely, grit sizes of 30, 36, 50 and 80, retention time of 2, 3, 4 and 5 min and rotational speed of 900 rpm were used for the experiment. Three replications for each condition were conducted.

Moisture content determination. The bran obtained by debranning in the Satake mill and TADD was tested for moisture content. Two to three grams of the samples (ground to pass circular 1mm sieve) were uniformly distributed on the dishes and dried at 135°C for 2 hours (AACC 44-19.01, 1999). Three runs were conducted for the samples from the two abrasive devices.

Starch Separation Efficiency. The data obtained for the percent bran fraction from Satake mill and TADD were compared and the combinations (speed, grit size and retention time) leading to optimal bran production were further analyzed for starch content. The method used to determine total starch in cereal products followed the procedure as stated in AOAC Method 996.11 and AACC Method 76.13 for Total Starch Assay Procedure (Megazyme Amyloglucosidase/ α-Amylase method).

The starch separation efficiency for the two abrasive devices, Satake mill and TADD was calculated using the value of starch content obtained. Three replications for each sample were conducted. Starch separation efficiency can be calculated using the following equation:

$$= \left(\frac{\text{wt. of debranned wheat} \times \text{total starch in debranned kernels}}{(\text{wt. of whole wheat} \times \text{total starch in whole wheat})}\right) \times 100$$

Statistical analysis. Statistical analysis of the results obtained for debranning and starch analysis were done using SAS Version 9.2 Software (SAS, Cary, NC). The GLM and ANOVA procedures will be used in the Student- Newman- Keuls test. Analysis of variance will be used to determine if differences between treatments are significant at 5% significance level. The analysis helps investigate the variables which have significant effect on debranning and starch analysis.

RESULTS AND DISCUSSION

Debranning. The bran percentage and moisture content obtained for the different grit sizes, rotation speed and retention times for Satake mill and TADD are shown in Table 1 and Table 2 respectively:

Debranning of wheat samples (200 g sample size) gave the following results under different combinations of rotational speed, grit size and retention times. Debranning results for the Satake mill for 200 g sample size indicated that using higher retention time (90s) resulted in removal of high amount of bran from the wheat grains. This could lead to undesirable loss in the starch content from the wheat kernels along with the bran as the inner layers of the husk and the outer layers of the germ and endosperm may get removed.

Table 1: Debranning of wheat using the Satake mill (number in parenthesis is standard deviation)

Rotation speed(rpm)	Grit Size	Retention time (s)	Bran fraction (%)*
1215	30	30	3.63[a] (0.09)
1215	30	60	17.11[b] (0.56)
1215	30	90	31.94[c] (0.23)
1215	36	30	4.44[a] (0.83)
1215	36	60	18.06[b] (0.12)
1215	36	90	33.05[c] (0.53)
1215	40	30	6.69[a] (0.05)
1215	40	60	18.19[b] (0.26)
1215	40	90	30.64[c] (0.06)
1412	30	30	5.65[a] (0.39)
1412	30	60	20.03[b] (1.16)
1412	30	90	35.73[c] (0.86)
1412	36	30	6.52[a] (0.11)
1412	36	60	21.65[b] (1.13)
1412	36	90	36.01[c] (0.19)
1412	40	30	5.65[a] (0.31)
1412	40	60	18.52[b] (0.76)
1412	40	90	33.21[c] (0.32)
1515	30	30	6.08[a] (0.98)
1515	30	60	14.03[b] (0.26)
1515	30	90	31.83[c] (0.29)
1515	36	30	6.75[a] (0.11)
1515	36	60	20.82[b] (0.32)
1515	36	90	37.85[c] (0.69)
1515	40	30	4.17[a] (0.10)
1515	40	60	22.90[b] (0.02)
1515	40	90	36.60[c] (0.34)

*n= 3; a,b, c= indicate that means with the same letter are not significantly different at 95% confidence

A combination of large grit size and high retention time resulted in excessive bran removal. The results indicated that grit sizes 30, 36 and 40; a retention time of 60s and all rotational speeds are optimum to produce the desirable amount of bran from the Satake mill.

Table 2: Debranning of wheat using the tangential abrasive dehulling device (TADD) (number in parenthesis is standard deviation)

Rotation speed (rpm)	Grit size	Retention time (s)	Bran fraction (%)*
900	30	120	3.53[a] (0.30)
900	30	180	3.99[a] (0.37)
900	30	240	5.63[b] (0.74)
900	30	300	7.10[c] (0.15)
900	36	120	3.19[a] (0.13)
900	36	180	5.18[a] (0.21)
900	36	240	6.61[b] (0.01)
900	36	300	8.13[c] (0.36)
900	50	120	9.17[a] (0.40)
900	50	180	13.43[b] (0.53)
900	50	240	16.38[c] (0.64)
900	50	300	18.61[d] (0.57)
900	80	120	10.78[a] (0.37)
900	80	180	16.01[b] (0.07)
900	80	240	19.94[c] (0.09)
900	80	300	21.51[d] (0.09)

*n= 3; a,b, c, d = indicate that means with the same letter are not significantly different at 95% confidence

Debranning in the TADD resulted in lower yield of bran under the above conditions as compared to Satake mill. Among the conditions provided above, the grit size 50 produced the highest amount of bran. The retention times 180, 240, and 300 seconds led to sufficient bran production.

Statistical analysis. The statistical analysis suggests that retention time and rotation speed have significant effect on debranning in case of Satake mill, whereas, grit size is most significant in TADD debranning as shown in Table 3 and 4.

Table 3: Statistical analysis for debranning fraction for Satake mill

Variable	Mean sq.	F-value	Pr (>F)
Time	3681.2514	1873.1804	< 2.2×10^{-16} ***
Rotational speed	24.8871	10.4126	0.0026 **
Grit size	20.3585	4.2709	0.0456 *
Rotational speed x grit x time	7.7699	6.2993	0.0164 *

Signif. Codes: 0 ‘***’ 0.001 ‘**’0.01 ‘*’0.05 ‘.’0.1 ‘’1

Table 4: Statistical analysis for debranning fraction for TADD mill

Variable	Mean sq.	F-value	Pr (>F)
Grit size	370.93	57.5492	6.449e-06 ***
Time	115.18	17.8695	0.001174 **
Grit x Time	16.66	2.5849	0.133866

Signif. Codes: 0 ‘***’ 0.001 ‘**’0.01 ‘*’0.05 ‘.’0.1 ‘’1

Starch separation efficiency. Debranned kernel samples from the two mills (selected optimized variables resulting in 12- 19% bran production) were tested for starch content. The moisture content data obtained were used for starch analysis of the samples. The results of starch analysis for bran and debranned kernels from Satake mill and TADD are given in Table 5 and 6.

Table 5: Starch content of debranned kernels from the Satake mill (number in parenthesis is standard deviation)

Speed (rpm)	Grit size (mm)	Retention time (s)	Moisture content* (%)	Starch content* (%)	Starch separation efficiency** (%)
1215	30	60	9.48	68.85^{a} (0.65)	80.63^{a} (0.76)
1215	36	60	9.45	63.42^{a} (0.65)	73.50^{a} (0.76)
1215	40	60	9.50	75.42^{a} (0.22)	88.12^{a} (0.26)
1412	40	60	9.85	85.79^{a} (0.96)	99.34^{a} (1.11)
1515	30	60	10.19	63.96^{a} (1.76)	78.42^{a} (2.16)

*n = 3, **initial whole wheat starch content = 69.04% ; a= indicate that means with the same letter are not significantly different at 95% confidence

Moisture content is considered as a prerequisite for starch gelatinization. Also, depending on the moisture content of the wheat, debranning caused a decrease of rapture point (Δ*h1)* from 55 to 71% (Dziki 2004). Furthermore, wheat grain moisture content influences grain hardness (Brown *et al.* 1993) which in turn affects debranning (Obuchowski and Bushuk 1980). The data obtained indicate that rotation speed of 1414 rpm, 40 grit size and 60 s retention time led to higher starch separation efficiency.

Table 6: Starch analysis from TADD mill (number in parenthesis is standard deviation)

Speed (rpm)	Grit size (mm)	Retention time (s)	Moisture content* (%)	Starch content* (%)	Starch separation efficiency** (%)
900	50	180	10.12	53.59[a] (0.27)	67.20[a] (0.34)
900	50	240	10.05	64.36[a] (0.28)	77.95[a] (0.34)
900	50	300	9.86	69.22[a] (0.93)	81.60[a] (1.10)
900	80	180	9.98	61.91[a] (0.79)	75.31[a] (0.96)

*n = 3, **initial whole wheat starch content = 69.04%; a = indicate that means with the same letter are not significantly different at 95% confidence

Starch separation efficiency was higher with; rotational speed of 900 rpm, 50 grit size and 300s retention time. Statistical analysis of the data suggests that both starch content and separation efficiency are not affected by rotation speed, retention time and grit size.

CONCLUSION. The experimental results on comparison indicate that Satake mill provides better debranning results as compared to TADD. This is because using the Satake mill, optimum bran production could be done in a short duration of 60 s whereas in case of the TADD mill, it takes 300s. Since bran production rate was high using Satake mill, this means that productivity will be higher using Satake mill for processing of wheat feedstock. Based upon starch separation efficiency, the optimized conditions for the Satake is more desirable compared to TADD. The results indicate that rotation speed of 1412 rpm, 40 grit size and 60 s retention time are the optimum condition for bran production for the Satake mill. Similarly, 900 rpm rotation speed, 50 grit size and 300 s retention time are the optimum conditions for the TADD mill. In the case of Satake mill, both retention time and grit size had significant effect on debranning whereas, only grit size had higher significance on debranning in case of the TADD mill.

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