Comparison of Different Methods for Rice Bran Stabilization and Their Impact on Oil Extraction and Nutrient Destruction

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ABSTRACT

The impact of four thermal processing methods on rice bran stabilization, oil extraction, and nutrient destruction was compared. All of the processing equipments, except the pellet mill, had a positive effect on rice bran stabilization. Maximum oil (204 g/kg) was extracted from samples processed using the pellet cooker, followed by the extruder (202 g/kg), while samples processed by the pellet mill gave the least (172 g/kg) oil yield. It was further observed that oil in samples with lower bulk densities and high fines tended to be easily extracted with few exceptions. The total energy input for the extruder (481 kJ) and expander cookers (412 kJ) was significantly higher than that of the pellet cooker (218 kJ) and pellet mill (167 kJ). This high-energy input causes the destruction of vitamin E, as was observed in the samples processed by extruder and expander cookers.

Rice bran, a by product of rice milling, is a powdery, fluffy material that consists of particles of pericarp, seed coat, aleurone, germ, and fine starchy endosperm. It may also contain parts of seeds or kernels. Rice bran consists of 12–25% fat, 10–16% protein, 10–20% starch, 3–8% reducing sugars, 8–11% hemicelluloses, 10–12% celluloses, 6–15% crude fiber, 6.5–10% ash, 0.9–2.9% oryzanol (10), and essential mineral contents (18). Rice bran contains low amounts of soluble fiber; therefore, it is cholesterol lowering. Other health-enhancing properties may be related to compounds, such as plant sterols, tocopherols, oryzanol, and β-sitosterol (15).

Rice bran contains trypsin, chemotrypsin inhibitors, phytate, and hemaglutinin-lectin. Due to these toxic or indigestible components, rice bran is not readily available as a human food source, although it is incorporated into poultry and cattle feed as a low-quality ingredient (6). However, knowledge and technological advances have made it possible to better overcome these toxicity problems. A significant development was achieved by applying a heat treatment to alleviate the adverse effects of toxicities caused by raw rice bran (6). Functional properties of starch of rice bran, such as water absorption, water solubility, bulk density, and enzyme susceptibility, were improved significantly after stabilization (18).

Rice bran can serve as a source of edible oil because it contains more than 20% oil and 0.1–0.14% vitamin E (17). However, upon milling, this oil hydrolyzes rapidly into free fatty acids (FFA) by the action of the lipase enzyme present in the bran (2). Therefore, enzymes present in rice bran must be denatured immediately after milling if the oil is to be extracted (16). Once the rice bran has stabilized, it can be stored for 30 to 60 days without an appreciable increase in FFA content (13). One method of stabilizing rice bran is extrusion (14) using twin-screw extruders called wet extrusion. During wet extrusion, steam increases the thermal energy and moisture content of extrudates, so it requires lower processing temperatures to inactivate the enzymes. However, the relatively high moisture content of the processed bran is a limitation since the bran requires drying prior to oil extraction.

A pellet cooker is used for the pelleted feed industry, and allows the rice bran to be processed at low moistures (14–17%) and requires medium temperatures (110–130ºC) to inactivate the enzymes. The cooker produces pellets that typically have a very open cell structure and are extremely dense and durable. Combinations of low moisture, excellent pellet durability, high pellet density, and an open cell structure seem to make the cooker an excellent machine for rice bran processing.

An expander cooker subjects the rice bran to high-pressure cooking, utilizing live steam and water to elevate the moisture and temperature and cause the agglomeration of the fine particles into porous collets (21). There is minimal functional difference between the expander and single-shaft extruder. Both systems work according to the known high temperature short time (HTST) principle and use approximately the same treatment parameters.

A pellet mill is also used to stabilize rice bran. But the pellet mill is also used to make feed pellets by increasing the bulk density and allowing more products in any given space. In the pellet mill, material is fed through the feeding hopper to a conditioner, where steam and other liquids are added. The conditioned material flows into the pellet chamber in which pellets are formed and is sent to the cooler where air coming from the fans cools these pellets (20).

All four methods mentioned above are used in food industries to stabilize the rice bran. To find out the most suitable method regarding stabilization of rice bran, oil extraction, vitamin E destruction, and energy inputs, this present study was conducted.

MATERIALS AND METHODS

Rice Bran

Rice bran (2,000 kg) was obtained from Riceland Foods, Inc. in Stuttgart, AK, U.S.A., and transported to the Wenger Manufacturing Pilot Plant in Sabetha, KS, U.S.A. Riceland Foods Inc. also sent 500 kg of rice bran to the Food Protein Research and Development Center (FPRDC), Texas A&M University in College Station, TX, U.S.A., for processing.

Processing of Rice Bran

The following four types of thermal/mechanical processing equipment were used to process the rice bran:

- Single-screw extruder (Wenger X-85 Extruder with conditioner model 2DDC, Sabetha, KS, U.S.A.)

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- Pellet cooker (Wenger Universal Pellet Cooker [UP/C], 1K with conditioner model 7 DDC, Sabetha)
- Lab pellet mill (California Pellet Mill [CPM], with single-shaft conditioner, Crawfordsville, IN, U.S.A.)
- Expander cooker (Anderson Expander Cooker [4.5"], Cleveland, OH, U.S.A.)

Rice bran stabilization using the single-screw extruder and the pellet cooker was performed at the pilot plant. The stabilized rice bran was stored in the freezer and sent to the FPRDC for oil extraction, while a sample was also shipped to the Eurofins Scientific Woodson-Tenent Laboratory, Des Moines, IA, U.S.A., for physical and chemical analysis.

At FPRDC, the pellet mill and expander cooker were used to stabilize the rice bran, while extraction of oil from all four processed samples was performed. All dry recipe parameters, calculations, and measurements used during these trials to stabilize the rice bran are given (Table I). These parameters include dry recipe moisture contents (% wb), temperature (°C), feeding rate (kg/hour), dry recipe specific heat (kJ/kg – °C), and enthalpy. The dry recipe heat was calculated using the formula: Cp = 4.187 × moisture content (MC) + 1.5 (1 – MC). This is a variation of Siebel's equation, which works well in the moisture range used for extrusion.

Preconditioner parameters, such as steam and water flow to preconditioner and temperature of process water used, are mentioned in Table II. These conditions are optimum and selected after a series of trials. Extruder barrel parameters, which include shaft speed (rpm), motor load (%), steam, water flow to barrel (kg/h), and process water temperatures, etc., are given in Table III. Again, these barrel parameters are optimum and selected after a series of trials. Preconditioner calculations and extruder barrel calculations, based on the optimum processing conditions, are given (Tables IV and V, respectively).

Table I. Dry recipe parameters and calculations

Dry Recipe	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Moisture contents (% wb)	7.42	7.42	8.4	8.4
Temperature (°C)	20	20	20	20
Rate (kg/hour)	386	475	25	237
Specific heat (kJ/kg) (°C)	1.69	1.69	1.73	1.73
Energy (enthalpy) (kJ/hour)	13117	16132	863	8181

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.

Table II. Preconditioner parameters

Parameters	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Steam flow to preconditioner (kg/hour)	20.15	29.35	1.5	n/a
Water flow to preconditioner (kg/hour)	22	25	1.1	n/a
Process water temperature (°C)	20	20	20	n/a

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.

Table III. Barrel parameters

Parameters	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Shaft speed (rpm)	650	850	100	100
Motor load (%)	50	22	54	55
Steam flow to barrel (kg/hour)	19.5	0	0	14.2
Water flow to barrel (kg/hour)	29	0	0	0
Process water temperature (°C)	20	20	20	20
Motor power (hp)	40	75	2	40

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.

Extraction of Rice Bran Oil

The following method (22) was used to extract the oil from processed rice bran: The extraction vessel was loaded with 300 g of processed rice bran and the oil was extracted for eight stages. In the first stage, 600 g of hexane was pumped over the rice bran bed. Percolation extraction was simulated by spraying the solvent on top of the rice bran bed, allowing it to drain through the rice bran, then recycling it back to the top of the bran. This cycle was continued for 6 min. At the conclusion of the extraction stage, the bed of rice bran was allowed to drain for 3 min. After draining, the volume of miscella (a mixture of oil and hexane) was measured, and the equivalent amount of fresh solvent was used in the next stage. The extraction temperature was maintained at 57 ± 1ºC. The extraction process was repeated eight times, using fresh solvent for each stage.

Physical and Chemical Analysis

The Woodson-Tenent Laboratory measured bulk density, moisture, protein, crude fiber, percent fat present in rice bran, FFA, and vitamin E of the rice bran, using standard procedures of the American Oil Chemists' Society (AOCS). Percent (%) cook (8) of the stabilized rice bran was also evaluated for all four samples used in this study.

Specific mechanical energy (SME) was calculated using the following formula (5): SME (kJ/kg) = net torque × screw speed/mass flow rate (kg/hr). Specific thermal energy (STE) was calculated using the following equation as mentioned by Dreiblatt (3): STE (kJ/kg) = thermal energy input (kWh/hour)/mass flow rate (kg/hour) × 3,600 seconds/hour. Total specific energy (TSE) was obtained by adding the SME and STE (11).

Statistical Analysis

Data obtained was analyzed at a 95% confidence interval statistically, by using the Statistical Package for the Social Sciences (SPSS) version 15.

RESULTS AND DISCUSSION

As mentioned earlier, rice bran stabilization using the extruder and the pellet cooker was performed at the pilot plant and stabilized rice bran was stored in the freezer and sent to FPRDC for oil extraction. At FPRDC, the pellet mill and expander cooker were used to stabilize the rice bran, while the extraction of oil from all four processed samples was also performed.

During the stabilization process, moisture content (% wb) of dry recipes ranged from 7.4 to 8.4 and the feed rate varied from 25 kg for the pellet mill to 475 kg for the pellet cooker per hour (Table I). Dry recipe specific heat (kJ/hour in °C) was almost the same for all processing equipment (1.69–1.73), while enthalpy varied from 863 kJ/hour for the pellet mill to 16132 kJ/hour for the pellet cooker (Table I).

Steam and water flows to the preconditioner for the pellet mill were 1.5 kg/hour and 1.1 kg/hour, respectively. For the pellet cooker, they were 29.35 kg/hour and 25 kg/hour, respectively (Table II). Shaft speed, motor load, steam flow to barrel, water flow to barrel, process water temperature and motor power for extruder, pellet cooker, the pellet mill, and expander cooker are given (Table III). These optimum conditions were selected after a series of trials.

Tables IV and V are based on the calculations of different parameters regarding the preconditioner and barrels that were calculated or measured during these trials. In Table V, the predicted temperature behind the die is mentioned, because there is not a feasible way to measure product temperature in an extruder. A flush-mounted thermocouple or temperature probe does not accurately measure product temperature, as the heating or cooling of the extruder heads can affect the measurement. In addition, a flush-mounted thermocouple does not protrude into the product flow and thus cannot give accurate results.

As expected, the resulting product properties differed significantly from all four types of processing equipment. Data obtained was analyzed and broken down into three sections, i.e., rice bran stabilization, oil extraction, and nutrient destruction.

Rice Bran Stabilization

Rice bran is abundant in oil (15–20%); the presence of lipase enzyme makes it very susceptible to rancidity. During the milling process, oil and lipase present in the rice bran comes into mutual contact, resulting in the rapid hydrolysis of the triglycerides of the oil into glycerol and free fatty acid (FFA) content. Such bran with higher amounts of FFA is unpalatable for food uses because of the development of an unpleasant and rancid odor.

The percents of FFA present in the rice bran before and after heat treatment using different methods are given in Figure 1. Figure 1 indicates that the percent of FFA in the raw material is higher than the percent of FFA in the rest of the products. The reason for this could be the time; the rice bran was milled in northern Arkansas (U.S.A.) and was shipped to the testing site. This resulted in a time lag from milling to heat treatment and stabilization. The raw material samples and the process samples were sent to an outside lab (Woodson-Tenent Laboratory) immediately after processing. The raw material sample con-

Table IV. Preconditioner calculations

Parameters	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Measured moisture in preconditioner (% wb)	16.6	16.9	17	n/a
Product mass flow in preconditioner (kg/hour)	428	412	28	n/a
Measured preconditioner discharge temperature (kg/h)	86	95	93.2	n/a

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.

Table V. Barrel calculations

Parameters	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Total mass flow in barrel (kg/hour)	477	529	28	251
Calculated moisture in barrel (% wb)	25.4	17	17	13.6
Predicted temperature behind die (°C)	166	116	93.2[e]	226

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.
[e] Since the pellet mill adds no mechanical energy.

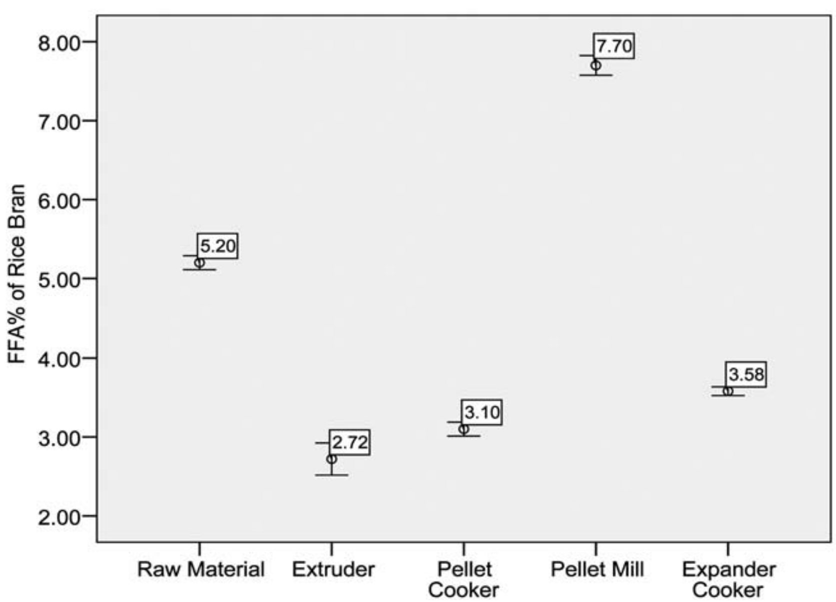

Fig. 1. Percent of free fatty acid (FFA) content in rice bran before and after processing. 1) Wenger X-85 Extruder; 2) Wenger Universal Pellet Cooker (UP/C); 3) California Pellet Mill (CPM); 4) Anderson Expander Cooker.

tinued to oxidize during this time and, as a result, FFA levels were higher. The oxidation was stopped in the processed samples and thus the FFA levels were lower.

Data shows that all of the samples, except the pellet mill processed rice bran, had lower FFA levels than the raw material. It is a well-known fact that the level of FFA correlates to the processing moisture and temperature (1). Rice bran samples, which were extruded, had the highest processing moisture and, as a result, exhibited the lowest level of FFA (2.7%). The FFA level of samples processed by using the pellet cooker was lower (3.1%) than the expander cooker samples that were processed with lower moisture contents and had an FFA level of 3.58%. The pellet mill samples had a significantly higher level (7.1%) of FFA than other samples.

This indicates that, if more time is required in a shear zone to denature the enzyme, it will cause fat splitting due to the availability of some favorable conditions for the working of the enzyme. The extruder sample had the lowest FFA because the lack of favorable operating parameters of a high feed rate and short retention time in the barrel. These findings verify the statement that the methods employed to stabilize the bran (prevention of rancidity by lipase action) are based on reducing the moisture content, treatment with high temperature, and/or by changing pH to destroy the activity of lipase (12). Some researchers have found that, at extrusion temperatures above 128°C, lipase activity in the bran was lost regardless of the moisture content of the bran fed (7).

Oil Extraction

The pellet cooker performed significantly better than any other process for preparing the rice bran to extract oil. The maximum oil recovered from the samples stabilized by the pellet cooker was 204 g/kg, while the minimum oil (185 g/kg) was extracted from the sample processed by the expander cooker (Fig. 2). The quantity of rice bran oil extracted by the expander cooker and the pellet mill was less than the oil quantity obtained by the pellet cooker. Figure 2 exhibits a statistically significant difference between the quantities of oil extracted from the rice bran by using different processing methods. The difference is nonsignificant between the extruder and pellet cooker.

Another method of expressing process efficiency is to determine the amount of oil extracted per unit of process energy consumed. Net specific energy (NSE) input varied with changes in die opening and moisture contents, while total power efficiency increased with increasing production rate without a change in NSE value (7). Energy consumed by all four processes for preparing the rice bran for oil extraction is given in Table VI, which compares process efficiency by expressing the total oil extracted per unit of energy input in Figure 3. The samples processed on the pellet cooker were the most efficient (0.81 g/kJ) in terms of oil removal per unit of energy; these were 26% more efficient than the other processes. On the other hand, oil extracted from the sample processed by using the expander cooker was the least efficient (0.41 g) with the same amount of energy.

Several other factors, such as bulk density of processed bran, percent fines present in the products, and cell structure, affect oil extraction from rice bran. (Here, the word "fines" means an amorphous,

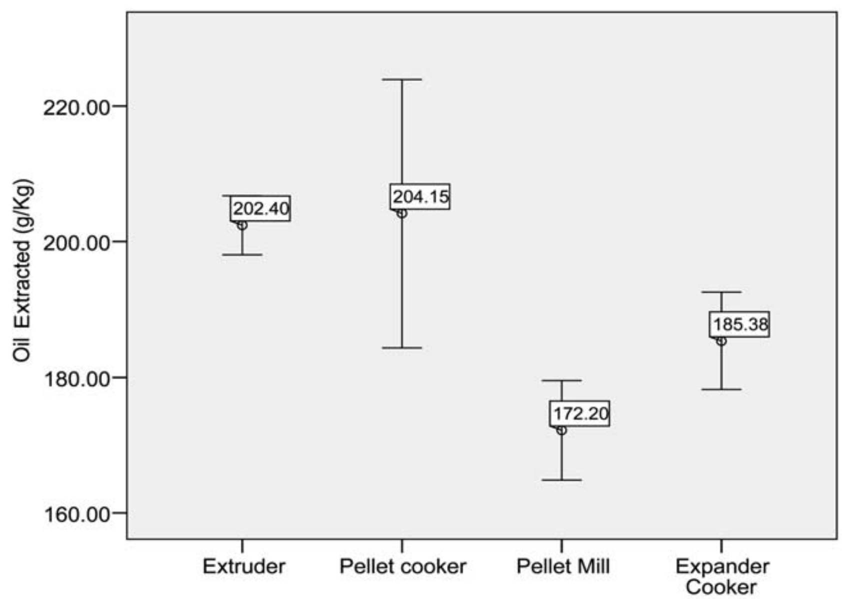

Fig. 2. Extraction of grams of rice bran oil per kilogram of rice bran. 1) Wenger X-85 Extruder; 2) Wenger Universal Pellet Cooker (UP/C); 3) California Pellet Mill (CPM); 4) Anderson Expander Cooker.

Table VI. Stabilized rice bran properties

Properties	Raw Material	Extruder[a]	Pellet Cooker[b]	Pellet Mill[c]	Expander Cooker[d]
Bulk density (kg/m^3)	408	449	507	629	458
Sample moisture (% wb)	7.4	5.1	9.2	7.2	6.0
Percent cook (%)	69.1	89.1	87.7	76.2	87.9
Protein Kjeldahl (%)	12.8	13.2	13.5	12.8	12.8
Crude fiber (%)	8.1	7.6	8.9	12.2	10.6
Fat (%)	20	20	20	20	20
Fines over #8 sieve (%)		93	92	98	71
SME[e] (kJ/kg)		115	45	0[f]	249
STE[g] (kJ/kg)		303	173	167	163
TSE[h] (kJ/kg)		418	218	167	412

[a] Wenger X-85 Extruder.
[b] Wenger Universal Pellet Cooker (UP/C).
[c] California Pellet Mill (CPM).
[d] Anderson Expander Cooker.
[e] Specific mechanical energy.
[f] This adds no mechanical energy.
[g] Specific thermal energy.
[h] Total specific energy.

open-cell structure material that is not in a pellet shape.) Since cell structure is very difficult to quantify, it is noted that, from the rice bran with lower bulk density and with more expansion, more oil could be extracted. Goodrum and Kilgo (4) stated similar findings in which they indicated that reducing the particle size of peanuts also demonstrated a positive effect on extraction. Smaller particles have a larger amount of surface area as well as an increased number of ruptured cells, resulting in a high oil concentration at the particle surface.

It was observed that in samples with high bulk densities and low fines, oil was easily extractable. The only exception was the samples processed by the pellet mill. Samples produced on a pellet mill had a closed cell structure that hindered the oil extraction. On the other hand, the pellet cooker samples were also very dense; nevertheless, it was easy to extract oil due to their fine but open cell structures.

Nutrient Destruction

Rice bran oil is a good source of vitamin E and oryzanol components, even though their concentrations (2–5% of oil) may vary substantially according to the origin of the rice bran (9). The last part of this study consists of examining the vitamin E loss from rice bran through different processing methods. However, vitamin E values ranged from 14.3 IU/kg to 24.6 IU/kg, as mentioned in Figure 4. The major goal of this study was to look at the effect of each process on extraction and FFA levels. The other analyses were done to see if the optimized processes affected other constituents.

During vitamin E analysis, considerable vitamin E destruction was exhibited in the oil extracted from extruded samples (202 g/kg), in comparison to samples produced by the pellet cooker. In other words, vitamin E values obtained from the sample processed by the extruder and by the expander cooker were lower than the pellet cooker and the pellet mill processed samples (Fig 4). This was due to higher energy inputs in these processing equipments. The extruded samples remained under a higher temperature and pressure for more time than the samples produced on the pellet cooker or the pellet mill. The total energy input for the extruder and expander cooker was significantly higher than the pellet mill and the pellet cooker.

Similar results were obtained by Shin and others (19), in which they mentioned that tocopherol present in rice bran decreased with increasing extrusion temperature, and bran extruded at 120–140°C lost more tocopherols over a year of storage than did bran extruded at 110°C.

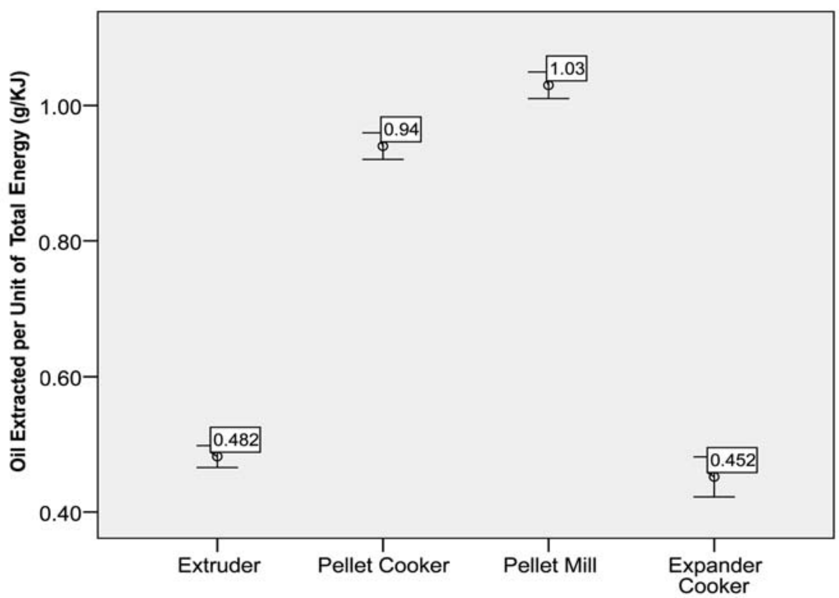

Fig. 3. Extraction of rice bran oil per total energy input (g/kJ). 1) Wenger X-85 Extruder; 2) Wenger Universal Pellet Cooker (UP/C); 3) California Pellet Mill (CPM); 4) Anderson Expander Cooker.

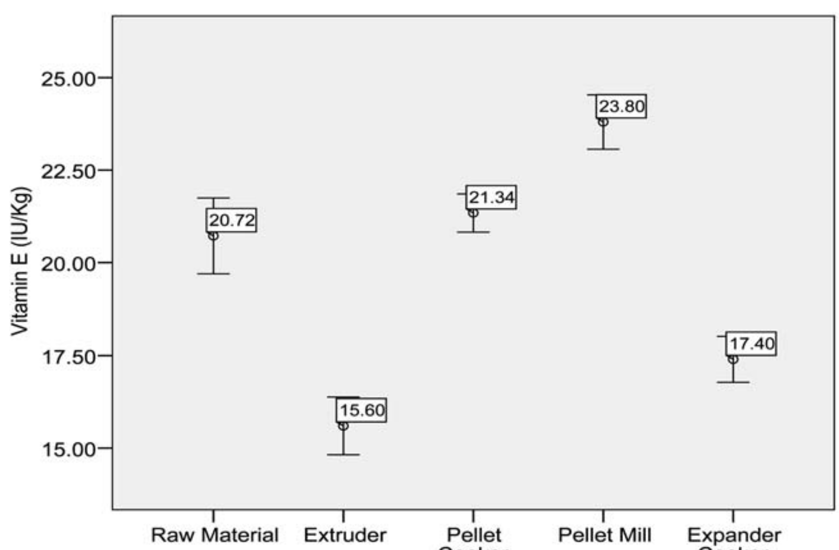

Fig. 4. Vitamin E contents of rice bran from before and after processing. 1) Wenger X-85 Extruder; 2) Wenger Universal Pellet Cooker (UP/C); 3) California Pellet Mill (CPM); 4) Anderson Expander Cooker.

CONCLUSION

In a comparison of all four methods of rice bran processing, the pellet cooker exhibited good results for rice bran stabilization because the sample processed by this method had low FFA, low vitamin E destruction, and a high yield of extracted oil. The pellet cooker also processed rice bran with a higher feed rate than any other processing equipment, and at moisture contents of 14–17% on a wet basis. Processing with low moisture contents indicates that it would help reduce the cost of drying and produce better products than other (wet) extrusion.

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