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Energy requirements of size reduction of some selected cereals using attrition mill

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Abstract

Maize, sorghum and millet are economic crops. Primary processing methods of these foods in either dry or wet state require size reduction, an energy driven unit operation. Hence, energy pattern during size reduction of these crops using attrition mill was studied. Maize, sorghum and millet (1, 2, 3, 4 and 5 kg/min) of two different moisture content levels (12.0, 32.0% wb) were separately milled using attrition mill. Temperature of product and machine parts, duration of operation, and quantity of fuel (diesel) consumed was recorded. Standard equations were adopted to quantify energy, energy intensity, exergy and exergy losses. Energy intensity of reducing dry (12.0 % wb) maize, sorghum and millet using attrition mill were 5.5 MJ/kg, 5.2 MJ/kg and 5.0 MJ/kg respectively. While 1.2 MJ/kg, 1.1MJ/kg and 0.8 MJ/kg were energy intensity for wet (32.0% wb) milling maize, sorghum and millet respectively. Exergy efficiency of grinding dry maize, sorghum and millet using attrition mill were 64.7, 64.9 and 66.8% respectively while 71.2, 71.4 and 71.9% were recorded for wet milling maize, sorghum and millet respectively. Energy and exergy utilization were significantly ($p < 0.05$) different between dry and wet milling. Smaller magnitudes of energy (14 – 30%) were destroy exergy while loss exergy accounts for the balance. Attrition mill is more appropriate for wet milling.

Introduction

Maize, sorghum and millet are important agricultural crops that play significant role in the diet of the people all over the world particularly in the developing nations. FAO (2012) respectively ranked maize, sorghum and millet as third, fifth and sixth important cereal in the world. According to Kent and Evers (1994), maize grain contains about 10.8% moisture, 10.0% protein, 4.3% fat, 1.7% fiber, 1.5% ash, and 71.7% starch. Millet contains moisture content (8.5%), protein (9.4%), fat (6.8%), fiber (1.4%), ash (3.6%) and starch (70.3%) while sorghum has moisture content (8.2%), protein (9.6), fat (3.4%), fiber (2.2%), ash (1.5%) and starch (75.1%). Products from these cereals include grit, meal, flour, flakes, starch and paste of different forms. Primary processing methods of these foods require size reduction in either wet or dry form. To accomplish this operation, size reduction machines are employed. Grain milling technologies involve size reduction operation in which grain kernels are broken into pieces of various sizes by machine. One measure of the efficiency of the milling operation is based on energy required to create new surfaces. Size reduction is one of the least energy-efficient of all the unit operation and the cost of power is a major expense in crushing and grinding, so the factors that control this cost are important (McCabe *et al*., 2005).

Energy is the prime mover of any economy and engine of growth around which all sectors of economy revolve (Aderemi *et al*., 2009). Therefore, improvement on energy generation, estimation and conservation is important for development of industries. Although some studies have been conducted that explore the multifaceted sources and uses of energy in agriculture at the farm level, there are however currently few studies on energy use for further downstream in the food chain especially in food processing, packaging, storage, and distribution (Ziesemer, 2007). Few of the processing factories have little precise idea of the energy consumption of different production areas and in the absence of detailed internal monitoring, the energy efficiencies of different operations is also usually unknown (Jekayinfa and Olajide, 2007). Research reports on energy consumption and conservation patterns

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in Nigeria include rice processing (Ezeike, 1981), beverage industry (Akinbami *et al.*, 2001), and palm kernel oil processing (Jekayinfa and Bamgboye, 2004). Energy expenditure on sugar processing (Abubakar *et al*., 2010), bread baking (Akinoso and Ganiyu, 2011) and gari (Akinoso and Kasali, 2012) have been reported.

Energy and foods are concerns of developing countries, because chains of food production consume a lot of energy (Wang, 2009). Energy efficiency is a fundamental element towards a sustainable food and energy development. Hence, energy and exergy utilization pattern during size reduction of sorghum, millet and maize, staple foods needs research attention. In Nigeria, attrition milling accounts for more than 80% of small-scale size reduction operations (Badmus *et al*., 2012). The aim of this work was to analyze energy pattern during size reduction of some grains using attrition mill.

Materials and Methods

Material preparation

Maize (95 T2EEW), sorghum (SAMSORG 2) and millet (SOSAT C88) used for the study were sourced from National Cereal Research Institute Badegi, Nigeria. The crops were used after eight months of harvest and their initial moisture content were determined using ASAE (2008) standard. Three samples, each weighing 20 g dehydrated in oven set at 130°C for 6 hours, and cooled in a glass jar containing silica gel as desiccant. Cooled samples were weighed and the difference in weight before and after drying was taken to be moisture loss. Ratio of moisture loss to weight of wet material in percentage was recorded as moisture content wet basis. The desired moisture content levels (12.0 and 32.0% wb) were achieved by adding calculated volume of distilled water as obtained from Equation 1. Each sample sealed in a separate polyethylene bag for 48 hours to equilibrate.

$$Q = A(b-a)/(100-b) \quad (1) \quad \text{(Akinoso et al., 2006)}$$

Where A is initial mass of the sample (kg), a is initial moisture content of the sample (% wet basis), b is final (desired) moisture content of sample (% wb) and Q is mass of water to be added (kg).

Milling

Maize (95 T2EEW), sorghum (SAMSORG 2) and millet (SOSAT C88) of known moisture contents were separately fed into attrition mill at rate of 1, 2, 3, 4 and 5 kg/min using K-tron type T-35 volumetric feeder (K-tron Corp. Pitman NJ USA). A 4.5 kW diesel engine (model 178F Chongqing GEGO power machine Ltd China) powered attrition plate mill (plate diameter 300mm) was used for milling. The inlet temperature of the crops and the outlet temperature in the paste/flour were recorded using digital thermometer (Mastech 266 C digital clamp multi-meter) before and after milling respectively. Duration of milling operation was recorded using stopwatch. This procedure was repeated thrice and mean value recorded as data obtained which was used for computation.

Energy analysis

Thermodynamic concepts and formulations were introduced for performing energy and exergy analysis (Sanaei *et al*., 2011). Since the objective of this research work was to have a qualitative assessment of the flow of energy and its conversion, standard equations as stated below were used (Equations 2 to 7).

$$E = Crv \quad (2)$$

$$E_{in} = E/Q \quad (3)$$

$$E_o = 0.75\,E \quad \text{(Dincer et al., 2005)} \quad (4)$$

$$E_x = E - E_o \quad (5)$$

$$Ex_d = E_o\left(1 - \frac{T_o}{T}\right) \quad (6)$$

$$E_{ex} = \frac{\sum E_{out}}{\sum E_{in}} \times 100\% \quad (7)$$

Where

E - energy input in (*MJ*)

Cr - calorific value of diesel (36 *MJ/L*)

v - volume of diesel (*L*)

E_{in} - energy intensity (MJ)

Q - quantity of product (kg)

E_o - output energy (MJ)

Ex - exergy (MJ)

E_{xd} - destroy exergy (MJ)

T_0 - reference temperature (K)

T - outlet temperature (K)

E_{ex} - energy efficiency (%)

Results and Discussion

Energy

The energy pattern of dry and wet milling maize, sorghum and millet were presented as Figures 1 and 2 respectively. As expected, energy requirements increase with quantity of milled product. The trend was best described by linear relationship using model fitness and coefficient of determination R^2 as criteria.

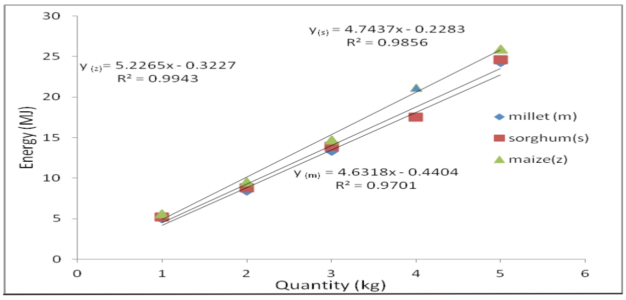

Figure 1. Energy input in dry milling of selected grains

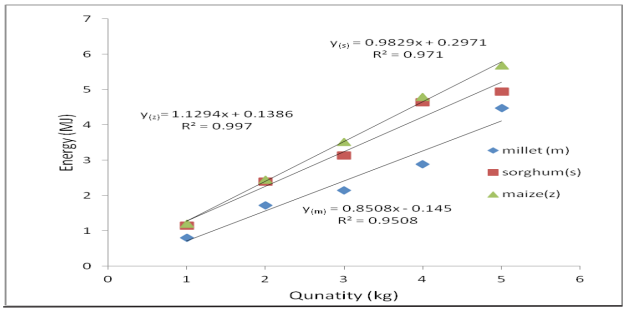

Figure 2. Energy input in wet milling selected grains

For both dry and wet products, maize demanded highest quantity of energy for size reduction, followed by sorghum and millet. In addition, significant differences ($p < 0.05$) were recorded between input for dry and wet milling. Energy intensity of reducing dry (12.0% wb) maize, sorghum and millet using attrition mill were 5.5 MJ/kg, 5.2 MJ/kg and 5.0 MJ/kg respectively. While 1.2 MJ/kg, 1.1 MJ/kg and 0.8 MJ/kg were energy intensity for wet (32.0% wb) milling maize, sorghum and millet respectively. The energy expended for dry milling was higher than 2.38 MJ/kg reported for extraction of crude soybean oil (Wang, 2009) and 2.95 MJ/kg for bread making (Akinoso and Ganiyu, 2011). Size reduction is one of the least energy-efficient of all the unit operation (McCabe *et al.*, 2005). In addition, Akinoso and Kasali (2012) and Akinoso and Olatoye (2012) reported size reduction as one of the high-energy intensive operations in gari and instant-pounded yam flour production respectively.

Exergy utilization

Exergy efficiency of grinding dry (12.0% wb) maize, sorghum and millet using attrition mill were 64.7, 64.9 and 66.8% respectively. Better utilization of energy was recorded using same attrition milling machine for same crops of higher moisture content (32.0% wb). This may be attributed to weakness of internal texture under the effect of increasing moisture content. Exergy efficiency of wet milling maize, sorghum and millet were 71.2, 71.4 and 71.9% respectively. Dincer *et al*. (2005), reported similar observation. Exergy efficiencies were significantly difference ($p < 0.05$) between dry and wet crops milled. However, no significance difference ($p > 0.05$) was recorded among crops of same moisture content. Altuntas and Yildiz (2007) and Fathollahzadeh and Rajabipour (2008) reported that forces required to initiate rupture decreased with moisture content on faba bean and barberry fruits respectively. At high moisture content, there was water absorption, swelling of seed and resultant reduction in strength. It can be inferred from the obtained results that the attrition-milling machine is more appropriate for grinding the grains using energy conservation as a major criterion. Complex machine such as roller mill is appropriate for flour production (NAMA, 2010). Exergy increases with quantity of material. Linear model best described relationship between exergy and quantity of maize, sorghum and millet milled (Figures 3 and 4). For the entire plot, coefficient of determination R^2 of the regression ranged from 0.95 to 0.99. Closeness of R^2 to one indicates good model fitness.

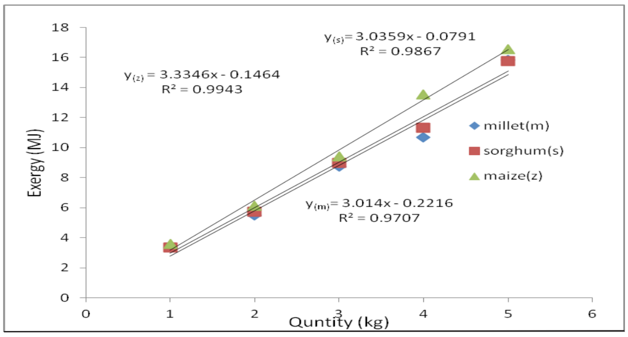

Figure 3. Exergy pattern in dry milling selected grains

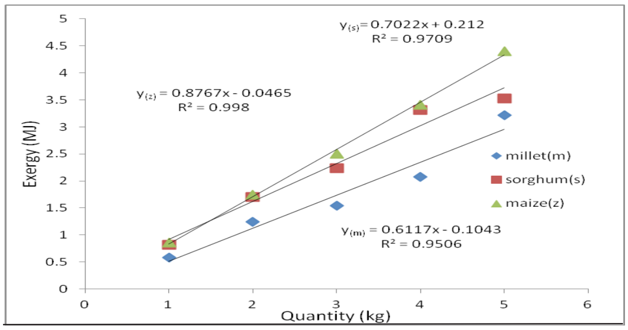

Figure 4. Exergy pattern in wet milling selected grains

Energy losses

Estimated energy losses for each sample are presented as Tables 1 and 2 for dry (12.0% wb) and wet (32.0% wb) milling respectively. For all the samples, smaller magnitudes of energy (14 – 30%) were destroy exergy. Invariably, over 70% of recorded loss exergy was due to inefficient machine. This finding agreed with previous published work on some agricultural sector in Saudi Arabia (Dincer *et* *al*., 2005), agricultural sector in Malaysia (Ahmed *et al*., 2011), and Iran industrial sector (Senaei *et al*., 2011). In this work, destroy energy is loss to the environment, while machine performance efficiency (power transmission, shaft rotation, grinding unit) accounts for loss exergy. Improving equipment efficiency has been identified as one of the ways of effective energy conservation approach (Wang, 2009).

Table 1. Energy loss analysis of dry milling of some grains

Quantity (kg)	Maize		Sorghum		Millet	
	DE (MJ)	LE (MJ)	DE (MJ)	LE (MJ)	DE (MJ)	LE (MJ)
1	0.57	1.39	0.52	1.3	0.41	1.25
2	0.99	2.38	0.89	2.21	0.82	2.10
3	1.59	3.67	1.46	3.48	1.24	3.33
4	2.29	5.28	1.83	4.38	1.52	4.06
5	2.85	6.47	2.66	6.14	2.36	6.07

Where DE and LE are destroy exergy and loss exergy respectively

Table 2. Energy loss analysis of wet milling of some grains

Quantity (kg)	Maize		Sorghum		Millet	
	DE (MJ)	LE (MJ)	DE (MJ)	LE (MJ)	DE (MJ)	LE (MJ)
1	0.05	0.30	0.04	0.29	0.03	0.20
2	0.09	0.61	0.09	0.60	0.05	0.43
3	0.13	0.88	0.11	0.78	0.07	0.54
4	0.18	1.20	0.17	1.16	0.09	0.72
5	0.22	1.42	0.18	1.23	0.14	1.12

Where DE and LE are destroy exergy and loss exergy respectively

Conclusions

Energy intensity of reducing dry (12.0% wb) maize, sorghum and millet using attrition mill were 5.5 MJ/kg, 5.2 MJ/kg and 5.0 MJ/kg respectively. While 1.2 MJ/kg, 1.1 MJ/kg and 0.8 MJ/kg were energy intensity for wet (32.0% wb) milling maize, sorghum and millet respectively. Wet milling of maize, sorghum and millet possess higher exergy efficiency than dry milling. Over 70% of exergy loss was associated with machine efficiency. Linear relationships exist between quantity of milled grains and energy pattern. Attrition mill is more appropriate for wet milling of maize, sorghum, and millet.

References

Abubakar, M. S., Umar, B. and Ahmad, D. 2010. Energy use patterns in sugar production: a case study of savannah sugar company, Numan, Adamawa State, Nigeria. Journal of Applied Science Research 6: 377-382.

Aderemi, A. O. 2009. Assessment of electrical energy use efficiency in Nigeria food industry. African Journal of Food Science 3: 206-216.

Ahmed, J. U., Saidur, R., Masjuki, H. H., Mekhilef, S., Ali, M.B. and Furqan, M. H. F. 2011. An application energy and exergy analysis in agricultural sector of Malaysia. Journal of Energy Policy 39: 7922-7929.

Akinbami, J. F. K., Ilori, M. O., Adeniyi, A. A. and Sanni, S A. 2001. Improving efficiency of energy use in Nigeria's industrial sector: a case study of a beverage plant. Nigeria Journal of Engineering Management 2: 1-8.

Akinoso, R., Igbeka, J. C., Olayanju, T. M. A. and Bankole, L. K. 2006. Modelling of oil expression from palm kernel (*Elaeis guneensis* Jacq). Agricultural Engineering International – the CIGR Ejournal 8: 1-7

Akinoso, R. and Ganiyu, I. A. 2011. Estimation of energy requirements in small-scale bread making. LAUTECH Journal of Engineering and Technology 6: 81-85.

Akinoso, R. and Kasali, W. O. 2012. Energy Expended in Processing *Gari*- Cassava (*Manihot esculenta* Crantz) Flakes - using three Levels of Mechanization. Pakistan Journal of Scientific and Industrial Research Series B Biological Sciences 55: 114 – 116.

Akinoso, R and Olatoye, K. K. 2013. Energy utilization and conservation in instant-pounded yam flour. International Food Research Journal 20: 575:579

Altuntas, E. and Yildiz, M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L) grains. Journal of Food Engineering 85: 606 – 612.

ASAE Standard 2008. Moisture measurement-peanuts. ASAE S410.1 DEC 1982 (R2008) 679-680.

Badmus, A. A., Raji, A. O. and Akinoso, R. 2012. Effect of process parameters on work index, milling efficiency and some technological properties of yam flour using attrition mill. Food and Bioprocess Technology: An International Journal DOI 10.1007/s11947-012-0838-1:1-8.

Dincer, I., Hussain, M. M. and AlZahar, I. 2005. Energy and exergy utilization in agricultural sector of Saudi Arabia. Journal of Energy Policy 33: 1461-1467.

Ezeike, G. O. I. 1981. Energy consumption in rice processing operation in Nigeria: selected case studies. Journal of Agricultural Mechanization in Asia, Africa, Latin America 18: 33-40.

Fathollahzadeh, H and Rajabipour, A. 2008. Some mechanical properties of barberry. International Agrophysics 22: 299-302.

FAO. 2012. Food and Agriculture Organization of the United Nations Economic and Social Department. *http://www.fao.org/giews/english/fo/index.htm*. Accessed on 12 April, 2012.

Jekayinfa, S. O. and Bamgboye, A. I. 2004. Energy requirements for palm kernel oil processing operations. Nutrition Food Science 34: 166-173.

Jekayinfa, S. O. and Olajide, J. O. 2007. Analysis of energy usage in the production of three selected cassava- based foods in Nigeria. Journal of Food Engineering 82: 322-329.

Kent, N. L. and Evers, A. D. 1994. Technology of cereals, an introduction for students of Food Science and

Agriculture, 4th Ed. Pergamon, Oxford, UK pp 129-169.
McCabe, W. L, Smith, J .C. and Harriott, P. 2005. Unit operations of chemical engineering. 7th Edn. McGraw-Hill International , New York pp 984-1000.
NAMA. 2010. North American Millers' Association West Washington, DC.
Sanaei, S. M., Furubayashi, T. and Nakata,T. 2011. Assessment of energy utilization in Iran's industrial sector using energy and exergy analysis. Journal of Applied Thermal Engineering10: 10-16.
Wang, L. J. 2009. Energy efficiency and management in food processing facilities. CRC Press Taylor & Francis Group, LLC, Boca Raton, FL, USA.
Ziesemer, J. 2007 Energy use in organic food systems. Natural Resources Management and Environment Department, Food and Agricultural Organization of the United Nations, Rome.