Arid Zone Journal of Engineering, Technology and Environment, February, 2017; Vol. 13(1): 1-5

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

PERFORMANCE EVALUATION OF A DEVELOPED GRAIN MILLING MACHINE

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Abstract
A locally developed grain milling machine was evaluated using maize (Sammaz - 12 variety) and millet (Lake Chad Dwarf variety) at different moisture range of 8.3% to 24.6% and 6.4% to 27.2% (db) respectively. The performance indices considered for the evaluation of the machine were milling efficiency, machine efficiency and milling rate. The results obtained were subjected to statistical analysis. The results showed that all the parameters evaluated decreased with increase in moisture content for both grains used in testing evaluating the performance of the machine. It was found that, the milling efficiency and milling rate decreased from 86.3% to 40% and 20.4 to 12.5kg/h for maize respectively and 89% to 26.6% and 23.4kg/h to 12.1kg/h for millet respectively as the moisture content was increased. Statistical analysis showed significant ($P < 0.05$) differences between the crop moisture content and milling efficiency and machine efficiency. The milling rate was not significantly affected by the moisture content for both grains used in the study.

Keywords: grain milling machine, performance evaluation, maize, millet and moisture content

Introduction

Grains are small hard dry seeds with or without attached hulls or fruit layers, harvested for human and/or animal consumption (FAO, 2011). The two main types of commercial grain crops are cereals such as millet, corn, sorghum, wheat, rye and so on; and legumes such as beans, groundnuts and soya beans. Nigeria produces a wide range of agricultural commodities which could serve as raw materials for industrial production and food for human consumption. Other grains produced and consumed in large quantities are sorghum, millet, maize, rice and wheat.
Grain milling refers to the act or process of grinding, especially grains into flour or meal (Kaul and Egbo, 1985). The grinding occurs by the application of mechanical forces, after which the state of the solid is changed. According to Culpin, (1992), the grinding of grains has been practiced since very early times when a device resembling a pestle and a mortar was employed in the production of meal for human consumption. The economic importance of milling grains cannot be over emphasized. Crops produced on the farm are processed in some forms before they are actually consumed. The grinding of solid matter occurs under the exposure of mechanical forces that change the structure by overcoming the interior binding forces. After grinding, the physical states of these grains are modified, the grain size is reduced, the grain disposition is altered and the grain shape is changed to suit the requirement (Ryan and Spencer, 2008). Milling is a unit operation designed to break a solid material into smaller pieces.
However, the crops are subjected to different processes before they are ready for consumption. One of such process is the conversion of grains or chips (in the case of cassava and yam) into flour (size reduction). In rural areas where accessibility to modern milling machines is lacking due to high initial capital investment, it is necessary to developed a locally motorized milling machine. The motorized grain milling machine will do the work in a little time and will require

less man power when compared to the manually operated systems of milling available in rural areas. Based on this, a grain milling machine was designed and constructed by Kawuyo *et al.*, (2014). The performance evaluation of the machine is therefore important so as to determind its ability to mill grains effectively and recommend it for use by farmers, flour producers and consumers. The objectives of this work was therefore, to carry out the performance evaluation (milling efficiency, machine efficiency and milling rate) of the locally developed grain milling machine using maize and millet at different moisture range of 8.3% to 24.6% and 6.4% to 27.2% (db) respectively.

2. Materials and Methods

2.1 Description of the Machine

The description and working principle of the machine was reported in Kawuyo *et al.*, 2014. According to them, this machine works by impact action of the rotary hammers. The rotating hammers are directly driven by the petrol engine outlet shaft. As grains are delivered into the milling chamber from the hopper, they are hitted by the rotating bars against the flat bars fixed around the drum. The longer the materials dwell inside the milling chamber, the more finer flour is obtained and it ensures that no grain escaped unmilled.

2.2 Experimental Design and Result Analysis

Complete Randomised Design was used in the test as experimental design. Samples at all levels of moisture contents were randomly assigned to the sequence of test runs. Each test at a particular moisture content was replicated three times. Simple descriptive statistics was used to report averages and standard deviations of the experimental data. Data obtained were subjected to Analysis of Variance (ANOVA) to determine the levels at which the effect of moisture content were significant. Microsoft Excel software was used to carry out the statistical analysis

2.3 Performance Evaluation Procedure

The locally fabricated grain milling machine was evaluated using maize and millet as the test grains. The machine was tested to ascertain its performance using the following procedures. Test grains maize (Sammaz - 12 variety) and millet (Lake Chad Dwarf variety) were obtained from Institute of Agricultural Research (IAR), ABU, Zaria and Lake Chad Institute Maiduguri respectively. The machine was evaluated based on three parameters: milling efficiency (η_m), machine efficiency (η_e) and milling rate (M_r). These parameters were determined using the maize and millet grains at different moisture range of 8.3% to 24.6% and 6.4% to 27.2% (db) respectively. The test was conducted at different moisture content for the two grains because the equilibrium moisture of the grains are different under the same relative humidity. The machine was run at the same speed during the evaluation. Each of the test grains was divided in to four different samples. Three out of each of the samples were conditioned to increase the moisture content. The fourth sample was used for test at storage condition. During the test, 2.5 kg mass of each sample was fed into the milling chamber through the hopper and the time to complete

grinding of each sample was recorded. The storage moisture content was determined and used as the forth moisture level.
The test samples were conditioned to the required moisture levels by adding water as calculated from the equation as reported by Ozumba and Obiakor (2011) as follows:

$$Q = \left(\frac{100-M_P}{100-M_g} - 1\right) \times W_s \quad \ldots\ldots 1$$

Where: M_p = storage moisture content, M_g = required moisture content, and W_s = weight of samples in grammes.

After adding water, each sample was thoroughly mixed and sealed in separate polyethylene bag and kept in a refrigirator to enable the moisture distribute uniformly throughoutthe samples.
The equations used in determining the parameters are described as follows:

a) Moisture content (MC) was determined on weight bases as:

$$\mathrm{MC} = \frac{W_1 - W_2}{W_1} \times 100, \% \quad \ldots\ldots 2$$

where: W_1 = weight of wet grains, g; W_2 = weight of dry grains, g.

b) Milling efficiency (η_m) is the ability of the machine to mill grain and was determined using the equation:

$$\eta_m = \frac{W_g}{W_i} \times 100, \% \quad \ldots\ldots 3$$

where: W_g = total weight of grains milled by the machine, g

c) Machine efficiency (η_e) is the total running efficiency of the machine and was determined using the equation:

$$\eta_e = \frac{W_i - W_r}{W_i} \times 100, \% \quad \ldots\ldots 4$$

where: W_i = total weight of grains introduced into the machine, g
W_r = total weight of grains retained by the machine, g

d) Milling rate (M_r) is the rate of milling grains introduced into the machine over time and was determined from the equation:

$$M_r = \frac{W_g}{t} \times 100, \mathrm{Kg/h} \quad \ldots\ldots 5$$

where: t = milling time, minutes.

3. Results and Discussion

The results of the machine efficiency, milling efficiency and milling rate for maize and millet at four different moisture levels is presented in Table 1. All the values are means of three replicates.

Table 1: Performance evaluation results of the milling machine on test grains:

Test Parameter	Moisture content					
	8.3%	13.4%	20.5%	24.6%	F ratio	P level
η_{m1}	86.3	64	49	40	101.42	0.0000
η_{e1}	93.9	81.6	39.6	35.7	58.2	0.0000
M_{r1}	20.43	15.67	12.51	12.51	1.9	0.2050
	6.37%	17.64%	24.11%	27.19%		
η_{m2}	89	60.9	44.7	26.6	1658.14	0.0000
η_{e2}	94.9	69.7	51.7	28.9	870.16	0.0000
M_{r2}	23.43	19.8	14.2	12.1	7.66	0.0098

Note: 1= Maize grain; 2 = Millet grain. (P≤0.05)

3.1 Milling Efficiency

The results for the effects of moisture content on milling efficiency is presented in Table 1 for both test grains. It was observed that, the milling efficiency decreased as the moisture content is increased from 8.3% to 24.6% and 6.37% to 27.19% (db) for maize and millet respectively. The highest milling efficiency was obtained at the storage moisture level for both test crops. The variation of moisture content significantly affected the milling efficiency for both test grains. This is in conformity with the study of Olajide *et al*, (2016) who reported that the milling efficiency of a burr mill for processing millet grits depends on the moisture content of the grains. The decrease in milling efficiency as moisture content is increased could be due to more cohesive forces that exist within the grain particles that tend to hold them together. The relationship between moisture content and milling efficiency for both maize and millet was found to be linear and expressed as shown in the equations below.

η_{m1} = 105.21 – 2.71Mc (R^2 = 0.9399) 6

η_{m2} = 108.8 – 2.84Mc (R^2 = 0.9743) 7

3.2 Machine Efficiency

The result for the effect of moisture content on machine efficiency is also represented in Table 1. It can be seen from the table, that, the machine efficiency was significantly decreased as the moisture contents of both maize and millet increased. The result of the regression analysis showed that linear relationship exists between moisture content and machine efficiency (equations 8 and 9). The values of R^2 for the two crops are 0.9092 and 0.9419 for maize and millet respectively.

η_{e1} = 128.71 – 3.96Mc (R^2 = 0.9092) 8

η_{e2} = 116.8 – 2.95Mc (R^2 = 0.9419) 9

3.3 Milling Rate

Results from Table 1 showed the variation of moisture content with milling rate of the machine. The milling rate for both test grainss decreased as the moisture content increased. This variation in moisture content did not significantly affect the milling rate of the machine. This indicates that the crop moisture content does not affect the milling time. The linear relationship between the moisture content and milling rate can be expressed using the following linear regression equations (equations 10 and 11) for maize and millet respectively.

M_{r1} = 23.4 – 0.487Mc (R^2 = 0.3000) 10

M_{r2} = 27.68 – 0.547Mc (R^2 = 0.7019) 11

4. Conclusions

The locally developed grain milling machine was evaluated using maize and millet at different grain moisture contents. All the parameters used in evaluating the machine performance decreased with increase in moisture content for both grains. For the maize grain, the milling efficiency decreased from 86.3 to 40%, the machine efficiency decreased from 93.9 to 35.7% and milling rate also decreased from 20.4 to 12.5 kg/h at moisture range of 8.3 to 24.6% respectively. For the millet grain, the milling efficiency decreased from 89 to 26.6%, the machine efficiency decreased from 94.9 to 28.9% and milling rate also decreased from 23.4 to 12.1 kg/h at moisture range of 6.4 to 27.2% respectively. Statistical analysis revealed significant differences between the crop moisture content and milling efficiency and machine efficiency ($P < 0.05$). There was no significant difference ($P < 0.05$) between the crop moisture content and the milling rate of the machine.

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