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The Effect of Moisture Content on the Performance of Melkassa Multicrop Thresher in Some Cereal Crops

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Abstract: The threshing quality of the machine was affected by moisture content. This parameter was one of the main causes of production losses. In Ethiopia, this problem was highly observed in the farm area during threshing. Therefore, the main aim of this research was, to minimize production losses during threshing by reducing the effect of moisture content on the crop, to improve threshing capacity, threshing and cleaning efficiency, to reduces fuel consumption, and to minimize grain damage by the machine during threshing. The experiment was done at four-time replication in the moisture level of 14%, 18%, and 22% for three selected cereal crops (barley, wheat, and tef) with a completely randomized design (RCBD) and 4 replicates as block giving 12 total experimental units. Crop moisture content, size of the grain, sphericity, angle of repose, density, thousand grain mass and coefficient of friction as well as threshing capacity, threshing efficiency, cleaning efficiency, germination rate, fuel consumption, and grain breakages were the parameters used to evaluate the performance of the thresher. Threshing capacity, threshing and cleaning efficiency, and density of grains showed decreased, as moisture content of crops increased. The other parameters mentioned above were increased with moisture content. A combined mean analysis of variances on the performance of thresher was significant at (p 0.05). The recommended amount of moisture content in this study was 14% because the result obtained by 14% moisture level was preferable to other moisture levels. At 14% of moisture content, the threshing capacity was (208.750, 285.45 and 68.181) kg/hr, threshing, and cleaning efficiency (%) were (98.603, 99.330 and 99.49 and 97.101, 98.22 and 93.731 respectively). Percentage of germination rate was (94.25, 94.50, and 91.25) and the amount of fuel consumption was also (1.14, 1.72, 1.70) l/hr., for barley, wheat, and tef crops respectively.

Keywords: Fuel Consumption, Grain Damage, Moisture Content, Performance of Thresher

1. Introduction

Cereal crops were mostly grasses cultivated for their edible seeds (actually called a caryopsis). Those were grown in greater quantities worldwide than any other type of crop and provide more food energy to the human race than other crops. It provides essential nutrients and energy in the everyday human diet through direct human consumption and also through meat production since they comprise a major livestock feed [8]. Cereal grains such as *tef*, maize, barley, sorghum, millet, and wheat are the major sources of food in Ethiopia. They represent about 86% of the total yearly production of 6-7 million tons of grains [6]. Cereal production involves various processes, including sowing, weeding, pesticide application/spraying, harvesting, cleaning, and processing [15]. Cereal seeds can be used for sowing crop plants, energy production, or food production. Among many cereal crops such as *tef*, maize, barley, sorghum, millet, wheat, etc., only three cereal crops (tef, barley, and wheat) were selected based on area coverage in Ethiopia for this research to check whether the moisture content of the biomass affects the performance of the thresher machine or not.

Barley (*Hordeum vulgare L.*) is an ancient and important cereal grain crop. It ranks fifth among all crops in dry matter production in the world today. It was mainly cultivated and used for human food supply in the last century but nowadays it is significantly grown as animal feed, malt products, beer

production, and human food [5]. Barley has been cultivated in Ethiopia as early as 3000 years B.C. This long history of cultivation and the large agro-ecological and cultural diversity in the country has resulted in a large number of landraces (farmers' varieties) and rich traditional practices. Barley culture is usually practiced with little or no external inputs, mainly in the higher altitudes or on steep slopes and eroded lands in Ethiopia. It was a major staple food grain in the highlands and used for making bread, porridge, soup, roasted grain, and alcoholic and non-alcoholic drinks such as beer and malts respectively. The straws were used for animal feed, thatched roofs, and bedding. The physical properties of barley grain, like those of other grains and seeds, are essential for the performance of the thresher and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting, and processing. Principal axial dimensions of barley grain are useful in selecting sieve separators [15].

Wheat (*Triticum spp*) also the most important staple food crop both in developed and developing countries and contributes more calories and proteins to the world diet than any other cereal crops. It is considered a good source of protein, minerals, B-group vitamins, and other necessary food products [22]. Although, the environmental conditions were affect the nutritional composition of wheat grains with its essential coating of bran, vitamins, and minerals. It is a portion of excellent health-building food. Wheat flour was used to prepare bread, biscuits, confectionery (sweet) products, and dynamic wheat gluten/ seitan. It was also used as animal feed, ethanol production, brewing of wheat beer, cosmetics production, wheat protein in meat substitutes and to make wheat straw composites [12]. The physical properties of wheat grain, like those of other grains and seeds, are essential for determining the performances of thresher and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, and processing.

On the other hand, *Tef (Eragrostis tef Zucc.)* is the most staple food crop in Ethiopia. It has existed in Ethiopia since the recorded history of the country and some authors believed that the pre-Semitic inhabitants might have domesticated it in B.C. *Tef* was originated and has distributed/disseminated in Ethiopia. Ethiopian farmers grew *tef* for centuries because of its various advantages such as food sources for human and animal feed, energy sources, minerals, etc. It has existed before the introduction of other cereals such as maize, wheat, barley, and others [31]. It was the smallest grain in the world, ranging from 1–1.7mm long and 0.6–1mm diameter, with an l000 average grain weight of 0.3–0.4 grams and taking 150 grains to weigh as much as one grain of wheat [19]. *Tef* accounts for about two-thirds of the daily protein in the diet of the Ethiopian population. Its grain is mainly used for making *Enjera*, porridge, bread, feed for animals, etc. *Tef* has a high economic value as its grain can be kept for many years in practice at any kind of storage facility without being seriously damaged by common storage insect pests [4]. The other grains can be used for making

Injera; however, *tef* alone is preferred. Physical characteristics of *tef* such as its moisture content, size, shape, etc., are very important to determine the performance of the thresher machine.

The ways of post-harvesting of such crops have been affected by different factors like moisture content, and size of the grain. Thus, factors were observed in the farm area. Mostly, the moisture content of crops was seriously affected productivity in terms of losses of quality and quantity. The physical property of cereal crops including the moisture content, size, types of grain, and environmental factors like weather conditions are the most common properties to affect the performance of the thresher during threshing. Therefore, these-mentioned problems could be solved by determining the physical properties of cereal crops and their characteristics by adjusting the clearance between drum and concave and by using appropriate moisture contents to get high threshing capacity, threshing efficiency, cleaning efficiency, and minimize grain damage and fuel consumption. The moisture content of the biomass is the most common properties to affect the performance of the threshing machine. This was an important property to solve many problems associated with the performances of machines and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting, and drying. During threshing, there is grain loss due to the factor of moisture content, grain damage, etc. This affects threshing efficiency, threshing capacity, cleaning efficiency, fuel consumption, and grain damages.

Moisture content is one of the most important factors affecting the quality of cereal grains production since the amount of dry matter of grain is inversely related to the moisture content of the grain [13]. The moisture content of the crop has its effect on the product quality *i.e.* when the moisture content of the grain is very high of the threshing efficiency becomes low due to the attachment of chaffs on the wall of concaves and drums, on the other hand, if the moisture content of the grain is very low there is less time requirement and has low fuel consumptions but, there is high grain breakage due to less resistance of impact and shear of grains and also, had shattering or spreading out of seeds from the grain outlets. Therefore, the optimum amount of moisture content is very crucial for obtaining good results both in the quality and quantity of products. It involves cutting the crop when the grain has reached the physiological mature stage (moisture usually between 20-30%).

Therefore, this study concerns the determination of moisture level and reduction of thus factors mentioned above. This means reduce grain damage during threshing and increase productivity through using appropriate moisture content, adjustment of clearance between concave and drum (cylinder), and use of available speed (revolution per minute (rpm)) during threshing. Hence, the study concerns the effect of the physical property of cereal crops mainly the determinations of moisture contents before threshing and the effect of moisture contents on the performance of the

machine. It also concerns the determinations of grain damage and fuel consumption of the thresher and concerns the reduction of brain damage during threshing.

The general objective of the study was to determine the effect of moisture content of cereal crops on the performance of Melkassa multi-crop thresher.

The specific objectives of the study were:

1. To determine the moisture content of the crop before threshing for *tef*, wheat, and barley crops.
2. To determine fuel consumption of the machine at different moisture content for *tef,* wheat, and barley crops.
3. To determine grain breakage during threshing for *tef,* wheat, and barley crops.

2. Material and Methods

2.1. The Area of Study

The performance evaluation of the thresher machine has been done at Melkassa Agricultural Research Center (MARC). It is one of the federal research centers located in the Oromia regional state of Ethiopia. The research center is geographically located in the central valley of Ethiopia around 117 km east of Addis Ababa and 17 km southeast of Adama town. The altitude of MARC is 1550m and lies between 8° 24' 0" to 8° 30' 12" N, 39° 21' 0" to 39° 35' 14" E latitude and longitude, respectively. Agro-ecologically, the area is characterized as arid and semi-arid with maximum and minimum temperatures are 28.40°C and 14.00°C, respectively.

2.2. Description of the Machine

MARC has many types of threshers among them one constructed thresher was taken for this study. The thresher is a diesel engine motor-operated type for threshing of cereal crops known as a multi-crop thresher. The dimension of the machine is over-all height 1068mm, length at the drum position is 940mm and drum length is 830mm, the width of the machine is 650mm, height up to the upper end of feeding rate is 1040mm. The dimension of the hopper is also width, length and height were 70mm, 930mm, and 21mm respectively, of the multi-crop thresher machine and the clearance between drum and concaves is 4mm. The diesel motor used for this thresher is the CF186FA model and 7.5hp (5.6 KW) and having 3000rpm made in Korea. The selected thresher is comparatively small in size and has less weight. During threshing, the performance of the machine was evaluated by varying the moisture content of the crop. The feeding rate and speed of the engine (revolution per minute, rpm) were kept constant during testing. The performance of the machine could be evaluated to determine the threshing capacity, threshing efficiency, cleaning efficiency, fuel consumption, and grain breakage. The experiment has been replicated four replications at a different moisture content of the crop stalks, which means 14%, 18%, and 22% dry base (*d.b.*) moisture content with the same or constant feeding rate

and constant revolution per minute (rpm) of barley, wheat and *tef* grains.

2.3. Performance Evaluation of the Machine

The crop varieties that have been used in this study were one of the prevalent varieties were used for procured in farmers around Amhara Region Semen Shewa Zone of Minjar Shenkora district. The samples were manually cleaned to remove unwanted materials from the crop stalks and then moisture by adding water on the samples to achieve the required amount of moisture contents that means, (14%, 18%, and 22%) through spreading of canvas on the ground and added water through sprayer by spraying. The initial moisture content of the crop stalks was measured by a moisture meter. After determining its initial moisture content, additional distilled water was added to the crops until it attains the required moisture content. Then started to thresh the crop with stalks and data was recorded. The recorded result includes threshing efficiency, cleaning efficiency, grain damage, threshing capacity, time taken, and fuel consumption. The initial moisture content was measured three times for getting of mean value by using a digital moisture meter (Draminski grain master, GM 667, Poland). The average initial moisture content was 13.73%, 13.065%, and 12.5% for barley, wheat, and tef crop with stalks respectively. Feed rate is the weight of total unthreshed grain fed into the thresher per unit of time. It was constant throughout the trials for determining the effect of moisture content on the performance of the thresher machine.

2.3.1. Computation of the Performance Parameters

(i) Physical Properties of Grains

The physical properties of wheat, barley, and *tef* grains, used during performance evaluation of the thresher machine, were identified and determined. The properties were the shape, shape factor (sphericity), bulk density, angle of friction, size, mass, bulk density, and static friction coefficient were measured and an average value was computed. The dimensions of seeds, in length, width, and thickness were measured in three directions by using a digital electronic caliper. Crops with initial damages such as scratches, abrasion, decay, and greening were not included in the sample.

(ii) Size of Grains

Fifty grains were randomly selected from the bulk of samples with three ranges of minimum, medium, and maximum sizes. Their three principal dimensions were measured using a digital Vanier caliper made in Taiwan that has an accuracy of 0.02 mm. Athematic and geometric mean diameter; sphericity, surface area, bulk density, volume, and angle of repose of tubers were analyzed using standard procedures with three replications.

(iii) Coefficient of Static Friction

The coefficient of static friction (μ) on galvanized steel sheet, mild steel sheet, rubber, and timber sheet was

measured for all crops by using the inclined plane method. The material was kept on a horizontally level surface and the slope was increased gradually. The angle (α) at impending slip was recorded and computed. The experiment was replicated three times and the mean value of the inclination angle was calculated. Then the coefficient of static friction (μ) was equal to tanα.

2.3.2. Dependent Variables

The performance of the machine could be evaluated through threshing capacity, threshing efficiency, cleaning efficiency, germination rate, fuel consumption, and grain loss. Data collection of dependent variables was applied through randomly selected three samples from each experimental unit. Variables examined and formulae used in computing the machine are stated as follows:

1. Threshing capacity: It is the weight of the threshed crop fed to the machine per unit of time. It can be defined as:

$$T_c = \frac{M_t}{t}$$

Where:
M_t=Total mass of the crop biomass fed into the machine
t=Total time is taken to thresh the crop.

2. Threshing efficiency (%):
It also defined as,

$$\eta_t = \frac{M_t - M_u}{M_t}$$

Where:
M_t=total mass of crop fed into the machine
M_U=mass of unthreshed crop.

3. Cleaning efficiency: It is the ratio of the mass impurities to the total mass of grain at the machine main outlet expressed in percentage and is given as:

$$\eta_c = \frac{M_c}{M_t}$$

Where:
M_C=the mass of cleaned grain at the machine main outlets
M_t=the total mass of grain& impurities at the main outlets

4. Percentage of loss (P_L): It is the ratio of the quantity of grain loss to the total quantity of the crop yield during threshing expressed as a percentage and is given as:

$$P_l = \frac{M_l}{M_t} \times 100$$

Where,
P_L=the percentage loss (%)
M_t=the total mass of grain yield (g)
M_l=mass of grain losses (unthreshed loss, separation loss, scattering, and loss blower loss) (g)

5. Germination rate (G): The germination test at a hundred (100) randomly selected seeds from each sample of the threshed crop was determined. The seeds were kept in a Petri dish lined with moist filter paper with distilled water in three replications and incubated at room temperature for eight days and then records the result in percent of the germinated to the total sample.

6. Fuel consumption (Fc): Before the start of each test trial, the fuel tank was filled to its capacity and after each test trial; the fuel consumed was measured by refilling the tank to the same level using a graduated cylinder. Mathematically can be calculated as [7].

$$Fc = \frac{Q}{t}$$

Where:
Q=Amount of fuel in (L) consumed by the thresher
t=Time taken in (hr.).

2.4. Experimental Design

Performance evaluation of the machine was through three levels of moisture contents: mc_1=14%, mc_2=18% and mc_3=22% was used. The experimental design was a CRD 4 replicates giving 12 total experimental units [29]. The other parameters including feeding rate, the thresher drum RPM, concave clearance, and other crop parameters were kept constant. The experiment has been repeated four times for replication at a different moisture content of the crop biomass, (14%, 18%, and 22%).

2.5. Data Analysis

Data were subjected to analysis of variance using statistical Analysis System Software (SAS)-8 and Statistix-10 statistical soft wares [29]. When the effects of the treatments were found significant, the LSD test was performed to assess the difference between the treatments at a 5% level of significance.

3. Result and Discussion

3.1. Physical Properties of Cereal Crops

Measurements made on some physical properties of cereal crops like barley (*HB 42*), wheat (*Kakaba*), and *tef* (*Magna*) varieties were measured in the experiment. Those are; moisture content, dimension (length, width, thickness), arithmetic, geometric, and equivalent mean diameter, sphericity, porosity, thousand-grain mass, density, surface area, coefficient of friction, and angle of repose.

3.1.1. Dimensions of Grain

The results of mean dimensions of barley and wheat seeds at different moisture content indicated that the size and dimensions of barley and wheat seed increased with increasing moisture content which validated previous results [2, 24]. The moisture content was increased from 14 to 22%, the length of barley and wheat seeds were increased from 9.87 to 11.13mm and 5.98 to 6.86mm, the width of barley and wheat seeds were increased from 3.28 to 3.81mm and 3.12 to 3.75mm and also thickness of barley and wheat seeds were increased from 2.21 to 2.96mm and 2.80 to 3.22mm respectively. The arithmetic, geometric, and equivalent mean diameter of the three principal axis is also increased with the moisture content of barley, and wheat grains. There was an increase in the arithmetic, geometric, and equivalent mean diameter from 5.20 to 5.90mm, 4.18 to

5.09mm, and 4.23 to 5.05mm for barley grains respectively, and 3.96 to 4.61mm, 3.71 to 4.34mm, and 3.72 to 4.37mm for wheat grains respectively. It indicates that barley seeds can absorb more water and increase larger than wheat seeds. These are similar trends as obtained by African yam bean, barley, paddy, and Lablab seeds [9, 15, 23, 27].

The threshing cylinder-concave clearance is determined by the length, width, and thickness of each grain. If the clearance is large, there will be un-threshed grain pass away to the straws while small clearance may result in excessive breakage of grains due to crushing. Generally, the moisture content of the crop increased, the dimension of grains also increased. Therefore, the moisture content and dimension of barley and wheat seeds have directly related to each other. The area based on the arithmetic and geometric mean diameter was also increased with an increased moisture content of barley, and wheat grains respectively. The area based on arithmetic and geometric mean diameter increases from 4.02 to 4.69mm^2, and 3.26 to 3.93mm^2 for barley grains respectively, and 3.11 to 3.62mm^2 and 2.93 to 3.42mm^2 for wheat grains respectively. The volume of seeds also increased from 37.44 to 65. 68mm^3 and 27.31 to 43.28mm^3 for barley and wheat seeds respectively, that showed similar trends were obtained for paddy and barley seeds [15, 27].

3.1.2. Sphericity (Sp)

The sphericity of barley and wheat seed increased with the increment of moisture content. The sphericity of barley and wheat seeds increased linearly from 42% to 45% and 62.5% to 63.5% for barley and wheat seeds respectively, as the moisture content increased from 14% to 22%. Sphericity values of most agricultural products have been reported to range between 0.32 and 1.00 [16]. This also is a similar trend obtained in barley, cowpea, and paddy grains [1, 9, 28]. This suggests that as the grain's moisture content increases, its shape approaches to sphere shape. This is due to the differential dimensional changes of the three major dimensions as the grain absorbs moisture. The effect of moisture content on the sphericity was significant at a 5% probability level [15].

3.1.3. Thousand Grain Mass

The average thousand grain mass of barley, wheat, and tef grains were increased with the increment of moisture content. The average 1000 grain mass of barley seeds increased from 31.00g at 14% to 34.50g at 22%, that of wheat seeds increased from 33.00g at 14% to 37.50g at 22% and *tef* seeds increased from 0.28g at 14% to 0.39g at 22% of moisture content (*w.b.*). This experiment was replicated three times to get a mean accuracy of the grain mass. This behavior occurs as a result of increased moisture content, which increases in size [9]. The outcomes are consistently obtained in lablab, wheat, cowpea, and barley seeds [15]. The individual seed mass of barley and wheat seeds also increased due to moisture content from 0.03g to 0.04g of each grain but the individual mass of *tef* grain was not measured due to the small size of *tef* grain that needs advanced measuring method.

3.1.4. Surface Area

The surface area of barley and wheat seeds was increased with an increase in moisture content. The surface area of barley and wheat grain increased linearly from 25.46 to 33.33mm^2 and 14.65 to 20.19mm^2 when the moisture content increased from 14 to 22% *w.b.* in each grain as similar trends were reported in cowpea and lablab seeds [1, 23]. The rate of heat transfer to the material was significantly dependent on the surface area of seeds. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer.

3.1.5. Density

A. Bulk density

The grains bulk density at different moisture levels varied from 497.83kg/m^3 to 444.14kg/m^3 and 932.50kg/m^3 to 887.64kg/m^3 for barley and wheat grains respectively. This indicates a decrease in bulk density was increasing in moisture content from 14 to 22% wet base. The negative relationship of bulk density with moisture content was also observed by various other research works in barley, cowpea, and wheat grains respectively [1, 15, 18]. This decreasing relation is because of an increase in mass owing to the moisture of again in the grain sample was lower than the accompanying volumetric expansion of the bulk [11]. Therefore, the volume of grains was more highly expanded than its mass possessing of water. Hence, the bulk density of grains was decreased due to the expansion of its volume.

B. True density

The true density of barley and wheat grains at different moisture content was varied from 934.95kg/m^3 to 776.52kg/m^3 and 1391.89kg/m^3 to 1201.51kg/m^3 respectively. An increase in moisture showed that a decrease in the true density of the crops. The result is similarly obtained in barley, cowpea, and wheat grains [1, 11, 15]. The decrease in the true density was mainly due to the larger increase in grains volume compared to the increase in grains mass.

3.1.6. Porosity

The porosity (percent of pore space between the grains) was calculated by using the data presented on the bulk and true densities of the barley, and wheat grains. The porosity of barley and wheat grain decreased linearly from 46.75 to 42.80% and 33.01 to 26.12%, with increasing moisture content from 14 to 22% respectively. This difference between the two crops could be due to the cell structure, volume, and also mass increase characteristics of the samples, as the moisture content of grains increases. The reason is the decreasing porosity of barley and wheat gains when the grain becomes more moisture and their volume increased more than its mass thus, the number of grains in a fixed volume decreased. Since the number of grains per unit volume decreases, the value of porosity also decreases. The outcomes are consistent with the outcome that was obtained in barley, lablab, wheat, cowpea, and barley seeds that affect packing and resistance to airflow through bulk seeds [1, 11, 18, 19, 23].

3.1.7. Angle of Repose

The measured average value of the angle of repose was increased from 28.50° to 37.85°, 25.75° to 34.15°, and 35.20° to 40.25° for barley, wheat, and *tef* grain respectively as the moisture content increased from (14 to 22)% wet bases. This increasing trend of the angle of repose with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of grain together by the surface tension [27]. These results were also reported in barley, soybean, and maize, and cereal and oilseeds [15, 24, 26]. The particle holds the aggregate of grain together by the surface in tension. It is also an important factor for designing the equipment of mass flow and storage structures.

3.1.8. Coefficient of Friction

The coefficient of friction of materials on various structural surfaces is important in predicting the movement of the materials in handling and harvesting equipment and the pressure exerted on the walls of the storage structures. The static coefficient of frictions of the grains on the surfaces of plywood and iron sheet metal was increased with moisture content in the moisture range of 14% to 22% (w.b.) for barley, wheat, and *tef* seeds respectively. It was observed that the static coefficient of friction increased linearly from 36.10 to 62.85%, 35.41 to 60.92%, and 44.94 to 67.91% of barley, wheat, and *tef* grains respectively, with moisture content, increased from 14 to 22% wet base. The reason for the increased friction coefficient at higher moisture content was owing to the water present in the grain which offers a cohesive force on the surface of contact. As the moisture content of grains increases, the surface of the samples becomes stickier. Water tends to adhere to surfaces and the water on the moist seed surface would be attracted to the surface across which the sample is being moved [28]. It was similar trends obtained in wheat, and cereal, and oilseeds respectively. The coefficient of friction increased with increasing moisture content in each grain [18, 24, 26].

3.2. Performance of Thresher

The performance evaluation of the thresher was determined by threshing capacity, threshing efficiency, cleaning efficiency, fuel consumption, and percentage of harvesting loss.

3.2.1. Threshing Capacity (Tc)

Threshing capacity was highly influenced by the moisture content of barley, wheat, and *tef* crop biomass. The mean with a standard error of threshing capacity and analysis of variance were presented in Table 1 for all grains. The ANOVA indicated that the threshing capacity of multi-crop thresher made in MARC was significantly affected by the moisture content of barley, wheat, and *tef* crop biomass at (P < 0.05). The maximum threshing capacity (Kg/hr.) was 651.66, 392.66, and 418.69 observed at 14% moisture content; whereas the minimum threshing capacity was 383.36, 327.00, and 325.98 for barley, wheat, and *tef* grains respectively when the moisture content was 22%. This

indicates that when the moisture content of the crop increased the threshing capacity (kg/hr.) of the machine was decreased because the moisture content of the crop affects the performance of the thresher. This result is the same trend as reported in wheat grains [30]. The regression analysis was made to establish a relationship between the moisture content of the crop biomass, and the performance of the thresher (kg/hr.). A regression question was made for their relationships between the threshing capacity (Tc) and the moisture content (M) of barley, wheat, and *tef* grains can be represented by the following equations:

$$Tc = -33.5371M + 1102.73, R^2 = 0.77 \text{ for barley}$$

$$Tc = -8.20719M + 507.284, R^2 = 0.45 \text{ for wheat}$$

$$Tc = -11.5878M + 587.163, R^2 = 0.66 \text{ for } tef$$

The regression equation shows that the moisture content of crops has a negative impact on threshing capacity with a strong correlation of $R^2 = 0.77$, an intermediate correlation of $R^2 = 0.66$ and a medium correlation of $R^2 = 0.45$ for barley, wheat, and tef grains respectively.

Table 1. Effects of moisture content on the threshing capacity of barley, wheat, and tef seeds.

Threshing capacity (kg/hr.) crops			
Moisture content (%)	Barley	Wheat	Tef
14	651.66[A]±37.814	392.66[A]±20.049	418.69[A]±10.318
18	462.18[B]±23.762	359.00[AB]±11.837	391.08[A]±18.347
22	383.36[B]±31.133	327.00[B]±18.533	325.98[B]±14.366
Mean	499.06±37.709	359.56±12.076	378.58±14.012
SE (%)	44.450	24.297	20.808
LSD	100.55	54.964	47.071
CV (%)	12.60	9.56	7.77

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

3.2.2. Threshing Efficiency (η_t)

The threshing efficiency (%) of the machine was highly influenced by the moisture content of barley, wheat, and tef crop biomass. The mean with a standard error of threshing efficiency and analysis of variance were presented in Table 2 of each grain. The ANOVA indicated that the threshing efficiency of multi-crop thresher made in MARC was significantly affected by the amount of moisture content of barley, wheat, and *tef* biomass at (P < 0.05). The maximum threshing efficiency (%) of the thresher was 97.629, 97.682, and 97.740, observed at 14% moisture content; whereas the minimum threshing efficiency of the machine was 95.091, 95.560, and 95.543 observed at the moisture content of 22% for barley, wheat, and *tef* crop threshing respectively. This indicates that when the moisture content increased, the threshing efficiency (%) of the machine was decreased because the amount of moisture content presented on the crop affects the performance of the thresher that results in line with other findings [20]. The regression analysis was made to establish a relationship between the moisture content

of the crop biomass and the performance of the thresher in (%). From regression coefficients their relationships between the threshing efficiency (η_t) and the moisture content (M) of barley, wheat, and *tef* grains can be represented by the following equations;

$$(\eta_t)=-0.31737M + 102.064, R^2=0.58 \text{ barley}$$

$$(\eta_t)=-0.26531M + 101.383, R^2=0.64 \text{ wheat}$$

$$(\eta_t)=-0.27469M + 101.650, R^2=0.68 \text{ } tef$$

The equation shows that the threshing efficiency had a negative relationship with the moisture content with an intermediate correlation of $R^2=0.58$, 0.64, and 0.68 for barley, wheat, and tef seeds respectively.

Table 2. *Effects of moisture content on threshing efficiency of barley, wheat, and tef seeds.*

Threshing efficiency (%) crops			
Moisture content (%)	Barley	Wheat	Tef
14	97.629[A]±0.1060	97.682[A]±0.0774	97.740[A]±0.2231
18	96.334[AB]±0.4603	96.580[AB]±0.3446	96.833[A]±0.5015
22	95.091[B]±0.7370	95.560[B]±0.5520	95.543[B]±0.2796
Mean	96.351±0.4091	96.608±0.3276	96.706±0.3292
SE (%)	0.7147	0.5350	0.5029
LSD	1.6169	1.2103	1.1377
CV (%)	1.0500	0.7800	0.7400

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

3.2.3. Cleaning Efficiency (η_c)

The cleaning efficiency of the thresher was highly influenced by the moisture content of barley, wheat, and *tef* crop in biomass. The mean with a standard error of cleaning efficiency and analysis of variance were presented in Table 3. The ANOVA indicated that the cleaning efficiency of multi-crop thresher made in MARC was significantly affected by the amount of moisture content of barley, wheat, and *tef* crops at ($P < 0.05$). The maximum cleaning efficiency (%) of the crops was 94.824, 88.335, and 88.604, observed at 14% moisture content; whereas the minimum cleaning efficiency was 89.246, 69.368, and 75.633 observed at the moisture content of 22% barley, wheat, and *tef* crop biomass.

In general, the cleaning efficiency (%) of the machine increased with a decrease in moisture content, while it declined with the increased moisture content of crops because the amount of moisture content presented on the crop affects the performance of the thresher. This means that increased moisture content gave less cleaning efficiency due to the presence of high amounts of impurity or chaff which causes the clogging effect of chaffs on the wall of the concave and drums of the thresher and also on the sieve screens, which also reported through other results [19].

The regression analysis was made to establish a relationship between the moisture content of the crop biomass and the performance of the thresher in (%). From regression coefficients their relationships between the

cleaning efficiency (η_c) and the moisture content (M) of barley, wheat, and *tef* grains can be represented through the following equations;

$$(\eta_c)=-0.69731M + 104.238 \text{ } R^2=0.75 \text{ barley}$$

$$(\eta_c)=-2.37094M + 121.939 \text{ } R^2=0.94 \text{ wheat}$$

$$(\eta_c)=-1.62141M + 110.755 \text{ } R^2=0.76 \text{ tef}$$

The regression equation above showed that the cleaning efficiency of the machine had an indirect (negative) relationship with the moisture content of crops. Therefore, when the moisture content of the crop increased, the cleaning efficiency of the thresher was decreased with a strong correlation of $R^2=0.75$, 0.94, and 0.76 for barley, wheat, and tef grains respectively.

Table 3. *Effects of moisture content on cleaning efficiency of barley, wheat, and tef seeds.*

Cleaning efficiency (%) crops			
Moisture content (%)	Barley	Wheat	Tef
14	94.824[A]±0.8357	88.335[A]±1.2796	88.604[A]±1.9378
18	90.989[B]±0.7098	80.082[B]±1.0854	80.471[B]±1.5084
22	89.246[B]±0.5032	69.368[C]±0.8449	75.633[B]±1.4694
Mean	91.686±0.7911	79.262±2.4088	81.569±1.8299
SE (%)	0.9851	1.5339	2.3366
LSD	2.2284	3.4698	5.2858
CV (%)	1.5200	2.7400	4.0500

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

3.2.4. Germination Rate

Germination rate was highly influenced by the moisture content of barley, wheat, and *tef* crop biomass. The mean with a standard error of the rate of germination and analysis of variance were presented in Table 4. The ANOVA table indicated that the rate of germination was significantly affected by the moisture content of crop biomass at ($P < 0.05$). The maximum germination rate (%) of the crop was 94.255, 95.360, and 95.854, observed at 14% moisture content; whereas the minimum rate of germination was 90.109, 89.763, and 89.605 at the moisture content of 22% for barley, wheat, and *tef* grains respectively. This is the same result obtained by other scholars [10]. It indicates that when the moisture content of grains increased the rate of germination decreased because the highest moisture content of grain affects the rate of transpiration of seeds.

The regression analysis was made to establish a relationship between the moisture content of the biomass and the germination rate (%). From regression coefficients, their relationships between the rate of germination (G) and the moisture content (M) of barley, wheat, and tef grains can be represented by the following equations.

$$G=-0.51822M + 101.645 \text{ } R^2=0.62 \text{ barley}$$

$$G=-0.69969 \text{ } M + 105.165 \text{ } R^2=0.79 \text{ wheat}$$

$$G = -0.78105 \, M + 107.356 \quad R^2 = 0.84 \; tef$$

The regression equation above shows that the rate of germination of the seeds had a negative relationship with moisture content. Therefore, when the moisture content of the crop increased, the rate of germination of the seed was decreased with an intermediate correlation $R^2 = 0.62$ of barley and a strong correlation of $R^2 = 0.79$ and 0.84 for wheat and *tef* respectively.

Table 4. *The germination rate of barley, wheat, and tef crops at different moisture content.*

Germination rate (%) of crops			
Moisture content (%)	Barley	Wheat	*Tef*
14	94.255^A±0.3990	95.360^A±0.3817	95.854^A±0.3266
18	92.586^A±0.3108	92.590^B±0.2796	94.431^B±0.3773
22	90.109^B±1.2015	89.763^C±1.0848	89.605^C±0.5567
Mean	92.317±0.6467	92.571±0.7759	93.297±0.8372
SE (%)	1.0644	0.9663	0.6104
LSD	2.4078	2.1860	1.3808
CV (%)	1.63	1.48	0.93

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

3.2.5. Fuel Consumption (fc)

Fuel consumption was highly influenced by the moisture content of barley, wheat, and tef crops in biomass. The mean with a standard error of fuel consumption and analysis of variance are presented in Table 5. It shows that the fuel consumption, in L/hr.,), of the machine when operated at different moisture contents, and the ANOVA table indicated that the fuel consumption of multi-crop thresher made in MARC was significantly affected by the amount of moisture content of barley, wheat, and *tef* biomass at (P < 0.05). The maximum fuel consumption (L/hr.) was 2.0213, 2.7300, and 2.3560, observed at 22% moisture content; whereas the minimum fuel consumption was 1.1650, 1.7200, and 1.6960, at the moisture content of 14%. Furthermore, the fuel consumption of the system was increasing sharply from 1.14 l/hr. to 2.02 l/hr., 1.72 l/hr. to 2.73 l/hr., and 1.70 l/hr. to 2.36 l/hr. at which the moisture content of the barley, wheat, and *tef* crop biomass was increased from 14% to 22% respectively. This indicates that at 22% moisture content the energy required to thresh the crop biomass was high. Therefore, the fuel consumption needed in this moisture content as high as obtained in other reports [30]. In general, the fuel consumption of the machine increased when, the moisture content of barley, wheat, and *tef* crop biomass was increased. As shown in Table 5, fuel consumption increased with an increased moisture content of crops during threshing operation.

The regression analysis was made to establish a relationship between the moisture content of the biomass and fuel consumption (l/hr.). From regression coefficients, their relationships between the fuel consumption (Fc) and the moisture content (M) of barley, wheat, and tef grains can be represented by the following equations.

$$F\,(c) = 0.11059 \, M - 0.40927 \quad R^2 = 0.94 \; barley$$

$$F\,(c) = 0.12625 \, M - 0.06083 \quad R^2 = 0.80 \; wheat$$

$$F\,(c) = 0.08250 \, M - 0.5405 \quad R^2 = 0.77 \; tef$$

Based on the regression coefficients, the moisture contents were found to be, the greater contribution to fuel consumption as indicated in the equation above. Moisture contents have a direct relationship to fuel consumption at a strong correlation of $R^2 = 0.94$, 0.80, and 0.77 for barley, wheat, and tef seeds respectively.

Table 5. *Fuel consumption of barley, wheat, and tef crops at different moisture content.*

Fuel consumption (l/hr) crops			
Moisture content (%)	Barley	Wheat	*Tef*
14	1.1365^C±0.0331	1.7200^C±0.0726	1.6960^C±0.0509
18	1.5865^B±0.0662	2.1850^B±0.1809	2.0248^B±0.0864
22	2.0213^A±0.0549	2.730^A±0.0610	2.3560^A±0.1069
Mean	1.5814±0.1124	2.2117±0.1388	2.0256±0.0925
SE (%)	0.0753	0.1667	0.1197
LSD	0.1703	0.377	0.2709
CV (%)	6.73	10.66	8.36

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

3.2.6. Threshing Loss

The percentage of loss during threshing was highly influenced by the moisture content of barley and wheat crops in biomass. The ANOVA, on the threshing data of the thresher, revealed that the moisture content of crops had highly significant effects on the grain breakage of the machine. ANOVA was presented in Table 6. It indicated that the grain threshing loss of multi-crop thresher made in MARC was significantly affected by the moisture content of barley and wheat crops at (P < 0.05). The maximum quantity of grain loss to the total quantity of the crop yield during threshing of grain (%) was 2.8655 and 2.6375%, observed at 14% moisture content while the minimum threshing loss (%) was 1.6300 and 1.3750% observed when the moisture content was 22% for barley, wheat, and *tef* crop respectively. It also showed that the grain loss was decreased at which the moisture content of crops increased as supported by similar findings in corn and wheat grains [3, 14]. But the breakage of *tef* grain was not identified (difficult to determined) because the size of the *tef* grain is very small, which needs an advanced measuring instrument. In general, the grain loss of the machine was decreased while, increasing the moisture content of crops. As shown in Table 6, the threshing loss of grain decreases with an increased moisture content of crops during threshing operation. The regression analysis was made to establish a relationship between the moisture content of the crop biomass and the breakage of grains (%). From regression coefficients, their relationships between the grain breakage (Gb) and the moisture content (M) of barley, wheat, and *tef* grains can be represented by the following equations.

$$Gb = -0.15444 M + 5.02421 \ R^2 = 0.60 \ barley$$

$$Gb = -0.15781 M + 4.83646 \ R^2 = 0.78 \ wheat$$

The regression equation above shows that the moisture content of crops is a negative impact on the contribution of a percentage of grain breakage at an intermediate correlation of $R^2 = 0.60$ for barley and a strong correlation of $R^2 = 0.78$ for wheat seeds.

Table 6. Grain breakage of barley and wheat crops at the different moisture content.

Grain breakage (%) crops		
Moisture content (%)	Barley	Wheat
14	$2.8655^A \pm 0.3414$	$2.6375^A \pm 0.1055$
18	$2.2375^{AB} \pm 0.2172$	$1.9750^B \pm 0.1841$
22	$1.6300^B \pm 0.0902$	$1.3750^C \pm 0.1684$
Mean	2.2443 ± 0.1969	1.9958 ± 0.1756
SE (%)	0.3385	0.2212
LSD	0.7658	0.5003
CV (%)	21.3300	15.67

SED: Standard errors of differences of means; LSD: Least significance difference; CV: Coefficient of variation; Means followed by the same letters are not significantly different at 5% level of probability.

4. Conclusion and Recommendation

4.1. Conclusion

This study concluded that wide variation exists among the barley and wheat grain dimensions concerning the physical properties determined. The linear dimensions (length, width, and thickness) and also arithmetic mean diameter, geometric mean diameter, equivalent mean diameter, surface area, sphericity, coefficient of friction, thousand-grain mass, fuel consumption, and angle of repose were linearly increased with increased grain moisture content at a range of 14 to 22% w.b. While bulk and true (particle) density, breakage of grain, threshing capacity, threshing efficiency, porosity, percentage of blower losses, and cleaning efficiency of the barley (HB 42 variety), wheat (Kakaba variety), and teff (Magna variety) were decreased with increasing of moisture content. This indicates that moisture content is the most important factor to determine the grain's physical property. In this study (14-18) % moisture content was suggested as the threshing capacity, threshing efficiency, and cleaning efficiency were gives better results compared to the other moisture levels, and also had least fuel consumptions.

4.2. Recommendation

The performance evaluation result obtained from Melkassa-made multi-crop thresher was recommended that:

1. Once the plants are cut, they are left in the ground of a small heap in the field for further drying. This causes losses of grains during drying.
2. To reduces this problem appropriate harvesting moisture content is required.
3. This study recommends that the harvesting and threshing moisture content of most cereal crops be laid between 14-18%.

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