THE EFFECT OF MOISTURE CONTENT OF CEREAL CROPS ON THE PERFORMANCE OF MELKASA MUTI-CROP THRESHER

BY

Melkamu Fetene Werku

FOR DEPARTMENT OF MECHANICAL SYSTEM AND VEHICLE ENGINEERING

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

A Thesis Submitted to Partial Fulfillment of the Requirements for the Award of Master of Science degree in Agricultural Machinery Engineering

Office of the Graduate Study

Adama Science and Technology University

Adama, Ethiopia

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Fekadu Lemessa (Ph. D)

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ADVISORS APPROVAL SHEETS

To; Mechanical System and Vehicle engineering

Subject; Thesis submission

This is to certify that the thesis entitled "**The effect of moisture content of cereal crops on the performance of Melkasa muti-crop thresher**" submitted in partial fulfillment of the requirement's for the Masters of science Degree in Agricultural Machinery Engineering, the Graduate program of the department of Mechanical System and Vehicle engineering, and has been carried out by Melkamu Fetene Werku Id. No. 18274/11, under my supervision.

Therefore, I recommend that the student has fulfilled the requirements and hence here he can submit the thesis to the department.

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Name of advisor	Signature	Date

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We, the undersigned, members of the Board of Examiners of the final open defense by **Mr. Melkamu Fetene Werku [PGR/18274/11]** have read and evaluated his thesis entitled "**The effect of moisture content of cereal crops on the performance of Melkasa muti-crop thresher**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Master of science Degree in Agriculture Machinery Engineering complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all source of material used for this thesis have been duly acknowledge.

Name: Melkamu Fetene Werku

Signature: ____

This MSc Thesis has been submitted for examination with my approval as thesis advisor.

Name: Fekadu Lemessa (Ph.D.)

Signature: ____

Date of submission

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LIST OF ACRONYMS

ANOVA	Analysis of Variances
BC	Before Christ
CRD	Completely Randomized design
CSA	Central Statistical Agency
CV	Coefficient of Variance
CZ	Central Zone
FC	Field Capacity
IAR	Institute of Agricultural Research
LSD	Least Significant Difference
MARC	Melkassa Agricultural Research Center
MASL	Meter Above Sea Level
MC	Moisture content
MOG	Material Out of Grain
NRVAC	Notification and Release of Varieties for Agricultural Crops.
RPM	Revolution per Minutes
SAS	Statistical Analysis Software
SE	Standard Error
SSA	Sub-Saharan Africa
TKW	Thousand Kernel Weight
USDA	United States Department of Agriculture

ABSTRACT

Cereal grains are growing in greater quantities worldwide than the other crops and supply more food energy to the humankind however, harvesting and threshing operation of such crops are affected by moisture content. Therefore, the main objective of this study was to evaluate the effect of moisture content on the threshing performance. Evaluation was carried out by measuring the initial moisture content and then by adding water to the crops, the desired moisture content was achieved. The dimension of the grains was determined. Completely randomized design (CRD) with three replications was used to determine the effect of threshing efficiency, threshing capacity, fuel consumption, breakage of grain, germination rate, percentage of unthreshed grain and blower loss at 14%, 18%, and 22% moisture content for barley, wheat, and teff selected varieties. Statistical analysis was made by (SAS-8) software. The results indicated that, as the crop moisture content increase, the dimension of grain, sphericity of seed, angle of repose, thousand grain mass, fuel consumption, and coefficient of friction were also increased. Whereas, threshing capacity, and efficiency, cleaning efficiency, density, germination rate, and grain breakages were deceased. This study concluded that for low fuel consumption, low unthreshed grain and better threshing, the moisture content of the crops should be between 14% to 18%.

Keywords: *Fuel Consumption, Grain Breakage, Moisture Content, Performance of Thresher*

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification

Cereal crops were mostly grasses cultivated for their edible seeds. Cereal grains were grown in greater quantities worldwide than the other sort of crops and supply more food energy to the humankind than other crops. It provides essential nutrients and energy within the everyday human diet through direct human consumption and also through meat production since they comprise a serious livestock feed (Ioannis *et. al*., 2008). Cereal grains such as *teff*, 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 (Hailu, 1993).

Cereal production involves various processes, including sowing, weeding, pesticide application/spraying, harvesting, cleaning, and processing (Mahmoud *et al*., 2009). Cereal seeds can be used for sowing crop plants, for energy production or food production. Among many cereal crops such as *teff*, maize, barley, sorghum, millet, wheat, etc, only three cereal crops (barley, wheat and *teff*) were selected for this research to check whether, the physical properties of the crop such as moisture content, size, and shapes affect the performance of the thresher machine or not.

The physical property of these crops is the most common properties to affect the performance of the thresher machine. It has been varied from place to place because of different factors such as soil type, weather condition, topographies of land or land levelness, a sawing condition that means sawing by broadcasting or by precision planting, amount of using fertilizer, etc.; so, the performance of the machine that used to thresh such crops were affected by the above criteria.

Physical and engineering properties were important to solve many problems related to the performances of machines and the analysis of the behavior of the product during agricultural process operations like handling, planting, harvesting, threshing, cleaning, sorting, and drying. Solutions to the issues in these processes involve knowledge of their physical and engineering properties (Zareiforoush, 2009). Knowledge of the physical properties of processed material was required at every stage of the production process (Markowski *et al*., 2013). There are many types of cereal crops found in Ethiopia among them the following three types were selected for this study.

1.1.1. Barley

Barley *(Hordeum vulgare L)* is an ancient and important cereal grain crop. It ranks fifth among all crops in dry matter production within the world today. Historically, barley has been a vital food source in many parts of the world, including the Middle East, North Africa, northern and Eastern Europe, and in Asia (Mollazade *et al*., 2009). Barely is widely grown cereal crops and grouped among the top ten crop plants in the world. 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 respectively (Hagberg & Wegman, 1987).

Barley was believed to be cultivated in Ethiopia as early as 3000 years B.C. This long history of cultivation and therefore the large agro-ecological and cultural diversity within the country has resulted in a very sizable number of landraces (farmers' varieties) and rich traditional practices. Barley production culture in Ethiopia is sometimes practiced with little or no external inputs, mainly in the higher altitudes or on steep slopes, eroded lands, or in moisture stress areas. It was a major staple food grain in the highlands. It is used in different forms such as bread, porridge, soup, roasted grain, and preparing alcoholic and non-alcoholic drinks e.g. beer & malts respectively. The straws were used for animal feed, thatched roofs, and bedding. Production of malting barley has started in 1975 to meet the growing demand of local breweries (Hailu, 1993).

The physical properties of barley grain, like those of other grains and seeds, are essential for the performance of 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 (Mahmoud *et al*., 2009).

1.1.2. Wheat

Wheat (*Triticumaestivum* L.) is the most important staple food crops in both developed and developing countries and contributes more calories and proteins to the world diet than any other cereal crops (Shewry, 2007).

Wheat is taken into account an honest source of protein, minerals, B-group vitamins, and other necessary food products (Shewry, 2007) although the environmental conditions can affect the nutritional composition of wheat grains with its essential coating of bran, vitamins, and minerals; it's a little of wonderful health-building food.

Wheat flour was accustomed to prepare bread, biscuits, confectionery (sweet) products, and dynamic wheat gluten. It had been also used as animal feed, ethanol production, brewing of ale, the wheat-based raw material for cosmetics, wheat protein in meat substitutes and to create wheat straw composites (Kumar *et al*., 2011). 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.

Wheat has many uses like that of other cereal crops produced in the country. In Ethiopia, wheat grain is used in the preparation of different traditional as well as modern processed food products such as *injera* and other industrial processed products like pasta and macaroni. Besides, wheat straw is commonly used as a roof tacking material and as a feed for animals. So, wheat is an important cereal crop which should get emphasis on both its production and its marketing (Anteneh & Asrat, 2020).

1.1.3. Teff

Teff *(Eragrostis teff (Zucc.)* is the most staple food crop in Ethiopia. It has existed in Ethiopia since the recorded history of the country. *Teff* was originated and has distributed/disseminated in Ethiopia. Ethiopian farmers grew teff 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 (Patricia, 2008).

The word *teff* was believed to have been derived from the Amharic word "*teffa*" which means "lost," due to the smallest size of the grain and how easily it is lost if dropped (Mariyam Idreis, 2004). It was the smallest grain in the world, ranging from 1–1.7mm long and 0.6–1mm diameter with l000 grain seed weights averaging 0.3–0.4 grams and taking 150 grains to weight as much as one grain of wheat (Patricia, 2008).

Teff accounts for about two-thirds of the daily protein intake in the diet of the Ethiopian population. Its grain is mainly used for making *injera*, porridge, bread, feed for animals, and attached wales. *Teff* 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 (Alemayehu, 2001). *Teff* crop contains more calcium, copper, zinc, aluminum, and barium than other cereal crops such as wheat, barley, and sorghum (Melak, 1966).

The other grains such as wheat, corn, sorghum, or a mixture of these, can be used for making Enjera; however, teff alone is preferred. *Teff* was believed to have originated in Ethiopia between 4000 and 1000 (B.C). Nowadays, it represents the discovery of a crop used by ancient civilizations (Stallknecht *et al*., 1993). Physical characteristics of *teff* such as its moisture content, size, shape, etc., are very important to determine the performance of the thresher machine.

1.2. Statement of the Problem

The moisture-dependent characteristics (the physical properties) of the agricultural products have effects on the adjustment, efficiency of machine, and fuel consumption of threshing machine. The property of cereal crops like moisture content, and the clearance between drum and concave are the common properties to affect the performance of the thresher. Such factors affect threshing capacity, threshing efficiency, cleaning efficiency, fuel consumption, and breakage of grains during threshing with the machine. To solve problems, that resulted from untimely harvesting and threshing of cereal grain crops, it is important to determine the effect of the physical properties and their characteristics by which optimum adjustment can be made where the clearance between drum and concave and appropriate moisture content selections would give high threshing capacity, threshing efficiency, and cleaning efficiency as well as reducing grain damage which will lead to post harvest storage loss, and lesser fuel consumption to lower the cost of threshing in order to address affordability of service provision for small holder farmers.

1.3. Objectives of the Studies

1.3.1. General objective

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

1.3.2. Specific objective of the study

- To determine moisture content of the crop before threshing for teff, wheat and barley crops.
- To determine fuel consumption of the machine at different moisture content for teff, wheat and barley crops.
- To determine grain breakage during threshing for teff, wheat and barley crops.

1.4. Significance of the Study

During threshing, there is grain loss because of different factors such as moisture content. This affects the threshing efficiency, threshing capacity, cleaning efficiency, fuel consumption, and grain damages. Therefore, this study concerns the determination of moisture content and reduction of its effects. This means that reduce grain damage during threshing and increase productivity of cereal crops by using appropriate moisture content, adjustment of clearance between drum & concave, and using available speed (revolution per minute (rpm)) during threshing.

1.5. Scope of the Study

This study was mainly focused on the determinations of moisture contents before threshing and the effect of moisture contents on the performance of the machine after threshing. Because moisture content affects threshing capacity, threshing efficiency, cleaning efficiency, and overall product quality of crops. It also concerns the determinations of grain damage and fuel consumption of the thresher and concerns on the reduction of grain damage during threshing.

1.6. Thesis Organization

This research is organized in five major parts. The first one is introductory part which contains the background, and justification of the study, statement of the problem, objective of the study, scope of the study, and other information's are presented. Then, followed by the literature reviews. The third part contains methodologies used in this study. The fourth part also concerned on the result and discussion of the studies. The fifth part contains conclusion and recommendations of this research.

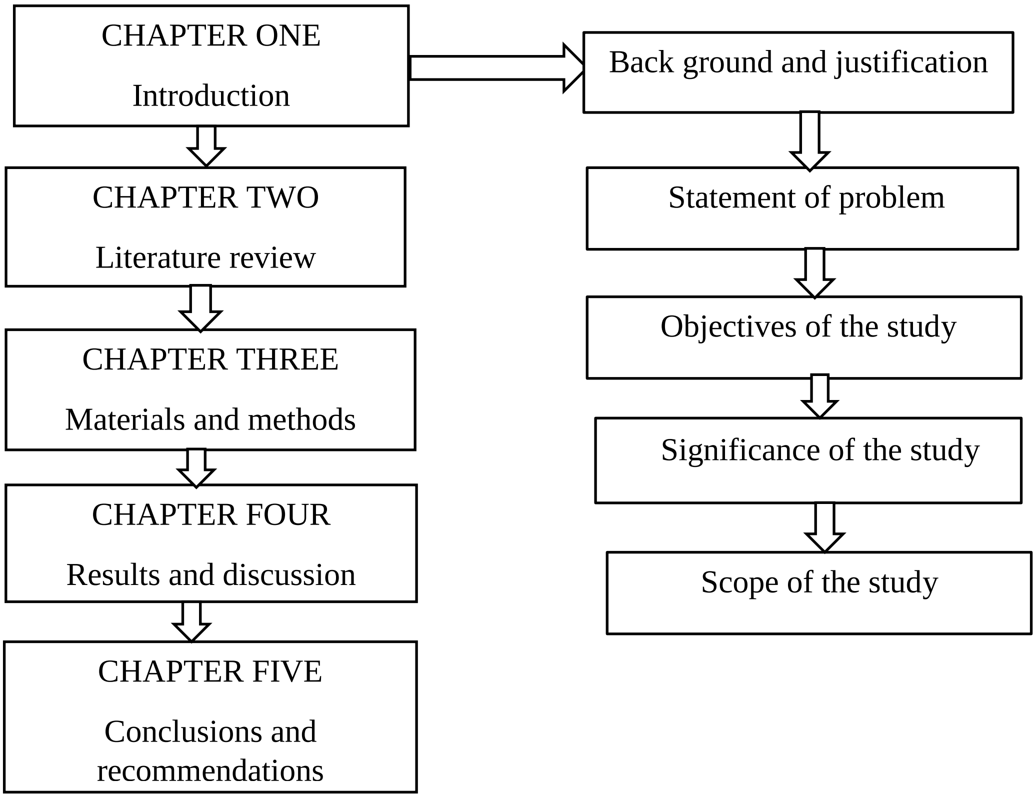

Figure 1.1.Organization of the study

CHAPTER TWO

2. LITERATURE REVIEW

2.1. General Information about Cereal Crops

Cereals are the most common food crops in Ethiopia. They provide essential nutrients and energy within the everyday human diet through direct human consumption and also through meat production since they comprise a significant livestock feed (Ioannis *et al*., 2008). Identifying the physical and engineering characteristic of cereal crops was very important to optimize the design parameters of agricultural equipment used in their production processes. So, it's essential to work out and recognize the physical and engineering properties of those agricultural products because these properties play a very important role in designing and developing of specific machines and their operations like separating, threshing, transporting, cleaning, storing, etc. (Fawal *et al*., 2009)

Knowledge of the physical properties of agricultural products like dimensions, sphericity, surface area, volume, thousand seed mass, porosity, angle of repose, terminal velocity and static coefficient of friction are the foremost important in designing grading, sorting, separating, cleaning, transporting, handling, sizing, storing and packaging systems. Besides, those parameters are useful in determining the efficiency of machines and operations, evaluating the ultimate product are quality, and distinguishing between different varieties. The physical properties of seeds are enthusiastic about moisture content. The moisture-dependent characteristics of the physical properties of agricultural products have effects on the adjustment, performance efficiency, and energy consumption of processing machines. In recent years, many researchers have reported the moisture dependence of the physical and mechanical properties of chosen agricultural materials, like wheat. The information on the physical properties of the agricultural product was needed in the design and adjustment of machines. The geometric properties like size and shape are one among the foremost important physical properties considered during the separation and cleaning of agricultural products. There are so many cereal crops found in Ethiopia among them the only three selected cereal crops were taken for this study. They are barley, wheat, and *teff.*

The production, productivity and area coverage of barley, wheat and *teff* crops are;

The area coverage, production and productivity of barley were estimated to be 959,273.4 ha, 2,024,921.7 tons and 2.11 tons/ha, respectively. In 2017 cropping session about 323,600 ha of land was covered by barley in Amhara region. The information about Malt barley and food barley production is merged in the report of Ethiopia Statistics Agency, whereas the area coverage of malt barley lower than the food barley. The report of CSA (2018, 2019) indicates that the total cereal production of wheat was 267.8 million quintals and 277.7 million quintals in 2017/2018 and 2018/ 2019 production seasons, respectively. In Ethiopia wheat is mostly produced from Oromia, Amhara and SNNP regions in terms of both total production and area coverage. In terms of productivity, still the Oromia region takes the first rank, and SNNP and Amhara region take the second and the third ranks, respectively (CSA, 2018). *Tef*f accounted approximately 28.4% of the total cereal crop's cultivated area and 50% of total cereal production quantity. Amhara and Oromia are the two major regions, and collectively, the two regions account for 85.5% of the teff area and 87.8% of the teff production.

Generally, the national average grain yield of cereals in Ethiopia is relatively low amounting to about 1.7 t ha^{-1} for *teff*, 2.1 t ha^{-1} for barley, and 2.7 t ha^{-1} for wheat in 2016 (CSA, 2017). This, amongst others, is due to the widespread use of low yielding varieties coupled with unimproved traditional practices that ultimately contribute to the low national average yield of major cereal in the country (Abebaw Dessie, 2018).

2.1.1. Barley

Barley (*Hordeum vulgare L.*) is one of the most important cereal crops in the world. It is mainly cultivated and used for human food supply within the last century but nowadays it's significantly grown as animal feed, malt products, and human food respectively (Taner *et al*., 2004). Barley is principally produced in destructive climate and soil conditions of the globe. It's also a really important source of malt and food for humans. According to (Bhatty, 1993), barley is especially produced for animal feeds. It can be cultivated at altitudes between 1500m and 3500m but it is predominantly grown between altitudes of 2000m and 3000m in Ethiopia. Barley is the fourth most important cereal crop after maize, teff, and sorghum. Where an average of 0.9 million hectares of land is covered by barley with an average production of 1.0 million tons annually (Hailu, 1993). Research on barley improvement was started in 1955 at the Debre Zeit Agricultural Research Center. Since

1967 the Institute of Agricultural Research (IAR) took the responsibility of coordinating the crop improvement work on food and malt barley (Hailu, 1993).

In Ethiopia, there are substantial potentials for the production of beer barley. Depending on the biological potential, relatively high barley yields are achieved (Mehandžić *et al*., 2010). There are many varieties of barley in the world and several hybrid varieties are available in the market which has been evolved from wild relatives, but, in Northern Ethiopia the popular barley verities that produced by the small-holder farmers are ‘Abay HB 42 and ‘ADU 12. This variety is the most popular variety in Ethiopia and used for human foods due to this purpose this variety is called food barley. From the given two variety taken only one variety that means HB 42 for this study because in Ethiopia this HB42 variety is the most popular one and widely used. Barley grows in two-row cultivars. The rows refer to the number of columns of grain running along with the head (Figure 2.1). All malting-grade barley grown in Ethiopia is two-rowed.

a) b)

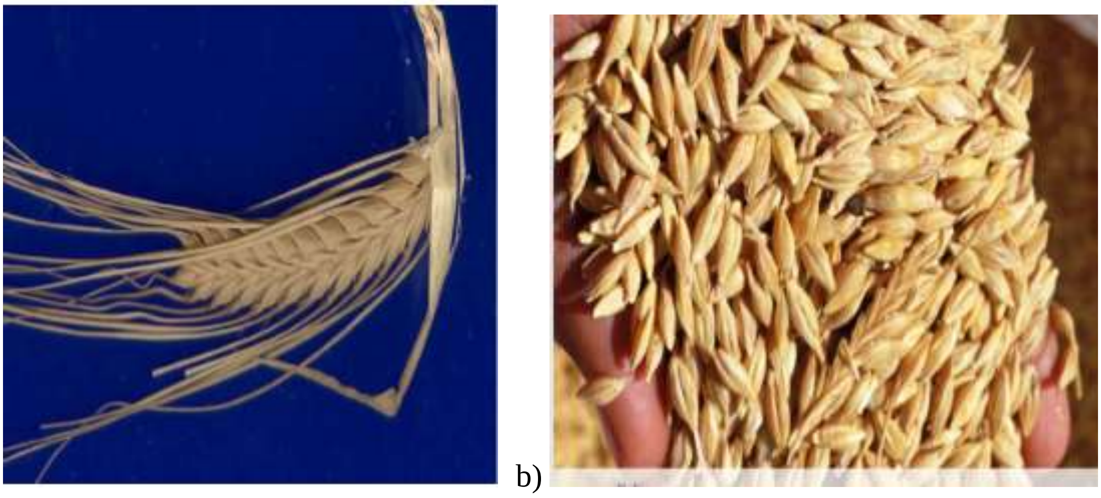

Figure 2.1. Barley a) before harvesting, and b) after threshing

2.1.2. Wheat

Wheat (*Triticumaestivum* L.) is the most important staple food crops in both developed and developing countries and contributes more calories and proteins to the world diet than any other cereal crops (Shewry, 2009). Wheat is that the most vital staple food crop for more than one-third of the globe population and contributes more calories and proteins to the world diet than the other cereal crops. It is healthy, easy to store and transport and can also be processed into various types of food (Kumar *et al*., 2011). East African countries have the highest per capital wheat consumption and it provides up to 50% of daily calories and protein. It is paramount/dominant for food security. In rapidly urbanizing sub-Saharan Africa (SSA) countries, wheat consumption is expected to grow by 38% in 2023 (Mason *et* *al*., 2012). Sub-Saharan Africa (SSA) has a great scope and potential for increasing bread and durum (pasta) wheat productivity, but it was affected by climate change e.g. shortened growing seasons, erratic rainfall, increases in both day & night temperatures, new emerging diseases, etc. (Harold, 2015).

The average wheat productivity in SSA is 1.7 tons/ha (FAOSTAT, 2014), nearly 50% below the world average, and also the national average productivity varies across the countries. To design a machine for handling, cleaning, threshing, etc.; the physical properties of wheat at different moisture contents must be known (Tabatabaeefar, 2003). Several hybrid wheat varieties are available in the market which has been evolved from wild relatives, for example, *kekeba*, king bord, and *otuba*, etc. Among this the latest high yielding varieties of wheat which have been released after the systematic examination and proved to be improved in several aspects. The preferable varieties of wheat are *kekeba* variety because it is one of the varieties of wheat having a high level of rust resistance. It’s a dual-purpose variety suitable for creating, pasta, and other traditional food products together with high protein content (12%), B-vitamin. Less gruel solid loss, high overall acceptability, and essential micronutrients like iron (42.1 ppm) and zinc (42.8 ppm) (Sangeeta *et al*., 2018).

Among the above variety, only three varieties are existing in northern part of Ethiopia. From this variety king bord and otuba varieties used for pasta and mekorony food productions and *kekeba* variety is used for different food productions, for example, bread, *injera*, and alcoholic drinks. For this study takes only one type of varieties of wheat which have been released after the systematic examination and to be improved in several aspects. This variety is *kekeba* varieties because it is one of the varieties of wheat having a high level of production in this area. It is a high yielding wheat variety with an average yield of 6 t/ha was released for a timely sown in the rainy season.

a)  b) 

Figure 2.2. a) wheat crop stand before harvesting and b) wheat grain after threshing

2.1.3. Teff

Teff (*Eragrostis tef (Zucc*.) is endemic to Ethiopia and its major diversity is found only during this country like several other crops, the precise date and placement for the domestication of teff is unknown. However, there's little question that it's an awfully early crop in Ethiopia, and its domestication took place before the birth of Christ BC (Seyfu Ketema, 1997). It is an ancient, minute in size, and packed with nutrition. It is also, believed to have originated in Ethiopia between 4000 and 1000 before Christ BC. Nowadays, *teff* represents the re-discovery of crops used by ancient civilizations. *Teff* seeds were discovered in a pyramid thought/assumed to date back to 3359 B.C (Mariyam, 2004).

Teff is well adapted to a wide range of environmental conditions: tolerant of both drought-stressed and water-logged environments. *Teff* performs best at an altitude of 1,800 – 2,100 m with an annual rainfall of 300 – 500 mm per growing season (Jennifer *et al*., 1997).
Teff is cheap and grows rapidly it also vital to Ethiopian farmers who use it as a source of nutrient-rich fodder for strengthening livestock. The straw of the *teff* plant is soft and fast-drying, making it perfect for several different applications, including adobe building materials and household clay pots (Lovis, 2003). The seeds of *teff* range from 1.0 to1.7mm long and are 0.6–1.0 mm diameter (Patricia, 2008). The average size resolve supported 100 randomly selected seeds. Careful visual observation through a light microscope and measurements revealed that *teff* seeds have a prolate spheroid shape with the 2 minor axes of comparable size. This leads to size measurement only along two (major and minor) axes using a digital caliper with an accuracy of 0.01 mm.

Knowledge of the physical properties of *teff* seeds is required for the design of storage, handling, or processing equipment. Size, shape, and density are important in the separation from undesirable materials on oscillating chaffers (Zewdu, 2007). The geometric properties like size and shape are one among the foremost important physical properties considered during the separation and cleaning of agricultural grains. According to the national estimates (CSA, 2017) *teff* accounts for about 16% of the gross grain production of all the cereals cultivated in Ethiopia covering about 2.7 million hectares of land in December 2011. Due to its importance in most Ethiopians nutrition and its intensive production within the country, recently there's growing attention on *teff* investigation to find its potential for food and economic advantages like starch production (Tsegaye & Abera 2020) and (Biresaw *et al*., 2012).

In Ethiopia, tef is principally cultivated to reap the economic a part of the grain for its consumption. The grains are used to bake injera after milled, a type of Ethiopian bread which is the most beloved national dish. *Teff* is one among the smallest amount famous yet most nutritional grains within the world and injera make from it have excellent flavor, aroma, texture, and sturdy quality. It's known for its nutrient quality and 99% high return quality after milling compared to 60-80% from wheat (Abrham, 2015). The harvesting activity of *teff* starts when the growing crops in the field completely change their color to straw or yellowish. This phenological stage of the crop occurs 60-120 days after sowing depending upon the growing period of the varieties and environmental conditions. The major indicators of maturity are changing the panicle which holds the spikelet into straw color. Early harvesting is advisable before the crop gets too dry and exposed to sever shatter which leads to high yield losses (Abrham, 2015).

Figure 2.3. *Teff* grain of cultivar

The above figure shows how and when the *teff* crops were harvested in traditional ways. In this case, the farmer starting to harvest the crops by using simple observation of the leaf of plants, but it is one of the causes of production quality loss during harvesting of cereal crops. There are many types of varieties of *teff* crops found in Ethiopia. Among them the two varieties of *teff* are commonly known thus are '*bosset'* and '*magna*' varieties. From the two variations, takes only ' D2-01-196' teff variety for this study because magna teff variety is the most popular and more cultivated in the country. Since *'magna' teff* variety is used for different food productions in the communities, such as *injera*, bread, porridge, alcoholic drinks e.g, ale (tela) and its straw are also used for animal feed and attached purposes of their house walls (Fikadu *et al*., 2019).

2.2. Physical Properties of Cereal Crops

The physical properties such as moisture content, size, shape, surface area, volume, density, porosity, and appearance are important for determining the designing of the thresher machine. Various kinds of cleaning grading and separation kinds of equipment are designed based on physical properties of seeds like size, shape, specific gravity, surface roughness, etc. For designing an air screen grain cleaner, the shape and size of the grain determine the shape and size of screen openings, angle of inclination and vibration amplitude, and frequency of screens. The density of the grains decides the size of the screening surface.

The frontal cortex, related diameter, and densities are essential for the determination of the velocity of the grain. Terminal velocity is critical to determine about the winnowing velocity of air blast for separation of lighter materials in air screen grain cleaners. The form of the merchandise is a very important parameter that affects the conveying characteristics of solid materials by air. The frontal area and the related diameters are essential for the determination of terminal velocity and drag coefficient (Krishnakumar, 2019).

The physical properties of selected grains, such as moisture content, size, etc, and those of other grains and seeds, are essential for the determination of the performances of types of equipment and the analysis of the behavior of the product during agricultural processing (Mahmoud *et al*., 2009). The need for knowledge of friction coefficient of agricultural materials on various surfaces has long been recognized by engineers who are concerned with the rational design of grain bins, silos, and other storage structures (Mohsenin, 1970). The physical and biochemical characteristics play a vital role in grain yield qualities. Physical properties of barley grains are essential for the design of the equipment for handling, harvesting, and aeration, drying, storing, grinding, and processing equipment. These properties are affected by numerous factors such as the moisture content of the grain (Tabakoli *et al*., 2009).

Some of the important physical properties of cereal crops are described below.

2.2.1. Moisture content of crops

Moisture is solely water diffused in an exceedingly relatively small quantity. Nearly all materials contain a minimum of a diminutive volume of moisture as a component of the molecular makeup. Moisture may be a given within the mass of materials, however, the relative percentage is dynamic and thus not constant. It’s one amongst the foremost important factors affecting the standard of cereal grains production since the amount of dry matter of grains is inversely associated with the moisture content. The moisture content of grain plays a vital role in post-harvest processing and is related to most of the induced characteristics. Vapor will diffuse throughout a bulk of grain and therefore the moisture content would tend to equalize. Low moisture content below 12% is that the optimum moisture level and facilitates future storage of barley and wheat grains in many developing countries. However, within the northern part of the planet referred to as humid climatic conditions, 16% of the moisture is permitted (Taner *et al*., 2004). Moisture content is one among the foremost important factors affecting the standard of cereal grains production since the quantity of dry matter of grain is inversely associated with the moisture content of the grain (Lovis, 2003).

The moisture content of the crop has its effect on the product quality i.e when the moisture content of the grain is incredibly high the threshing efficiency becomes low due to the attachment of chaffs on the wall of concaves and drums on the opposite hand, If the moisture content of the grain is extremely low there's less time requirement and has low fuel consumptions but, there is high grain breakage due to less resistance of impact and shear force of grains and also, had high grain loss due to shattering or spreading out of seeds from the grain outlets. Therefore, the optimum amount of moisture content is very crucial for obtained good results in both 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% (Meharie and Kindie, 2019).

2.2.2. Dimension of grains

The physical properties of cereal crops like size, density, shape, and coefficient of friction are required for calculating the velocity and coefficient of drag of the agricultural products. The shape is one in every of the key discriminating factors in seeds, which enables one to differentiate one sort of seeds from another. It plays a significant role in seed cleaning and sorting, and it influences the majority behavior of seeds (Zdzisław *et al*., 2015).

In the handling and processing of agricultural products, the air is commonly used as a carrier for transport or for separating the desirable products from unwanted materials, therefore the aerodynamic properties, like velocity and coefficient, are needed for air conveying and pneumatic separation of materials. As the air velocity, greater than terminal velocity ($V_a > V_t$), lifts the particles to allow greater fall of a particle, the air velocity could be adjusted to a point just below the terminal velocity. The fluidization velocity for granular material and settling velocity are also calculated for the body immersed in a viscous fluid. The following parameters may be measured for describing the shape and size of the granular agricultural materials. The dimensions of seeds, namely length, width, and thickness, measure the seed in three directions by using a digital electronic caliper.

2.2.3. Spherecity

The geometric properties like size and shape are one in every of the foremost important physical properties considered during the separation and cleaning of agricultural grains. In theoretical calculations, agricultural seeds are assumed to be spheres or ellipse because of their irregular shapes (Gürsoy and Güzel, 2010). Therefore, sphericity (Sp) may be defined as the ratio of the surface area of the sphere having the identical volume as that of the grain to the surface area of the grain.

It is possible to observe an overlap in terminal velocities between grain and straw of teff. As a result, complete pneumatic separation is not possible, because, the terminal velocities of end node straws are greater than that of teff grain. This is likely due to the small size and weight of teff grain (Zewdu, 2007). During threshing, it is not possible to get all the grains out of the straw (Seyfu, 1997). Kernel weight, usually expressed in terms of weight per 1,000 kernels, could be a function of kernel size and kernel density. The thousand kernels' weight of teff grains is averaging 0.3 – 0.4 grams (Lovis, 2003).

2.2.4. Bulk density

The bulk density could be determined mathematically by dividing the bulk mass by the bulk volume.

2.2.5. True density

The true density was determined by finding the individual density of 10 random samples from the bulk of 100. The mass and the volume of the 10 samples can be determined by using the displacement method. The volume to get the density for the 10 samples divides the mass. To get the unit density then divided the density. The procedure was repeated three times for the bulk 100 grain to get the average.

2.2.6. Angle of repose

Angle of repose is that the cone formed on free vertical fall of the granular material to a horizontal plane. It's sometimes noted as cone angle or slope angle. Angle of repose could be a critical design and management consideration for grain bins because the form of the grain pile, indicated by its angle of repose, affects storage capacity, aeration system design and performance, and grain pressure on the walls of grain silos (Bhadra *et al.*, 2017).

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the granular material to a horizontal plane. When bulk granular materials are poured onto a surface, a conical pile will form. The interior angle between the surface of the pile and therefore the surface is thought because the angle of repose and is said to the density, extent, shapes of the particles, and coefficient of friction of the fabric. It is ranged from 0° to 90°

Figure 2. 4. Angle of repose

Material with a low angle of repose forms flatter piles than material with a high angle of repose. The term features a related usage in mechanics, where it refers to the maximum angle at which an object can rest on an inclined plane without sliding down. The physical properties like size, shape, moisture content, and orientation of the grains affect the angle of repose.

2.2.7. 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 (Deshpande *et al.*, 1993). Coefficient of friction across the different surface, which are; mild steel, stainless steel, and galvanized steel, all which is used in the determination of the coefficient of friction

2.3. Mechanical Properties

Mechanical properties may be defined as those which affect the behavior of agricultural material under the applied force. The mechanical properties such as hardness, compressive strength, impact, and shear resistance affects the various operations of agricultural processing. The instrument used to measure the mechanical properties of agricultural materials are called universal testing machine (UTM). The test was done on three axes which are the major axis, the minor axis and the intermediate axis. The dimension of every axis decided before starting the test. The grain was placed between a fixed jaw and therefore the load applied at required rates. There's a screen that's accustomed visualize the entire process. in spite of everything the mandatory procedures, compression began. Compression stopped automatically when rupture occurred, this is often known by the clicking sound made by the machine.

Data on these properties are useful for applications in designing equipment for milling, handling, storage, transportation, and food processing. The mechanical damage of grain and seeds during threshing and handling operations causes a reduction in germination power and viability of seeds, increases the chances of insect and pest infestation, and also affects the quality of the final product. The hardness of the grain affects the milling characteristics and it is also useful to livestock feeders and plant breeders. The impact and shear resistance are important for size reduction of food grains. This information is useful in the determination of the appropriate methods of crushing, breaking, or grinding the grains. These properties also play important roles in seed resistance to cracking under harvesting and threshing conditions (Krishnakumar, 2019).

2.4. Thermal Properties

Thermal properties are involved in almost every crop processing operation. Knowledge of the thermal properties of crops is essential in the analysis and design of various crop processing equipment involved in heat transport, concerning heat transfer. The thermal properties like specific heat, thermal conductivity, thermal diffusivity, enthalpy, surface heat transfer coefficient, emissivity, etc. are important for the development of any thermal processing system. The thermal processing may include heating, cooling, freezing, drying, and evaporation. There is another thermal property like melting or freezing points, latent heats, the heat of adsorption, the heat of respiration, and coefficient of thermal expansion but these aren't of much importance for the foremost heat transfer applications (Krishnakumar, 2019).

The rate of heat transfer to the material also significantly depends on the heat transfer surface. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer. The effects of size and surface area on drying rates of particulate materials also can be characterized by using the surface to volume ratio. When diffusion of water within the particle limits drying rate, larger particles dry more slowly than smaller particles of the identical shape. Also, the ratio of surface area to volume affects drying time and energy requirements (Karimi, 2009).

2.5. Aerodynamic Properties of Crops

Terminal Velocity

It is the utmost velocity attainable by an object because it falls through a fluid (air is that the commonest example). It occurs when the sum of the drag force and also the buoyancy is equal to the downward force of gravity working on the item. Since the web force on the article is zero, the article has zero acceleration. In fluid dynamics, an object is moving at its terminal velocity if its speed is constant due to the restraining force exerted by the fluid through which it moving.

As the speed of an object increases, so does the drag force working on it, which also depends on the substance it is passing through in air or water. At some speed, the drag force of resistance will equal the gravitational pull on the thing. At this time the article ceases to accelerate and continues falling at a relentless speed called the terminal velocity (settling velocity). An object moving downward faster than the terminal velocity (thrown downwards, it fell from a thinner a part of the atmosphere, or it changed shape) will impede until it reaches the terminal velocity. An object with an out-sized projected area relative to its mass encompasses a lower terminal velocity than one with a little projected area relative to its mass, like a bullet. In general, for the identical shape and material, the terminal velocity of an object increases with size. This can be because the downward force (weight) is proportional to the cube of the linear dimension, but the air resistance is approximately proportional to the cross-section area which increases only because the square of the linear dimension.

2.6. Effect of Physical Properties of Cereal Crops on the Performance of thresher

The physical properties of cereal crops on the performance of the thresher machine plays an important role in the performance of the machine that means moisture content, size, and shapes of the grain affect the performance of the machine. The shape and size of the grain influence the quality of the product that means when the size of the grain is large (big) the clearance between concave and drum also high, when the size of the grain is small the clearance between concave and drum also small or less. In general, the performance of the thresher was affected by the size of the crop, and the shape of the grain also affects the performances of the thresher machine i.e length, width, sphericity of the seeds, the roundness of the seeds and so on.

2.7. Effect of Moisture Contents of Cereal Crops on the Performance of thresher

Moisture content is one of the physical properties of cereal crops that affect the performance of the thresher machine. It influences the performances of the machine as well as the final product of the crops. If the moisture content of the crop is very high the performance of the machine becomes reduced because of the attachment of chaffs on the machine parts i.e on the wall of the cylinder and on the concaves as well as influences the performance of cleaning efficiency that means it affects sieve quality and breakage of seeds due to the presence of low shear force resistances of crops or if the moisture content of the crop is very low the performance of the machine becomes high but, there is high grain damage due to the presence of low impact force resistance of the crops.

The recommended harvesting moisture content of most cereal crops were 20-30 % as concluded by most authors because below this moisture level the crops are shatter(scatter) down to the ground during cutting and also brittle simply during harvesting. Therefore, the harvesting time of cereal crops are appropriate with the range 20-30 % moisture content. However, the machine has high threshing performance when it operates below 20 % moisture content particularly within the range of 14-18 % moisture content but, in case of combine harvester, both harvesting, and threshing activities were done simultaneously, so this is the gap of most authors because they do not set the solution of this problems (Meharie and Kindie, 2019).

2.8. Grain Damage

The grain is marketed normally in whole grain form and is taken into account to be inferior quality if broken. Breakage may occur from cracks as a result of excessive drying/ weathering conditions within the field or during handling. Breakage reduces quality by reducing acceptability and by increasing susceptibility to infestation during storage.

Grain damage is such a broad term that it can be difficult to identify all factors that can be considered the damage. Also, these factors are not easily measured. The United States Department of Agriculture, USDA, has many years listed standards for many types of grains. In those standards, they have identified a normalized grading scale based on factors such as test weight and limits of damaged kernels and foreign material. Throughout these standards, the definitions listed for damage can be open to interpretation by the person evaluating the grain. Many common methods for determining grain damage levels include visible inspection, which can carry with it a large amount of error. Mass of damaged Grain = total mass of grain – the mass of undamaged grain (Kg). It is mostly a brake of seeds during threshing. Loss is defined as a measurable decrease in product quality and quantity. Quantitative loss is physical and can be measured in weight or volume, while qualitative loss can only be assessed. Quantitative loss, qualitative loss, nutritional loss, seed viability loss, and commercial loss may gauge this reduction (Umar and Baloch, 1999).

2.9. Summary of Literature Review

The research outputs indicated that crop threshing operations specifically cereal harvesting is sequential and critical work to be performed in time. Determining the right time to harvest is essential for achieving high-quality products. If harvesting is late or fast it increased the chance of insect (pest) infection, loss of minerals & vitamins, and shorten storage life. Different kinds of the literature revealed that the range of post-harvest moisture content of cereal crops was 10-29 % (Meharie and Kindie, 2019).

Different post-harvesting machines were developed around the world but, smallholder farmer harvest their product either premature or latterly mostly early harvesting was popular in our country-level because of the lack of tractors and this leads to poor product quality.

According to Olayinka, (2004), threshing of most cereal crops at fewer moisture contents below 20 % was recommended to get high production quality and good efficiency of products, but the gap between researchers was observed that means, the appropriate harvesting time of cereal crops was 20 %- 30 % moisture content because the harvesting of crops below 20 % had scattered and exploding of seeds. While for threshing of cereal crops the recommended amount of moisture content was less than 20 % since above this moisture content there was less threshing capacity, threshing and cleaning efficiency, and also, has high fuel consumption.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of Study Area

The performance evaluation of the thresher machine has been done at Melkassa Agricultural Research Center. 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. Agroecologically, the area is characterized as arid and semi-arid with maximum and minimum temperatures are 28.40^{o}C and 14.00^{o}C, respectively.

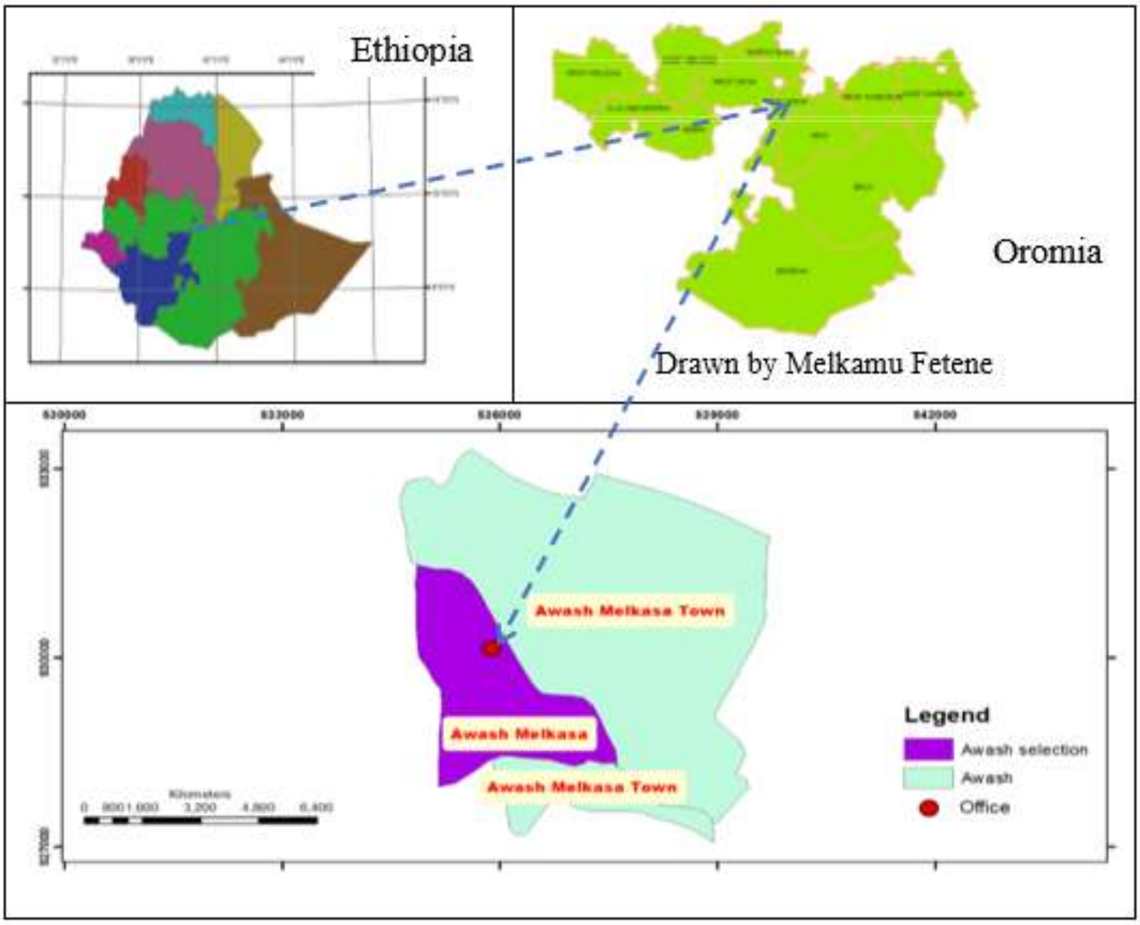

Figure 3. 1. Location of the study area

3.2. Materials

Table 3. 1. Materials and measurement specification

No.	Items	Application
1	Thresher	For the threshing purpose (multi-crop thresher constructed in Melkasa Agricultural Engineering Research).
2	Electronic digital caliper an accuracy of (0.02mm)	Used for measuring the length, width, and thickness of the grain.
3	Stopwatch	Used to know time duration.
4	Plastic bucket	Collect the threshed grain from the outlet of the thresher.
5	Seed counter	Used to count sample grains
6	Anemometer	Used to measure speed of wind
7	Electronic balances	Used to measure grain sample mass
8	Moisture meter	Used to measure the moisture content of the crops. Its type is (Draminski grain master, GM 667, Poland).
9	Graduated cylinders	Used to determine fuel consumption its capacity is (100-1000) ml.

3.3. Machine Description

The experiment was done at Melkassa Agricultural Research Center in agricultural Engineering Research directorate. The Research Center 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 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, width of machine is 650mm, height up to upper end of feeding rate is 1040mm, and the dimension of hopper is; width of hopper 70mm, length of hopper 930mm, and its height is 21mm of the multi-crop thresher machine and the clearance between drum and concaves are 4mm. The diesel motor used for this thresher is CF186FA model and 7.5hp (5.6 KW) & having 3000rpm made in Korea. It is operated by diesel fuel because diesel fuel is more available in the market and relatively cheap. The selected thresher is comparatively small in size and has less weight. Therefore, it is easy to use and move from place to place for rural farmers. 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 as constant during testing.

The performance of the machine could be evaluated by determining threshing capacity, threshing efficiency, cleaning efficiency, fuel consumption, and grain breakage. The experiment has been replicated nine replications at a different moisture content of the crop stalks, that means 14%, 18% and 22% moisture content with the same or constant feeding rate and constant revolution per minute (rpm) of barley, wheat and teff grains.

3.4. Sampling Procedure

The crop varieties that have been used in this study were one of the prevalent varieties in northern Ethiopia. The samples were manually cleaned to remove unwanted materials from the crop stalks and then moistured by adding water to the samples to achieve the required amount of moisture contents that means, (14%, 18%, and 22%) by bespreading of canvas on the ground and added water through spryer 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.

3.5. Moisture Content of Crops

The samples of the required moisture contents were prepared by adding the quantity of water, Ww has been calculated from the subsequent relationship (Bulent *et al.*, 2006).

$$\mathrm{Ww} = \frac{\mathrm{Wi(Mf-Mi)}}{100-\mathrm{Mf}} \quad \text{..........} 3.1$$

where: Ww = mass of water added (kg).

Wi = initial mass of the sample (kg)

Mi = initial moisture content of the sample (wet basis %)

M_f = final moisture content of the sample (wet basis %)

The initial moisture content was measured three times for getting of mean value by using 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 & teff crop with stalks respectively.

3.6. Feeding Rate

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.

3.7. Size of Grains

The dimensions of seeds, namely length, width, and thickness, measure the seed in three directions by using a digital electronic caliper. Thus, dimensions represented by the later L, W, and T then the mean diameter can be calculated based on (Song & Litchfield, 1991).

Fifty seeds were randomly selected from the bulk of samples and measured each seed by using a digital electronic caliper. This electronic digital caliper made in Taiwan has an accuracy of 0.02 mm was used to measure the grain dimensions. Then the measured grain dimensions like Length (L), Width (W), and Thickness (T), of the Barley and Wheat grain sizes, are used to calculate the volume (V), geometric mean diameter (Dg) and arithmetic mean diameter (Da) of barley and wheat seeds.

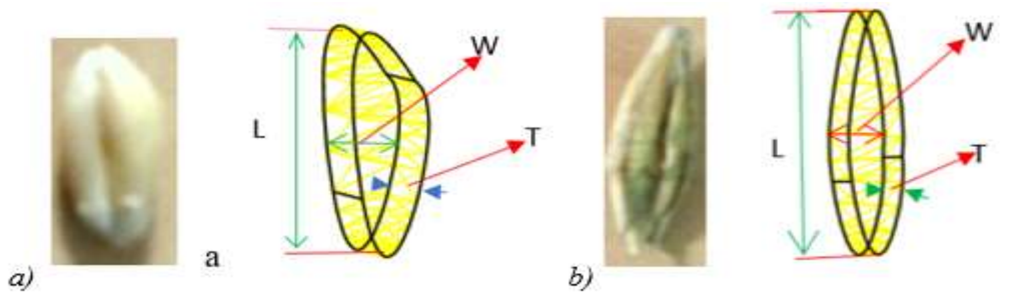

Figure 3. 2. Grain orientation, a) for wheat grain and b) for barley grain

The equation according to (Raie *et al*., 1996), is used to determine the values of the above-mentioned properties are;

$$V = \frac{\pi}{6} LWT \text{ mm}^3 \quad \ldots 3.2$$

$$Dg = (LWT)^{1/3} \text{ mm} \quad \ldots 3.3$$

$$Da = \frac{(L + W + T)}{3} \text{ mm} \quad \ldots 3.4$$

$$Dp = [\frac{L(W+T)^2}{4}]1/3 \quad \ldots 3.5$$

$$Af = \frac{\pi}{4} LW \text{ mm} \quad \ldots 3.6$$

Where L= length of seed, mm

W= width of seed, mm

T = thickness of seed, mm

V= volume of the seeds

Da = arithmetic diameter of seeds

Dg = geometric diameter of seeds

Dp = Equivalent diameter

A_f = Area of surface

Area-based on arithmetic diameter (Aa) and area based on geometric diameter (Ag) were calculated as;

$$A_a = \frac{1}{4} * \pi D_a^2 \text{……………} 3.7$$

$$A_g = \frac{1}{4} * \pi D_g^2 \text{……………} 3.8$$

Where Aa = area based on the arithmetic mean diameter

Ag = area based on geometric mean diameter

Da = arithmetic mean diameter

Dg = geometric mean diameter

Teff seeds are difficult to measure its dimensions but most researcher concludes that the equivalent diameter of teff grain was reported to vary between 0.71 and 0.87mm and thousand-grain mass 0.257–0.421g (Zewdu, 2007).

3.7.1. Sphericity

In theoretical calculations, agricultural seeds are assumed to be spheres or ellipse due to their irregular shapes (Nalbandi *et al*., 2010).

Therefore, sphericity (Sp) will be defined because the ratio of the surface area of the sphere having the identical volume as that of the grain to the surface area of the seeds, which decided using the subsequent formula (Mohsenin, 1986).

$$S_p = \frac{(LWT)^{1/3}}{L} \text{……………} 3.9$$

Where S_p = sphericity

L = length of kernel

W = width of kernel

T = thickness of kernel

3.7.2. Thousand grain mass

Thousand-grain mass was measured by randomly selecting grains from the bulk sample and take the average of the three replications in the laboratory. The measurement was carried out by an electronic balance (YP200 Model made in China) having an accuracy of 0.01g.

3.7.3. Density

Graduated cylinder was used for measuring volume for the investigated crop seeds to obtain true and bulk density.

3.7.3.1.Bulk density

The bulk density was determined mathematically by dividing the bulk mass of the grains to the bulk volume:

$$\text{Bulk density} = \frac{Mass}{Volume} \quad \text{.....3.10}$$

3.7.3.2. True density

The true density was determined by finding the individual density of randomly selected samples using the displacement method as do in the determination of the bulk density. The procedure was repeated three times for the bulk 100 grain to get the average, and can be calculated as;

$$\rho_t = \frac{M}{V} \quad \text{.....3.11}$$

Where ρ_t = true density, g/cm3

M = mass of individual seed, g

V = volume of water displaced by one seed, cm3

3.7.3.3. porosity

Porosity was determined using the following equation as described by (Mohammad, 2010)

$$\text{Porosity} = 1 - \frac{Bulk\ density}{True\ density} \quad \text{.....3.12}$$

3.7.4. Angle of repose and measurement of angle of repose

The angle of repose sometimes referred to as the cone angle or slope angle, is one of the key parameters for measuring and evaluating grain storage systems, including grain bins and outdoor piles. Angle of repose could be a critical design and management consideration for grain bins because the shape of the grain pile, indicated by its Angle of repose, affects storage capacity, aeration system design and performance, and grain pressure on the walls of grain silos (Bhadra *et al*., 2017). The angle of repose is important for the design, processing, storage, and conveying systems of particulate materials. In this case it is important to define it for someone's who read it he/she can simply understand about what is the its importance?

Angle of repose will be calculated as;

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad \text{......3.13}$$

Where, H = height from the base to the peak (mm)

D = diameter of the base (mm)

A wooden frame stuffed with grain sample is mounted on a tilting top work table. The table top is tilted till the grain starts to maneuver over the inclined surface. The selection of wooden plate is based on the high contact friction between the grain and the plates rather than other plates. The angle of inclination is measured which is that the angle of repose of the grain sample as shown on the fig bellow.

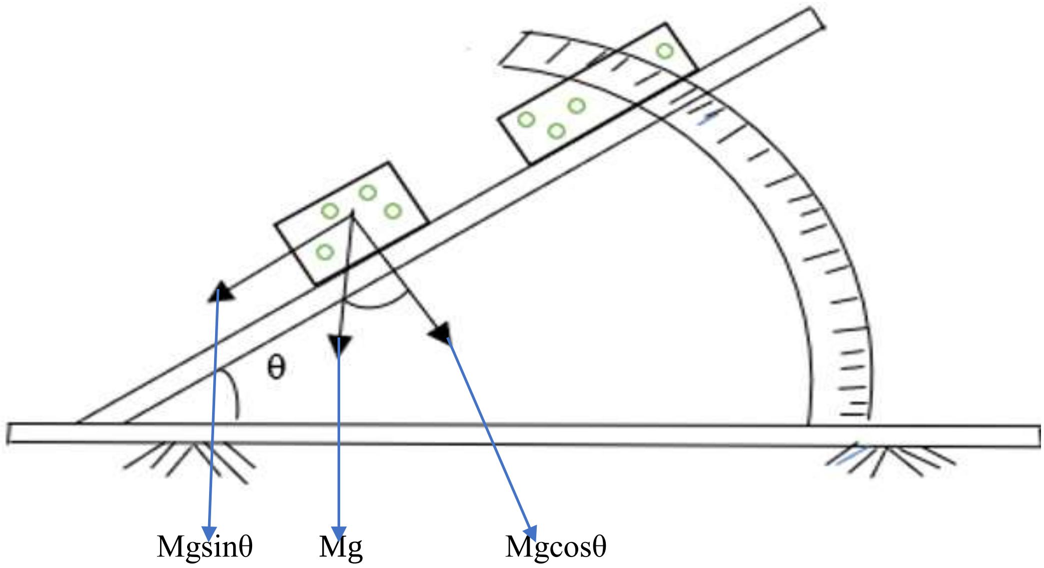

Figure 3.3. Angle of repose measuring device made by Melkassa Agricultural Engineering Research

3.7.5. Coefficient of friction

The determination of the coefficient of friction is determined using the equation described by (Tabakoli *et al*., 2009).

$$\mu = \tan\theta \quad \text{......3.14}$$

Where, μ = the coefficient of friction and

θ = the angle of tilt in, (°).

3.8. Terminal Velocity

The terminal velocity of crop seeds is determined by measuring the air velocities, required to suspend a seed in a vertical air stream by using terminal velocity instrument known as an anemometer. The density of air at ambient temperature is 1.28 kg/m^3 (Gorial and O'Callaghan, 1990).

$$V^2_t = \frac{2Mg}{Cd\rho a\ A} \quad \text{……………………………………………………………………}3.15$$

Where Cd = the drag coefficient,

M = the grain mass (g),

g = the gravitational acceleration (m/s^2),

V_t = terminal velocity (m/s)

ρ_a = density of air (kg/m^3)

A = the projection area (mm^2).

3.9. Performance of the Machine

3.9.1. Threshing capacity

Threshing capacity is the weight of the threshed grain collected from the main grain outlet per unit time (Hamada *et al*., 2008). It can be defined as follows.

$$\text{Threshing capacity (Kg/hr)} = \frac{Mt}{T} \times 3600 \quad \text{…………..…………………………..……}3.16$$

Where, Mt = Total mass of the crop fed into the machine

T = Total time taken to thresh the crop.

3.9.2. Threshing efficiency

It is the ratio of threshed grain received from all outlets with regard to total grain input expressed as percentage by weight. The whole quantities of material obtained at these outlets were processed for eliminating unwanted materials from the grain. The grain from outlet was weighed for determining the threshing efficiency using the subsequent equation (Hamada *et al*., 2008).

$$\text{Threshing efficiency (\%)} = \frac{(Mt - Mu)}{Mt} \times 100 \quad \text{…………………... …...…...……………..…}3.17$$

Where, Mt = total mass of crop fed into the machine.

M_U = mass of unthreshed crop.

3.9.3. Cleaning efficiency

After threshing, the straw, chaff, immature grains, sand, and other substances are separated from the grain by sieving and winnowing. Lighter weight broken grain, straw, and weed seed are carried by the wind to at least one side, because the whole grain falls to the bottom of the winnowing device. The winnowing device should stand on a stool to provide the falling grain longer exposure to the wind.

For calculating the cleaning efficiency of different harvesting techniques of grain samples of different cereal crops analyzed for quality losses of grains was utilized. The cleaning efficiency was calculated as (Hamada *et al*., 2008):

Cleaning efficiency (%) $= \frac{\mathrm{Mc}}{\mathrm{Mt}} \mathrm{x}\ 100$…………………………………...……………3.18

Where, M_C = the mass of cleaned grain delivered by the machine

M_t = the total mass of the crop fed into the machine

3.9.4. Percentage of unthreshed grain

It is the ratio of total quantity of unthreshed grains from all outlets to the total grain feed in to the machine per unit time and expressed in percentage. Percentage of unthreshed grain was calculated as;

Percentage of unthreshed grains = $\frac{D}{A}$ x 100 …………………...……...………………3.19

Where, A = Total grain feed in to the machine

D = Quantity of unthreshed grain from all outlets per unit time.

3.9.5. Percentage of blown out grain

It is the ratio of the quantity of the grain blown out to the quantity of the total clean grain delivered by the machine in weight. Percentage of blown out grain was calculated as;

Blown out grain (%) = $\frac{G}{A}$ x 100 ………...…………………...………………………... 3.20

Where, G = Quantity of clean grain obtained per unit time.

A = Total clean grain delivered by the machine.

3.9.6. Germination rate

The germination test at hundred (100) randomly selected seeds from each sampled crop was determined. The seeds were kept in Petri dishlined container with moist filter paper with distilled water in three replications and incubated at room temperature for three to eight days and then recorded the result.

3.10. Fuel Consumption

It is the consumption of fuels by the thresher machine during threshing that depends on the amounts of moisture contents. Fuel consumption before the beginning of every t test trial, the fuel tank had filled to its capacity and after each test trial; the fuel consumed shall be measured by refilling the tank to the identical level by using a graduated cylinder. A graduated cylinder is an instrument used to measure the amount of fuel consumption during the testing. Its measuring capacity is 100 – 1000 ml. Fuel consumption could be measured in L/hr.

Mathematically it can be calculated based on (Hamada *et al*., 2008) as follows;

Fuel consumption (L/hr) $\frac{Fc}{T}$…………………...………...…..……………………....…3.21

Where, Fc = Amount of fuel in (L) consumed by the thresher

T = Time taken in (hr).

3.11. Breakage of Grain during Threshing

Grain damage is such a broad term that it can be difficult to identify all factors that can be considered the damage. It is a breakdown/ damaging of grains during threshing. It can be minimized by different means such as adjustment of the machine that means clearance between concave and drum, using optimum moisture content, etc. This can be determined by using mathematical expirations.

Grain damage/breakage (%) can be calculated based on (Hamada *et al*., 2008) as follows.

Grain breakage (%) = $\frac{Mb}{Mt}$ x 100…………...………...………………………………3.22

Where, M_b = mass of broken grain

M_t = the total mass of grain.

3.12. Data Analysis

Completely randomized design (CRD) experimental design with replications of each sample was used, and analysis was made using the Statistical Analysis Software (SAS Version-8). The analysis of variance was performed to examine the significant effect on all parameters. The LSD test was performed to assess the difference between the treatments at a 5% level of significance. Regression analysis was made to establish a relationship between the moisture content and the other variables understudy.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Physical Properties of Cereal Crops

The physical properties of cereal crops like barley (HB 42), wheat (*kekeba*), and *teff (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.

4.1.1. Moisture content

The amount of water added in the samples was recorded and the moisture content was determined in percentages. The average masses of 40, 38 & 30 kilograms of samples from barley, wheat and teff crops were taken respectively. The measured average initial moisture content of the crop was 13.73%, 13.07%, and 12.50% for barley, wheat & teff crop respectively and the amount of water added in kilograms to the samples to achieve the required amount of moisture content was;

Table 4.1. Amount of water added to the sample in kg

Moisture Content (%)	**Barley**	**Wheat**	**Teff**
14	0.13	0.41	0.52
18	2.08	2.29	2.01
22	4.24	4.35	3.65

4.1.2. Dimensions of grain

From threshed barley and wheat crops, hundred seeds were randomly selected. Again, fifty seed grains were randomly selected from previously selected hundred samples. Fifty selected seeds were measured their length, width, and thickness. The results of mean dimensions of barley and wheat seeds at different moisture contents were presented in (Appendix Table A1). The table shows that the size and dimensions of barley and wheat seed increased with increasing moisture content. This is similar trends obtained by (Adinoyi *et al.*, 2017) and (Soyoye *et al.*, 2018) in sorghum and soybean & maize grains respectively.

As the moisture content was increased from 14 to 22%, the length of barley and wheat seeds were increased from 9.87 to 11.13 mm and 5.98 to 6.86 mm, width of barley and wheat seeds were increased from 3.28 to 3.81 mm and 3.12 to 3.75 mm and also thickness of barley and wheat seeds were increased from 2.21 to 2.96 mm and 2.80 to 3.22 mm respectively.

There was an increase in the arithmetic, geometric, and equivalent mean diameter from 5.20 to 5.90 mm, 4.18 to 5.09 mm, and 4.23 to 5.05 mm for barley grains respectively, and 3.96 to 4.61 mm, 3.71 to 4.34 mm, and 3.72 to 4.37 mm for wheat grains respectively (Appendix Table A2 & A3) of barley, and wheat grains respectively. The result indicates that barley seed has a capacity to absorb more water and increase in size than wheat seeds. The result is consistent with the result obtained by Irtwange & Igbeka (2002), Tabakoli *et al*., (2009), Zareiforoush *et al*., (2009) and Simonyan *et al*., (2009) of African yam bean, barley, paddy and Lablab seeds, respectively. The clearance between cylinder (drum), and concave is determined by the length, width, and thickness of each grains. 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, as the moisture content of the crop increased, the dimension of grains also increased. Therefore, moisture content and dimension of barley and wheat seeds have direct relationships with each other.

The area based on arithmetic and geometric mean diameter increases from 4.02 to 4.69 mm^2, and 3.26 to 3.93 mm^2 for barley grains respectively, and 3.11 to 3.62 mm^2 & 2.93 to 3.42 mm^2 for wheat grains respectively. The volume of seeds also increased from 37.44 to 65. 68 mm^3, and 27.31 to 43.28 mm^3 for barley and wheat seeds respectively as shown (Appendix Table A2 & A3) with increased moisture content. Similar trends were obtained by Zareiforoush *et al*., (2009) and Tabakoli *et al*., (2009) for barley seeds.

4.1.3. Sphericity

The sphericity of barley & wheat seeds increased linearly from 42 % to 45 % and 62.5 % to 63.5 % (Appendix Table A2 & A3) 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 Mohsenin, (1970). This is similar trends obtained by Irtwange & Igbeka (2002) Aderinlewo *et al*., (2011) and Zareiforoush *et al*., (2009) in barley, cowpea and paddy grains respectively.

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 5% probability level Mahmoud *et al*., (2009).

4.1.4. Thousand grain mass

The average thousand grain mass of barley, wheat, and teff grains were increased with increment of moisture content as presented in the Appendix Table A2, A3 & A4 respectively. The average thousand grain mass of barley seeds increased from 31.00 g at 14% to 34.50 g at 22%, that of wheat seeds increased from 33.00 g at 14% to 37.50 g at 22% and teff seeds increased from 0.28 g at 14% to 0.39 g at 22% of moisture content. This experiment was replicated three times. This behavior occurs due to an increase in water amount by weight as a result of increasing moisture content which results in increased in size. The result is consistent with the findings of Simonyan *et al*., (2009), Karimi *et al*., (2009), Aderinlewo *et al*., (2011) and Tabakoli et al., (2009) in lablab, wheat, cowpea and barley seeds respectively. The individual seed mass of barley and wheat seeds also increased because of moisture content from 0.03g to 0.04g and 0.03g to 0.04g of each grain respectively but the individual mass of teff grain was not measured due to the small size of teff grain to measure its dimension.

4.1.5. Surface area

The surface area of barley, and wheat seeds were increased with an increasing of moisture content as indicated in the (Appendix Table A2 &A3) respectively. The surface area of barley and wheat grain increased linearly from 25.46 to 33.33 mm^2 and 14.65 to 20.19 mm^2 when the moisture content increased from 14 to 22% wet base in each grain respectively.

The surface area affects the rate of moisture loss during drying of grains and other particulate materials. The rate of heat transfer to the material also significantly depends on the surface area of seeds. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer.

4.1.6. Density

4.1.6.1. Bulk density

The grains bulk density at different moisture levels varied from 497.83 kg/m^3 to 444.14 kg/m^3 and 932.50 kg/m^3 to 887.64 kg/m^3 for barley and wheat grains respectively. This indicates that the decreasing in bulk density was due to increasing in moisture content from 14 to 22% wet base. This result is in line with the finding of Tabakoli *et al*., (2009), Aderinlewo *et al*., (2011) and Öztürk & Esen, (2008) in barley, cowpea and wheat grains respectively. This decreasing relationship is because of the actual fact that an increasing in mass owing to moisture gain within the grain sample was less than the accompanying volumetric expansion of the majority Karimi *et al*., (2009). Therefore, the volume of grains was more highly expanded than its mass possessing of water. Hence, the density of grains was decreased rapidly because of high expansion of its volume.

4.1.6.2. True density

The true density of barley and wheat grains at different moisture content was varied from 934.95 kg/m^3 to 776.52 kg/m^3 and 1391.89 kg/m^3 to 1201.51 kg/m^3 respectively. An increase in moisture content showed that a decrease in true density of the crops. The result obtained contains a similar trend as reported by Tavakoli *et al*., (2009), Aderinlewo *et al*., (2011) and Karimi *et al*., (2009) in barley, cowpea and wheat grains respectively. The decrease within the true density was mainly because of the larger increase in grains volume compared to the rise in grains mass.

4.1.6.3. 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 respectively as shown (Appendix Table A2 & A3). The porosity of barley, and wheat grain decreased linearly from 46.75 to 42.80% and 33.01 to 26.12%, respectively with increasing moisture content from 14 to 22 %. This difference between two crops could be due to the cell structure, existence of awns and volume and also mass increase characteristics of the samples, as the moisture content of grains increases. The reason for this decreasing of porosity of barley and wheat gains is that when, the grain becomes more moisture, 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 result in line with the finding of by Mahmoud *et al*., (2009), Karimi *et al*.,

(2009) Aderinlewo *et al*., (2011) and Öztürk & Esen, (2008) for barley, and wheat seeds respectively. The porosity is the most important factor for packing and it affects the resistance to airflow through bulk seeds.

4.1.7. Angle of repose

The experimental results for the angle of repose of barley, wheat, and teff with respect to moisture content are shown in the (Appendix Table A2, A3 & A4) respectively. The measured average value of the angle of repose was increased from 19.85° to 32.15°, 19. 50° to 31.35°, and 24.19° to 34.18° for barley, wheat, and teff grain respectively as the moisture content increased from 14 to 22 % wet bases. This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the combination of grain together by the surface tension Zareiforoush *et al*., (2009).

These results have similar trends with reported by Mahmoud *et al*., (2009), Soyoye *et al*., (2018), and Muir & Sinha, (1987) in barley, soybean & maize, and cereal seeds respectively. This increasing movement of the angle of repose with moisture content occurs because of the surface layer of moisture surrounding. The particle holds the combination of grain together by the surface tension. The angle of repose is additionally a very important factor for designing the equipment of mass flow and storage structures.

4.1.8. 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 were increased with moisture content in the moisture range of 14% to 22 % (w.b.) as shown in the (Appendix Table A2, A3 & A4) for barley, wheat, and teff seeds respectively. It was observed that the static coefficient of friction increased linearly from 54.30 to 77.71 %, 48.23 to 67.83%, and 70.54 to 84.66 % for barley, wheat and teff grains respectively, with moisture content increased from 14 to 22 % wet base. The reason for the increased friction coefficient at higher moisture content was attributable to the water present within the grain which offers a cohesive force on the surface of contact. Because the moisture content of grains increases, the surface of the samples becomes stickier. Water tends to stick to surfaces and also the water on the moist seed surface would be attracted to the surface across which the sample is being moved Zareiforoush *et al*., (2009). Similar trends were reported by Öztürk & Esen, (2008), Soyoye *et al*., (2018), and Muir & Sinha, (1987) for wheat, and cereal seeds respectively.

4.2. Aerodynamic Properties of Grains

Terminal velocity

The terminal velocity of barley, wheat, and teff seeds were increased with an increasing of moisture content. The terminal velocity of barley, wheat, and teff grain increased linearly from 7.1 to 8.9 m/s, 8.3 to 9.6 m/s, and 4.4 to 5.8 m/s respectively, when the moisture content increased from 14 to 22% wet base. The recommended range of terminal velocity of barley, wheat, and teff grains was 7.3 to 9 m/s, 8.4 to 9.7 m/s, and 4.4 to 5.7 m/s respectively (Garrett, and Brooker, 1965). The result is consistent with obtained by Gürsoy, (2010), and El Fawal, (2009). The previous results showed that the variation in terminal velocity for the sorts of the crop because of the variation of moisture content, particle mass, and particle density. Hence, the difference in velocity offers the chance of separating such materials from one another in an air stream and it can be utilized in designing of, threshing, and cleaning equipment.

4.3. Performance of Thresher

The performance evaluation of thresher was determined by threshing capacity, threshing efficiency, cleaning efficiency, fuel consumption, and percentage of grain breakage.

4.3.1. Threshing capacity

Threshing capacity was highly influenced by the moisture content of barley, wheat, and teff crop. The mean with a standard error of threshing capacity and analysis of variance were presented in Table 4.2, and Appendix Table A5 for barley, wheat, and teff grains respectively. The ANOVA table indicated that the threshing capacity of multi-crop thresher made in Melkassa Agricultural Research Center was significantly affected by the moisture content of barley, wheat, and teff crop biomass at ($P < 0.05$). The maximum threshing capacity (Kg/hr) of 651.66, 392.66, and 418.69 were observed at 14 % moisture content; whereas the minimum threshing capacity of 383.36, 327.00 and 325.98 were barley, wheat, and teff 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. However, the interaction effect of moisture contents on the threshing capacity of barley, wheat, and *teff* grains were not significantly affected ($P > 0.05$) at which grand mean, and coefficient of variance was 499.06, 359.56 & 378.58, and 12.60, 9.56 & 7.77 respectively as shown in (Table 4.2). This result is the same trend as reported by Ahmad *et al*., (2013) for wheat grains.

The regression analysis was made to establish a relationship between the moisture content of the crop biomass, and the performance of thresher (kg/hr). From regression coefficients (Appendix Table B1), their relationships between the threshing capacity (Tc) and the moisture content (M) of barley, wheat and *teff* grains can be represented by the following equations;

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

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

$$Tc = -11.5878M + 587.163 \quad R^2 = 0.66 \quad \textit{teff}$$

The regression equation above shows that the moisture content of crops has found to be the negative impact on the contribution of threshing capacity with a strong correlation of $R^2 = 0.77$, an intermediate correlation of $R^2 = 0.45$ & 0.66 for barley, wheat & *teff* grains respectively.

Table 4. 2. Effects of moisture content on threshing capacity of barley, wheat, and *teff* seeds.

Threshing capacity (kg/hr) crops			
Moisture content (%)	**Barley**	**Wheat**	**Teff**
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

SE: 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.

4.3.2. Threshing efficiency

Threshing efficiency (%) of the machine was highly influenced by the moisture content of barley, wheat, and teff crop biomass. The mean with a standard error of threshing efficiency and analysis of variance were presented in Table 4.3 and Appendix Table A6 for each grain respectively. The ANOVA indicated that the threshing efficiency of multi-crop thresher made in Melkassa Agricultural Research Center was significantly affected by the amount of moisture content of barley, wheat, and teff biomass at ($P < 0.05$). The maximum threshing efficiency (%) of the thresher was 97.629, 97.682, and 97.740, for barley, wheat and teff at 14% moisture content; whereas the minimum threshing efficiency of the machine was 95.091, 95.560, and 95.543 for barley, wheat and teff at the moisture content of 22%. The interaction of moisture content with the threshing efficiency was highly significant at ($P<0.05$). This indicates that when the moisture content increased, the threshing efficiency (%) of the machine was decreased. The results are in line with the findings reported of Salih *et al*., (2019) and Ahmad *et al*., (2013). The observed grand mean and CV of threshing efficiency of the machine was 96.35, 96.61 & 96.71%, and 1.05, 0.78 & 0.74% of barley, wheat, and *teff* crops respectively. The regression analysis was made to establish a relationship between the moisture content of the crop and the performance of thresher (%). From regression coefficients (Appendix Table B2), their relationships between the threshing efficiency (η_t) and the moisture content (M) of barley, wheat and *teff* grains can be represented by the following equations;

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

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

$$\eta_t = -0.27469M + 101.650 \quad R^2 = 0.68 \quad \textit{teff}$$

The above regression equation shows that the threshing efficiency of the machine had negative relationship with moisture content of crops. Therefore, when the moisture content of the crop increased, the threshing efficiency of the machine was decreased. with an intermediate correlation of R^2 = 0.58, 0.64 & 0.68 for barley, wheat and *teff* seeds respectively.

Table4.3. Effects of moisture content on threshing efficiency of barley, wheat, and *teff* seeds.

	Threshing efficiency (%) crops		
Moisture content (%)	**Barley**	**Wheat**	***Teff***
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

SE: 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.

4.3.3. Cleaning efficiency

The cleaning efficiency of different post-harvesting techniques reflects the amount of unwanted material present in the grain sample. The cleaning efficiency of the thresher was highly influenced by the moisture content of barley, wheat, and *teff* crop in biomass. The mean with a standard error of cleaning efficiency and analysis of variance were presented in Table 4.4, and also (Appendix Table A7) for barley, wheat, and *teff* grains respectively. The ANOVA indicated that the cleaning efficiency of multi-crop thresher was significantly affected by the amount of moisture content of barley, wheat, and *teff* 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%. The interaction was highly significant effect at $P<0.05$. This indicates that when the moisture content of the crops increased the cleaning efficiency of the machine was decreased.

In general, cleaning efficiency (%) of the machine was increased with a decrease in moisture content, while it was declined with an increased moisture content of crops because the amount of moisture content presented on the crop affects the performance of thresher. This means that an 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. This is the same trend as reported by Salih *et al*., (2019) and Ahmad *et al*., (2013). The observed grand mean and coefficient of variance of cleaning efficiency of the thresher was 91.69, 79.26 & 81.57 %, and 1.52, 2.74 & 4.05 % of barley, wheat, and teff crops respectively.

The regression analysis was made to establish a relationship between the moisture content of the crop biomass and the performance of thresher in (%). From regression coefficients (Appendix Table B3), the relationships between the cleaning efficiency η_c and the moisture content (M) of barley, wheat and *teff* grains can be represented by the following equations;

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

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

$$\eta_c = -1.62141M + 110.755 \quad R^2 = 0.76 \quad \textit{teff}$$

The regression equation above shows that the cleaning efficiency of the machine had an indirect (negative) relationship with 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 & 0.76 for barley, wheat and teff grains respectively.

Table 4. 4. Effects of moisture content on cleaning efficiency of barley, wheat, and *teff* seeds.

	Cleaning efficiency (%) crops		
Moisture content (%)	**Barley**	**Wheat**	**Teff**
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

SE: 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.

4.3.4. Percentage of unthreshed grain

Percentage of un-threshed grain was highly influenced by the moisture content of crops in biomass. The mean with a standard error of percentage of un-threshed grain and analysis of variance were presented in Table 4.5, and Appendix Table A8 for barley, wheat, and *teff* grains respectively. The ANOVA table indicated that the percentage of un-threshed grain was significantly affected by the moisture content of barley, wheat, and *teff* crops at ($P < 0.05$). The maximum percentage of un-threshed grain was 11.19, 12.32, and 12.60 observed at 22 % moisture content; whereas the minimum percentage of un-threshed grain was 5.55, 6.02 and 6.63 for barley, wheat, and *teff* grains respectively when the moisture content was 14 %. This indicates that when the moisture content of the crop increased the percentage of un-threshed grain (%) of the machine was also increased. However, the interaction effect of moisture content with percentage of un-threshed grains of barley, wheat, and *teff* grains were not significantly affected ($P > 0.05$) at which grand mean, and

CV was 8.26, 9.11 & 9.53, and 18.49, 18.69 & 16.20 respectively as shown in (Table 4.5). The result was consistent with the result reported by Singh et al., (2018), and Agidi Gbabo et al., (2013) for wheat and corn grains respectively.

The regression analysis was made to establish a relationship between the moisture content of the crop biomass, and the percentage of un-threshed grains. From regression coefficients (Appendix Table B4), their relationships between the percentage of un-threshed grain (T_{un}) and the moisture content (M) of barley, wheat and *teff* grains can be represented by the following equations;

$$T_{un} = 0.70387\ M - 4.41300 \quad R^2 = 0.75 \quad \text{barley}$$

$$T_{un} = 0.78719\ M - 5.05771 \quad R^2 = 0.75 \quad \text{wheat}$$

$$T_{un} = 0.74390\ M - 3.90612 \quad R^2 = 0.77 \quad \textit{teff}$$

The regression equation above shows that the moisture content of crops has found to have the negative impact on the contribution of percentage of un-threshed grain with a strong correlation of R^2 = 0.75, R^2 = 0.75 and R^2 = 0.77 for barley, wheat & *teff* grains respectively.

Table 4. 5. Effects of moisture content on percentage of un-threshed grains of barley, wheat, and teff seeds

	Percentage of un-threshed grains		
Moisture content (%)	**Barley**	**Wheat**	**Teff**
14	5.555 ^{C} ± 0.3049	6.018 ^{C} ± 0.1207	6.633 ^{C} ± 0.2288
18	8.0297 ^{B} ± 1.1478	9.003 ^{B} ± 0.6548	9.340 ^{B} ± 0.5049
22	11.186 ^{A} ± 0.1816	12.315 ^{A} ± 1.3163	12.602 ^{A} ± 1.2157
Mean	8.2568 ± 0.8011	9.1117 ± 0.8940	9.5252 ± 0.8389
SE (%)	1.0797	1.2044	1.0909
LSD	2.4425	2.7246	2.4078
CV (%)	18.49	18.69	16.20

SE: 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.

4.3.5. Percentage of blower losses

Percentage of blower losses of the grain was highly influenced by the moisture content of the crops. The mean with a standard error of blower losses and analysis of variance were presented in Table 4.6 and Appendix Table A9 for each grain respectively. The ANOVA indicated that the percentage of blower losses of multi-crop thresher was significantly affected by the amount of moisture content of crop biomass at ($P < 0.05$). The maximum percentage of blower loss was 4.20, 4.07, and 3.65, at 14 % moisture content for barley, wheat and *teff* crops respectively; whereas the minimum percentage of blower losses of the crop was 1.55, 1.71, and 1.31 observed at the moisture content of 22 %. The interaction was highly significant at ($P<0.05$). This indicates that when the moisture content increased, the percentage of blower loss was decreased. The results are consistent with the findings of Singh *et al.*, (2018). The observed grand mean and CV of percentage of blower loss was 2.98, 2.94 & 2.54%, and 19.88, 13.21 & 20.27% of barley, wheat, and *teff* crops respectively.

The regression analysis was made to establish a relationship between the moisture content of the crop biomass and the percentage of blower loss. From regression coefficients Appendix Table B5, their relationships between the percentage of blower loss (B_L) and the moisture content (M) of barley, wheat and teff grains can be represented by the following equations;

$$B_L = -0.8030\ M + 8.955129 \quad R^2 = 0.80 \quad \text{barley}$$

$$B_L = -0.29562\ M + 8.26125 \quad R^2 = 0.89 \quad \text{wheat}$$

$$B_L = -0.29244\ M + 7.80496 \quad R^2 = 0.82 \quad \textit{teff}$$

The regression equation above shows that the percentage of blower loss had negative relationship with moisture content of crops. Therefore, when the moisture content of the crop increased, the percentage of blower loss was decreased. with a strong correlation of $R^2 = 0.80$, 0.89 & 0.82 for barley, wheat and *teff* seeds respectively.

Table 4. 6. Effects of moisture content on percentage of blower loss of barley, wheat, and *teff* seeds.

	Percentage of blower loss		
Moisture content (%)	**Barley**	**Wheat**	**Teff**
14	$4.2000^{A} \pm 0.2306$	$4.0700^{A} \pm 0.1627$	$3.6482^{A} \pm 0.2482$
18	$3.2020^{B} \pm 0.1545$	$3.0450^{B} \pm 0.2207$	$2.6662^{B} \pm 0.2857$
22	$1.5475^{C} \pm 0.4321$	$1.7050^{C} \pm 0.1946$	$1.3088^{C} \pm 0.2359$
Mean	3.1498 ± 0.3644	2.9400 ± 0.3091	2.5411 ± 0.3189
SE (%)	0.4193	0.2746	0.3642
LSD	0.9488	0.6210	0.8238
CV (%)	19.88	13.21	20.27

SE: 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.

4.3.6. Germination rate

Germination rate was highly influenced by the moisture content of crops. The mean with a standard error of the rate of germination and analysis of variance were presented in Table 4.7, and also Appendix Table A10 for barley, wheat, and *teff* respectively. The ANOVA table indicated that the rate of germination was significantly affected by the moisture content of the crops 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 for barley, wheat and *teff* grains respectively, at the moisture content of 22 %. This is the same trend as reported by Hanumantharaju *et al*., (2017). 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 the regression coefficients (Appendix Table B6), their relationships between the rate of germination (G) and the moisture content (M) of barley, wheat and teff grains can be represented by the following equations.

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

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

$$G = -0.78105\,M + 107.356 \quad R^2 = 0.84 \quad \textit{teff}$$

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

Table 4. 7. Germination rate of barley, wheat, and *teff* crops at different moisture content.

	Germination rate (%) of crops		
Moisture content (%)	**Barley**	**Wheat**	**Teff**
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

SE: 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.

4.4. Fuel Consumption

Fuel consumption was highly influenced by the moisture content of barley, wheat, and *teff* crops. The mean with a standard error of fuel consumption and analysis of variance are presented in Table 4.5, and Appendix Table A11 for barley, wheat & teff grains respectively. The table shows that the fuel consumption, in liters per hour ($l.hr^{-}$.), of the machine when operated at different moisture contents, and the ANOVA table indicated that the fuel consumption of multi-crop thresher made in Melkassa Agricultural Research Center was significantly affected by the amount of moisture content of biomass at ($P < 0.05$). The maximum fuel consumption ($l.hr^{-}$.) was 2.0213, 2.7300, and 2.3560, at 22% moisture content; whereas the minimum fuel consumption was 1.1650, 1.7200, and 1.6960, at the moisture content of 14% barley, wheat, and *teff*. Furthermore, the fuel consumption of the system was increased sharply from 1.14 $l.hr^{-1}$ to 2.02 $l.hr^{-1}$, 1.72 $l.hr^{-1}$ to 2.73 $l.hr^{-1}$, and 1.70 $l.hr^{-1}$ to 2.36 $l.hr^{-1}$ when the moisture content of the barley, wheat, and *teff* crop biomass were increased from 14 % to 22 %. This indicates that at 22% moisture content the energy required to thresh the crop biomass was high. This is the same trend as reported by Ahmad *et al*., (2013). The grand mean and coefficient of variance of fuel consumption of each crops were 1.58, 2.21, & 2.02 $l.hr^{-1}$ and 6.73, 10.66 & 8.36 % respectively.

In general, the fuel consumption of the machine increased when, the moisture content of barley, wheat, and *teff* crop biomass was increased. (Table 4.5) indicating that fuel consumption increased with an increased moisture content.

The regression analysis was made to establish a relationship between the moisture content of the biomass and fuel consumption $l.hr^{-1}$. From regression coefficients (Appendix Table B7), the relationships between the fuel consumptions Fc and the moisture content (M) of barley, wheat and *teff* grains can be represented by the following equations.

$$Fc = 0.11059\ M - 0.40927 \quad R^2 = 0.94 \quad \text{barley}$$

$$Fc = 0.12625\ M - 0.06083 \quad R^2 = 0.80 \quad \text{wheat}$$

$$Fc = 0.08250\ M - 0.5405 \quad R^2 = 0.77 \quad \textit{teff}$$

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 *teff* seeds respectively.

Table 4. 8. Fuel consumption of barley, wheat, and *teff* crops at different moisture content.

	Fuel consumption (l/hr) crops		
Moisture content (%)	**Barley**	**Wheat**	**Teff**
14	$1.1365^{C} \pm 0.0331$	$1.7200^{C} \pm 0.0726$	$1.6960^{C} \pm 0.0509$
18	$1.5865^{B} \pm 0.0662$	$2.1850^{B} \pm 0.1809$	$2.0248^{B} \pm 0.0864$
22	$2.0213^{A} \pm 0.0549$	$2.730^{A} \pm 0.0610$	$2.3560^{A} \pm 0.1069$
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

SE: 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.

4.5. Breakage of Grain during Threshing

Grain breakage of the machine was highly influenced by the moisture content of barley and wheat crop in biomass. The analysis of variance, on the grain breakage data of the thresher, revealed that moisture content of crops had highly significant effects on the grain breakage of the machine. The mean with a standard error of breakage of grain and analysis of variance were presented in Table 4.6 and Appendix Table A12 for barley and wheat grains respectively. The ANOVA indicated that the grain breakage of multi-crop thresher was significantly affected by the amount of moisture content of barley and wheat crops ($P < 0.05$). The maximum breakage of grain (%) was 2.8655 and 2.6375, at 14 % moisture content while the minimum breakage of grain (%) was 1.6300 and 1.3750 when the moisture content was 22 % for each grain, respectively. At 14 % moisture content maximum grain damages were observed, because the elasticity of the grains is very low but this was increased the threshing capacity of the machine and the clear increase in performances of thresher was observed. This indicated that the grain breakage of the system was decreased as the moisture content of crops increased. However, the interaction effect of moisture content with the breakage of barley, and wheat grains were not significantly affected (P > 0.05) at which grand mean, and CV was 2.24 & 1.9958, and 21.33 & 15.67 respectively as shown in (Table 4.6). This is similar trends as reported by Al Sharifi *et al*., (2019) and Lupu *et al*., (2014) in corn and wheat grains respectively. But the breakage of teff grain was not identified difficult to determine due to the smaller size of the teff grain. In general, the grain breakage of the machine was decreased as, the moisture content of crops decreased (Table 4.6).

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 (Appendix Table B8), the relationships between the grain breakage (Gb) and the moisture content (M) of barley and wheat grains can be represented by the following equations.

$$Gb = -\ 0.15444\ M + 5.02421 \quad R^2 = 0.60 \quad \text{barley}$$

$$Gb = -0.15781M + 4.83646 \quad R^2 = 0.78 \quad \text{wheat}$$

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

Table 4. 9. Grain breakage of barley, and wheat crops at different moisture content

	Grain breakage (%) crops	
Moisture content (%)	**Barley**	**Wheat**
14	2.8655 ^{A} ± 0.3414	2.6375 ^{A} ± 0.1055
18	2.2375 ^{AB} ± 0.2172	1.9750 ^{B} ± 0.1841
22	1.6300 ^{B} ± 0.0902	1.3750 ^{C} ± 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

SE: 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.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study concluded that wide variation exists among the barley and wheat grain dimensions with respect to 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 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 (*kekeba* variety) and teff (D2-01-196 variety) were decreased with increasing of moisture content. This indicates that moisture content is the most important factors to determine the grains 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.

5.2. Recommendation

The performance evaluation result obtained from Melkasa-made muli-crop thresher was recommended that:

1. Once the plants are cut, they are left in the ground of a small heaps in the field for farther 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 to be lay between 14-18%.

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APPENDIX

Table A 1. The result of measured dimension of fifty randomly selected barley and wheat grains at different moisture contents.

At 14 (%) moisture content the dimension of barley and wheat grains were;

Crop dimensions						
Numbers	Barley			Wheat		
	Length (mm)	Width (mm)	Thickness(mm)	Length (mm)	Width (mm)	Thickne ss (mm)
1	8.20	3.50	2.40	6.40	3.20	3.00
2	9.50	3.40	2.45	5.25	3.10	2.65
3	9.40	3.00	1.70	5.85	3.00	2.75
4	9.30	3.60	2.45	6.45	3.40	3.15
5	9.70	3.45	2.20	6.45	2.80	2.50
6	11.20	3.60	2.45	6.65	3.00	2.50
7	9.50	3.00	2.00	5.75	3.00	2.55
8	10.00	3.30	2.30	5.15	3.15	2.50
9	11.40	3.30	2.40	5.60	3.10	2.90
10	7.50	2.30	2.30	7.55	3.50	3.10
11	10.30	3.50	2.35	6.50	3.05	2.65
12	9.20	3.15	2.20	5.80	3.00	2.85
13	10.50	3.60	2.30	5.45	3.25	2.90
14	10.00	2.90	2.20	5.85	3.25	3.00
15	10.50	3.10	2.00	5.50	2.95	2.70
16	9.65	3.45	2.20	5.60	3.40	3.10
17	9.40	3.45	2.20	5.80	3.20	2.90
18	10.00	3.10	2..10	5.30	3.10	2.60
19	9.70	3.50	2.20	6.00	3.20	2.80
20	10.00	3.65	2.50	6.10	3.40	3.00
21	9.60	3.20	2.20	5.50	3.35	2.95
22	11.00	3.80	2.60	5.70	3.15	2.90
23	8.20	3.10	2.30	5.90	3.30	2.85
24	9.50	3.30	2.40	5.10	3.10	3.00
25	10.80	3.00	2.00	5.25	3.00	2.85
26	10.50	3.10	2.25	5.90	3.10	2.65

27	10.40	2.90	2.00	4.85	2.50	2.30
28	10.20	3.20	2.40	5.95	3.10	2.65
29	9.80	3.40	2.30	6.45	3.20	3.00
30	8.80	3.00	2.40	7.10	3.40	2.95
31	10.85	3.40	2.50	6.80	2.95	2.50
32	9.90	3.20	2.40	6.50	3.20	2.85
33	11.00	3.60	2.20	6.40	3.00	2.75
34	8.75	3.00	2.10	5.95	3.10	2.65
35	10.70	3.20	2.40	6.80	2.85	2.60
36	10.70	3.50	2.30	6.50	3.30	2.80
37	11.00	3.10	2.20	6.10	3.10	2.50
38	9.60	3.20	2.50	6.85	3.30	3.10
39	8.00	3.60	2.40	5.80	2.90	2.75
40	9.50	3.60	2.65	6.50	3.20	2.85
41	10.60	3.50	2.40	5.90	3.10	2.75
42	10.40	3.40	2.30	6.40	3.15	2.90
43	9.80	3.20	2.20	5.95	3.00	2.85
44	9.50	3.40	2.50	5.90	2.90	2.70
45	10.60	3.50	2.30	5.50	3.10	3.00
46	9.30	2.95	1.85	5.90	3.30	3.00
47	9.00	2.70	1.50	5.30	3.00	2.60
48	9.40	3.30	2.10	5.60	2.80	2.50
49	10.85	3.10	2.55	5.65	3.10	2.70
50	10.00	3.45	2.40	6.00	3.40	3.10
average	9.378	3.186	2.255	5.933	3.114	2.772
At 18 (%) moisture content the dimension of each crops was;						
1	9.80	3.40	2.45	590	3.40	2.80
2	10.75	3.15	2.65	6.60	3.50	3.05
3	9.95	3.40	2.85	6.40	3.05	3.00
4	10.85	3.35	2.25	6.20	3.25	3.10
5	11.50	2.95	2.60	5.70	3.60	2.20
6	12.20	3.15	2.70	5.80	2.90	2.30
7	10.35	3.35	2.30	6.20	3.20	3.05

8	12.05	3.45	3.05	7.45	3.70	3.25
9	9.60	3.40	3.15	7.15	3.20	3.15
10	10.80	3.25	3.30	6.65	3.30	2.30
11	11.25	3.05	2.90	5.40	2.90	2.20
12	12.35	3.20	2.50	5.60	2.70	2.40
13	11.75	3.50	2.75	6.25	3.00	3.10
14	10.35	3.35	3.00	6.35	3.20	3.00
15	10.20	3.40	2.85	7.05	3.80	3.30
16	8.95	2.90	1.95	5.85	2.70	2.40
17	9.80	2.85	2.05	5.60	3.50	2.30
18	11.70	3.40	2.25	6.00	3.25	2.40
19	10.40	3.40	3.15	7.00	3.60	3.00
20	9.50	3.15	3.20	6.20	3.25	2.60
21	10.60	3.40	2.25	5.90	2.95	2.50
22	11.70	3.30	2.35	5.70	2.80	2.70
23	12.00	3.05	2.40	6.20	3.20	2.80
24	10.50	3.25	2.30	5.40	3.30	2.60
25	9.60	3.15	1.85	5.85	3.40	2.65
26	9.10	2.95	1.90	6.20	3.30	3.40
27	9.50	3.10	2.25	7.10	3.40	3.00
28	11.80	3.05	2.60	6.15	3.50	2.75
29	12.05	3.25	2.15	7.00	3.25	3.75
30	11.15	11.15	2.20	5.70	2.85	3.40
31	10.60	10.60	2.40	5.80	2.90	2.95
32	9.80	3.20	2.85	6.30	3.20	2.70
33	9.75	3.15	2.25	6.40	3.00	2.85
34	10.50	3.30	2.60	5.50	3.15	2.70
35	9.90	3.45	2.15	4.95	2.30	2.55
36	9.85	3.05	2.20	7.00	3.45	3.45
37	10.60	3.25	2.10	6.35	3.60	2.85
38	11.15	3.15	2.30	6.40	3.50	3.25
39	12.10	3.75	3.00	5.80	2.80	2.70
40	11.30	3.00	2.40	6.20	3.60	2.95

41	10.50	3.40	2.15	5.80	3.60	2.85
42	9.90	3.15	2.20	7.00	3.10	3.40
43	9.90	2.95	2.30	7.10	3.40	3.50
44	12.00	3.25	2.10	5.70	2.60	2.85
45	11.15	3.45	2.40	6.20	3.50	2.80
46	10.25	3.35	2.20	6.30	3.25	2.70
47	10.40	3.45	2.30	6.30	3.40	2.65
48	10.25	3.20	2.40	6.25	3.30	2.90
49	9.75	3.30	2.10	5.60	2.90	2.50
50	9.75	3.05	2.20	7.20	3.30	3.70
Average	10.220	3.434	2.630	6.311	3.421	2.929
At 22 (%) moisture content the dimension of each grains also given:						
1	10.35	3.65	2.40	6.70	3.70	2.80
2	11.40	3.45	2.50	6.80	3.60	2.90
3	12.30	3.80	3.25	7.10	3.80	3.20
4	12.05	4.00	3.00	5.90	2.90	2.80
5	11.70	3.85	280	6.30	3.10	3.00
6	11.60	3.70	2.80	7.30	3.80	3.20
7	12.50	3.90	3.10	7.00	3.80	3.10
8	10.90	3.50	2.60	6.50	3.40	2.80
9	11.30	3.60	2.80	5.80	3.70	2.75
10	10.50	3.50	2.50	6.40	3.20	3.40
11	11.30	3.45	2.80	6.50	3.30	2.80
12	12.00	4.00	3.50	6.80	3.40	2.75
13	11.30	3.40	3.10	7.30	3.80	3.50
14	10.35	3.20	2.80	6.50	3.50	2.80
15	9.40	3.10	2.35	6.40	3.60	2.85
16	12.00	3.90	3.60	7.05	3.75	3.30
17	11.50	3.40	3.00	7.10	3.80	3.35
18	10.90	3.30	2.80	5.90	3.60	2.60
19	10.20	3.40	2.60	6.60	3.40	2.80
20	10.10	3.20	2.40	6.70	3.45	2.80
21	9.90	3.10	2.40	6.80	3.50	2.75

22	12.10	4.00	2.60	7.00	3.90	3.40
23	10.45	3.50	2.80	5.90	2.80	2.20
24	12.05	3.85	3.45	6.50	3.40	2.30
25	11.40	3.60	3.05	6.50	3.45	2.60
26	10.60	3.45	2.60	6.70	3.40	2.80
27	10.50	3.40	2.50	7.80	3.90	3.70
28	11.25	3.60	2.90	7.00	3.70	3.40
29	12.10	3.90	3.50	6.50	3.60	3.00
30	12.00	3.85	3.40	6.50	3.65	2.70
31	11.50	3.40	2.30	6.80	3.60	2.80
32	10.80	3.20	2.40	7.15	3.85	3.40
33	9.75	3.20	2.20	7.05	3.90	3.30
34	10.65	3.50	3.00	7.20	3.70	3.25
35	11.70	3.60	2.90	6.80	3.50	2.80
36	10.50	3.50	2.80	6.50	3.30	2.70
37	9.80	3.35	2.30	6.70	3.40	2.65
38	10.90	3.70	2.60	7.00	3.60	3.10
39	11.35	3.75	2.80	6.60	3.40	2.70
40	12.05	4.05	3.70	6.50	3.30	2.75
41	11.30	3.35	3.05	6.70	3.25	2.60
42	11.40	3.60	3.00	5.90	2.85	2.45
43	12.15	3.90	3.40	6.40	3.60	3.00
44	10.30	3.40	2.60	6.40	3.50	2.60
45	11.40	3.60	2.70	6.50	3.45	2.70
46	12.00	3.90	3.50	6.45	3.45	2.80
47	10.60	3.50	2.60	6.60	3.60	2.75
48	11.35	3.70	2.70	7.10	3.80	3.20
49	12.25	3.85	3.30	6.60	3.50	3.00
50	11.30	3.65	2.70	7.80	4.00	3.70
Average	11.094	3.728	2.849	6.887	3.760	3.220

Table A 2.Means with standard errors (SE) of physical properties of 'barley' grains

Dimension of grains	Moisture content (%)		
	14	18	22
Length mm	9.378 ± 0.1999	10.220 ± 0.0431	11.094 ± 0.0632
Width mm	3.1863 ± 0.0695	3.4337 ± 0.0299	3.7280 ± 0.0570
Thickness mm	2.2552 ± 0.0612	2.6298 ± 0.0483	2.8827 ± 0.0337
Arithmetic mean diameter mm	5.1958 ± 0.0502	5.3907 ± 0.0363	5.9040 ± 0.0201
Geometric mean diameter mm	4.180 ± 4.1800	4.5905 ± 4.5905	5.0855 ± 5.0855
Equivalent mean diameter mm	4.2302 ± 0.0551	4.5945 ± 0.0516	5.0520 ± 0.0218
Area based on arithmetic mean diameter mm^2	4.1275 ± 0.0415	4.3163 ± 0.0139	4.5110 ± 0.1550
Area based on geometric mean diameter mm^2	3.2065 ± 0.0343	3.6387 ± 0.0241	3.9380 ± 0.0241
Volume of seeds mm^3	37.079 ± 0.1477	51.273 ± 0.2552	65.536 ± 0.2206
Sphericity (%)	41.525 ± 0.4479	45.000 ± 0.2041	45.775 ± 0.3425
Thousand grain mass (g)	31.250 ± 0.3227	32.950 ± 0.2102	34.500 ± 0.2041
Surface area mm^2	25.410 ± 0.0159	28.380 ± 0.1952	33.048 ± 0.1156
Bulk density kg/m^3	496.90 ± 0.3821	465.61 ± 0.1545	443.98 ± 0.0631
True density kg/m^3	934.94 ± 0.0344	823.04 ± 0.0927	776.08 ± 0.1531
Porosity (%)	46.581 ± 0.2189	43.227 ± 0.1500	42.830 ± 0.1550
Angle of repose 'degree'	19.850 ± 0.1272	22.57 ± 0.0625	32.150 ± 0.0836
Coefficient of friction (%)	54.300 ± 0.1477	65.157 ± 5.1645	77.708 ± 0.0649

Table A 3. Means with standard errors (SE) of physical properties of 'wheat' crops

Dimension of grains	Moisture content (%)		
	14	18	22
Length mm	5.9325 ± 0.0202	6.3110 ± 6.272E-03	6.8870 ± 0.0107
Width mm	3.1138 ± 0.0380	3.4212 ± 0.0155	3.7688 ± 0.0192
Thickness mm	2.7715 ±0.0192	2.9287 ± 0.0284	3.2200 ± 0.0102
Arithmetic mean diameter mm	3.9603 ± 4.479E-03	4.2315 ± 7.399E-03	4.6120 ± 0.0131
Geometric mean diameter mm	3.7135 ± 0.0101	4.0370 ± 0.0295	4.3410 ± 0.0181
Equivalent mean diameter mm	3.7188 ± 9.656E-03	4.0938 ± 0.0515	4.3712 ± 7.465E-03
Area based on arithmetic mean diameter mm^2	3.0930 ± 0.0220	3.3127 ± 0.0391	3.5995 ± 7.489E-03
Area based on geometric mean diameter mm^2	2.9035 ± 0.0110	3.1923 ± 0.0439	3.4120 ± 6.519E-03
Volume of seeds mm^3	27.510 ± 0.1752	33.540 ± 0.2359	43.166 ± 0.0634
Sphericity (%)	62.163 ± 0.1279	63.087 ± 0.1405	63.358 ± 0.1548
Thousand grain mass (g)	33.300 ± 0.2121	35.325 ± 0.2689	37.288 ± 0.1983
Surface area mm^2	14.667 ± 0.1664	16.896 ± 0.0443	20.243 ± 0.1142
Bulk density kg/m^3	932.41 ± 0.2263	915.04 ± 0.4093	887.32 ± 0.2484
True density kg/m^3	1391.7 ± 0.2425	1361.0 ± 0.0535	1201.4 ± 0.2416
Porosity (%)	33.090 ± 0.0465	32.547 ± 0.1946	25.992 ± 0.0496
Angle of repose 'degree'	19.500 ± 0.1080	24.986 ± 0.1854	31.350 ± 0.0629
Coefficient of friction (%)	48.23 ± 0.1781	56.108 ± 0.2243	67.827 ± 0.4604

Table A 4. Means with standard errors (SE) of physical properties of 'teff' crops

Properties of grains	Moisture content (%)		
	14	18	22
Thousand grain mass (g)	0.2820 ± 0.147	0.3240 ± 0.2071	0.3842 ± 0.1750
Angle of repose 'degree'	24.190 ± 0.1470	27.578 ± 0.2055	34.180 ± 0.1321
Coefficient of friction (%)	70.540 ± 1.080E-03	76.997 ± 2.082E-03	84.660 ± 1.797E-03

Table A 5. ANOVA of threshing capacity in (kg/hr) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	152130	76065.1	19.2	0.0006
	Error	9	35565	3951.7		
	Total	11	187695			
Wheat	Moisture	2	8623.7	4311.84	3.65	0.0690
	Error	9	10626.5	1180.72		

	Total	11	19250.1			
Teff	Moisture	2	18124.3	9062.14	10.5	0.0045
	Error	9	7793.6	865.95		
	Total	11	25917.8			

Significant at 1% level; significant at 5% level; ns, non-significant; df, degrees of freedom

Table A 6. ANOVA of threshing efficiency in (%) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	12.8949	6.44746	6.31	0.0194
	Error	9	9.1956	1.02173		
	Total	11	22.0905			
Wheat	Moisture	2	9.0145	4.50727	7.87	0.0106
	Error	9	5.1527	0.57252		
	Total	11	14.1672			
Teff	Moisture	2	9.7561	4.87803	9.64	0.0058
	Error	9	4.5530	0.50589		
	Total	11	14.3091			

Significant at 1% level; significant at 5% level; df, degrees of freedom

Table A 7. ANOVA of cleaning efficiency in (%) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	65.1542	32.5771	16.8	0.0009
	Error	9	17.4661	1.9407		
	Total	11	82.6203			
Wheat	Moisture	2	723.575	361.787	76.9	0.0000
	Error	9	42.349	4.705		
	Total	11	765.924			
Teff	Moisture	2	343.741	171.871	15.7	0.0012
	Error	9	98.275	10.919		
	Total	11	442.017			

Highly significant at 1% level; significant at 5% level; df, degrees of freedom

Table. A 8. ANOVA of percentage of unthreshed grains of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MSS	F- value	P- Value

Barley	Moisture	2	63.7255	31.8627	13.70	0.0019
	Error	9	20.9843	2.3316		
	Total	11	84.7098			
Wheat	Moisture	2	79.389	39.6943	13.7	0.0019
	Error	9	26.112	2.9013		
	Total	11	105.500			
Teff	Moisture	2	71.4752	35.7376	15.0	0.0014
	Error	9	21.4207	2.3801		
	Total	11	92.8959			

Highly significant at 1% level; significant at 5% level; df, degrees of freedom

Table A 9. ANOVA of percentage of blown out grains of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MSS	F-value	P-value
Barley	Moisture	2	14.3588	7.17942	20.4	0.0005
	Error	9	3.1650	0.35167		
	Total	11	17.5239			
Wheat	Moisture	2	11.2526	5.62630	37.3	0.0000
	Error	9	1.3566	0.15073		
	Total	11	12.6092			
Teff	Moisture	2	11.0405	5.52026	20.8	0.0004
	Error	9	2.3870	0.26522		
	Total	11	13.4275			

Highly significant at 1% level; significant at 5% level; df, degrees of freedom

Table A 10. ANOVA of rate of germination in (%) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	34.8084	17.4042	7.68	0.0113
	Error	9	20.3919	2.2658		
	Total	11	55.2003			
Wheat	Moisture	2	62.6662	31.3331	16.8	0.0009
	Error	9	16.8079	1.8675		
	Total	11	79.4741			
Teff	Moisture	2	85.8077	42.9039	57.6	0.0000
	Error	9	6.7067	0.7452		

	Total	11	92.5145			

Significant at 1% level; significant at 5% level; df, degrees of freedom

Table A 11. ANOVA of fuel consumption in (L/hr) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	1.56572	0.78286	69.1	0.0000
	Error	9	0.10202	0.01134		
	Total	11	1.66774			
Wheat	Moisture	2	2.04447	1.02223	18.4	0.0007
	Error	9	0.50030	0.05559		
	Total	11	2.54477			
Teff	Moisture	2	0.87120	0.43560	15.2	0.0013
	Error	9	0.25806	0.02867		
	Total	11	1.12926			

Highly significant at 1% level; significant at 5% level; df, degrees of freedom

Table A 12. ANOVA of breakage of grain (%) of barley, wheat and teff crops on the performance of thresher.

Crops	Source	DF	SS	MS	F-value	P-value
Barley	Moisture	2	3.05320	1.52660	6.66	0.0168
	Error	9	2.06261	0.22918		
	Total	11	5.11581			
Wheat	Moisture	2	3.19042	1.59521	16.3	0.0010
	Error	9	0.88048	0.22918		
	Total	11	4.07089			

Significant at 5% level; df, degrees of freedom

Table B 1. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the threshing capacity of the machine.

Parameters to be determined	Threshing capacity (kg/hr)					
	$R^2 = 0.77$		$R^2 = 0.45$		$R^2 = 0.66$	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	1102.73	-33.5371	507.284	-8.20719	587.163	-11.5878
Std. Error	106.927	5.84496	52.7150	2.88156	47.7773	2.61165
F-value	10.31	-5.74	9.6	-2.85	12.29	-4.44

P-value	0.0000	0.0002	0.0000	0.0173	0.0000	0.0013

Table B 2. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the threshing efficiency of the machine.

Parameters to be determined	Threshing efficiency					
	R^2 = 0.58		R^2 = 0.64		R^2 = 0.68	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	102.064	-0.31737	101.383	-0.26531	101.65	-0.27469
Std. Error	1.55072	0.08477	1.16120	0.06347	1.10275	0.0602
F-value	65.82	-3.74	87.31	-4.18	92.18	-4.56
P-value	0.0000	0.0038	0.0000	0.0019	0.0000	0.0010

Table B 3. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the cleaning efficiency of the machine.

Parameters to be determined	Cleaning efficiency					
	R^2 = 0.75		R^2 = 0.94		R^2 = 0.76	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	104.238	-0.69731	121.939	-2.37094	110.755	-1.62141
Std. Error	2.30841	0.12618	3.48275	0.19038	5.25229	0.28711
F-value	45.16	-5.53	35.01	-12.45	21.09	-5.65
P-value	0.0000	0.0003	0.0000	0.0000	0.0000	0.0002

Table B 4. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the percentage of unthreshed grains.

Parameters to be determined	Percentage of unthreshed grains					
	R^2 = 0.75		R^2 = 0. 75		R^2 = 0.77	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	-4.41300	0.70387	-5.05771	0.78719	-3.90612	0.74619
Std. Error	2.35953	0.12898	2.61646	0.14302	2.37788	0.12998
F-value	-1.87	5.46	-1.93	5.50	-1.64	5.74
P-value	0.0910	0.0003	0.0820	0.0003	0.1315	0.0002

Table B 5. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the percentage of blown out grains.

Parameters to be determined	Percentage of blown out grains					
	R^2 = 0. 80		R^2 = 0. 89		R^2 = 0.82	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	8.95129	0.8030	8.26125	-0.29562	7.80496	-0.29244
Std. Error	0.95008	0.05193	0.60991	0.03334	0.80541	0.04403
F-value	9.42	-6.38	13.55	-8.87	9.69	-6.64
P-value	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001

Table B 6. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the germination rates of the machine.

Parameters to be determined	germination rates					
	R^2 = 0.63		R^2 = 0.79		R^2 = 0.84	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	101.645	-0.51822	105.165	-0.69969	107.356	-0.78105
Std. Error	2.33347	0.12755	2.09646	0.11460	1.94237	0.10618
F-value	43.56	-4.06	50.16	-6.1	55.27	-7.36
P-value	0.0000	0.0023	0.0000	0.0001	0.0000	0.0000

Table B 7. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the fuel consumption of the machine.

Parameters to be determined	Fuel consumption					
	R^2 = 0.94		R^2 = 0.80		R^2 = 0.77	
	Barley		Wheat		Teff	
	Constant	Moisture	Constant	Moisture	Constant	Moisture
Coefficient	-0.40927	0.11059	-0.06083	0.12625	0.54058	0.08250
Std. Error	0.16345	0.00893	0.36321	0.01985	0.25976	0.01420
F-value	-2.50	12.38	-0.17	6.36	2.08	5.81
P-value	0.0312	0.0000	0.8703	0.0001	0.0641	0.0002

Table B 8. Regression coefficient relating the moisture content of the barley, wheat and teff crops against the grain breakage of the machine.

Parameters to be determined	Grain breakage			
	$R^2 = 0.60$		$R^2 = 0.78$	
	Barley		Wheat	
	Constant	Moisture	Constant	Moisture
Coefficient	5.02421	-0.15444	4.83646	-0.15781
Std. Error	0.73441	0.04015	0.48051	0.02627
F-value	6.84	-3.85	10.07	-6.01
P-value	0.0000	0.0032	0.0000	0.0001

ANNEXES

Photography during the testing activities at Melkasa Agricultural Research Center Facilities

1. Crops to be threshed



a, wheat (kekeba) varieties   b, teff (D2-01-196) variteies   c, Barley (HB 42) variteies

Measurement of moisture content and addition of required amount of water.


a, Measuring of water   b, Addition of water to the crops

2. Measurements of fuel consumption during threshing.


a. Reading of fuel level   b. Addition of fuel

3. Threshing of crops at different moisture content

Keeping of feed rate constant Removal of straws

4. Measuring instruments in the laboratory at (MARC).

a. Measuring of coefficient of friction

b. Measuring of angle of repose

C, Seed-counter used to count threshed seeds

d, Electronic balances used to measure thousand grain mass

E, Electronic moisture meter

f, Graduate cylinder

G, an instrument used to measure angle of repose as well as coefficient of friction.

H, Electronic digital caliper used to measure dimension of seeds.

a) Measuring of seed dimensions

b) Digital electronic caliper

a) Straw and chaff samples

Anemometer to measure wind speeds

a) Threshed grain samples to determine thousand grain masses

b) Multi-crop thresher