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Technological and Physicochemical Characterization of Bread Wheat Varieties Grown in Ethiopia

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TECHNOLOGICAL AND PHYSICOCHEMICAL CHARACTERIZATION OF BREAD WHEAT VARIETIES GROWN IN ETHIOPIA

BY

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By

Alemu Engashu

A Thesis

Submitted to School of Research and Post Graduate, Bahir Dar Institute of Technology, Bahir Dar University in Partial Fulfillment of the Requirements for the Degree of master of Science in Post-Harvest Technology

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DECLARATION

I declare that this thesis entitled "Technological and Physiochemical Characterization of Wheat Varieties Grown in Ethiopia" is my own original work carried out under the supervisions of Admasu Fanta Worku (Assi.prof.) and Karta Kaske Kalsa (PhD). It is being submitted to the Faculty of Chemical and Food Engineering for the Degree Master of Science in Post-harvest Technology. It has not been submitted before for any degree or evaluation to other University. Permission is herewith granted to Bahir Dar Institute of Technology to circulate and to have copied for noncommercial purpose while the author reserves other publication rights. Besides, neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

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Acronyms and Abbreviations

AACC	American Association of Cereal Chemists
ARARI	Amhara Region Agricultural Research Institute
ASE	Amhara Seed Enterprise
CGIAR	Consultative group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Stastical Agency
EIAR	Ethiopian Institute of Agricultural research
ESE	Ethiopia Seed Enterprise
FAO	Food and Agriculture Organization
HSD	Tukey's Honest Significance Difference
ICRC	International Federation of Red Cross and Red Crescent Societies
NGO	Non-Governmental Organization
NIRT	Near Infrared Transmittance
OSE	Oromia Seed Enterprise
RARI	Regional Agricultural Research Institute
SKCS	Single Kernel Characterization Systems
SNNP	South Nations Nationalities and People

Abstract

The major target of wheat research and extension system of Ethiopia is increased production and productivity of the crop. Little information is available with regard to end-use quality of wheat varieties grown in the country. Hence, 13 bread wheat varieties, grown on same location and year, were assessed for their physicochemical and technological properties. Data such as protein, starch, wet gluten, zeleny, SKCS hardness index, flour color, particle size & color distri- bution, flour water absorption, dough development time, dough stability, degree of softening were measured. Results show that there were significant effects of variety on physicochemical properties of wheat ($P < 0.05$). Protein, starch, wet gluten, and zeleny values were in the range from 10.3 to 13.2%, 64.8 – 68.3%, 20.7 - 29.3% and 24.9 - 39.5%, respectively. The L*-value of whole grain flour was significantly affected by variety, ranging from 77.0 (*Guna*, darkest variety) to 122.9 (*Shorima*, lightest variety). The single kernel characteristics namely ker- nel weight, hardness index, and diameter were significantly affected by variety ($P <$ 0.05). Highest grain hardness was recorded by the variety *Guna*, whereas the least hardness value was observed by *Taye*. The color of flour was significantly ($P <$ 0.05) affected by particle size of flour, regardless of variety. In all cases, the color tended to be whiter as particle size decreased. However, the magnitude of change showed differences among the varieties. Fine flour particles of the variety *Tsehaye* resulted in the highest L*- value (lightest of all varieties), whereas flour of the same particle size category of the variety *Danda'a* resulted in the least L*-value. The farinograph properties were significantly affected by the wheat variety. Among the varieties tested, a higher water absorption was observed by the varieties *Guna*, *Densa*, and *Dinknesh*, whereas the variety *Ali- dero* showed the least farinograph water absorption. Flour water absorption and dough stability of particle size category < 90 µm flour was lowest and highest of the studied particle size groups, respectively. Generally, *Taye*, *Shorima*, and *Ali- dero* varieties belonged to the soft category whereas *Densa*, *Guna*, and *Dinknesh* varieties fell under the hard wheat category. Segregation of course and fine flour particles improved the color and technological quality of the finer particles.

1 Introduction

1.1 Background

Wheat is a cereal grass of the Graminae (Poaceae) family and belongs to genus *Triticum*. It is the world's largest cereal crop species. It has been described as the 'King of Cereals' because of the acreage it occupies, high productivity and the prominent position it holds in the International food grain trade (Mansing, 2010). Majority of the cultivated wheat varieties belong to three main species of the genus *Triticum*. These are the hexaploid *Triticum aestivum* L. (bread wheat), the tetraploid *Triticum durum*, *Triticum dicoccum*, and *Triticum monococcum* (Mansing, 2010). In general, there are two main wheat varieties, such as bread wheat and durum wheat. Bread wheat (*Triticum aestivum* accounts for 95% of all the consumed wheat in the world; the other five percent is made up of durum (*T. durum*) or hard wheat (*T. turgidum*) (Von Braun, 2007). Wheat is among the most important cereal grains in the world, as it is the third most cultivated crop next to maize and rice (FAOSTAT, 2019). It is a major source of energy, protein, and dietary fiber in human nutrition and animal feeding. It provides approxim- ately one-fifth of the total calorific input of the World's population (Odegard and Van der Voet, 2014). It is grown from below sea level to elevations exceeding 3000 m above sea level and at latitudes ranging from 30° and 60°N to 27° and 40°S (Hei, 2014). Food and Agriculture Organization (FAO) records show that 65% of wheat is used as food, 17% as animal feed and 12% as industrial inputs including biofuel (Tubiello et al., 2013).

Ethiopia is the second largest wheat producer country in sub-Saharan Africa after South Africa (Shiferaw et al., 2014). Wheat is cultivated on 1.7 million hectares accounting for 13.38% of the crop land, with an annual production of 5.1 million metric tons (FAO, 2010). Wheat contributes about 15.17% of the cereal production in the country and ranks fourth after teff (*Eragrostis teff* (Zucc.) Trotter), maize (*Zea mays* L) and sorghum (*Sorghum bicolor* (L.) Moench) in area coverage and total grain production in Ethiopia (Central Statistical Agency, 2018). Bread wheat is an introduced crop whereas durum wheat is an indigenous crop. According to Mendola (2007), bread wheat is a recent introduction to Ethiopia and mainly grown in the Central and Northern highlands. However, bread wheat cultivation is expanding due to its high yield and wide adaptability (Shiferaw et al., 2014). Bread wheat is widely cultivated in the highlands of the country. The crop is grown at an altitude ranging from 1500 to 3000 meters above sea level (masl), between 6-16^{o} N latitude and 35- 42^{o} E longitude. The most suit- able agro-ecological zones, however, fall between 1900 and 2700 masl (Kotu et al., 2000). The major bread wheat producing areas in Ethiopia are located in Arsi, Bale, Shewa, Ilubabor, Western Hareghe, Sidamo, Tigray, Northern Gondar and Gojam zones (Belderok et al., 2000). Over the last several years, the International Maize and Wheat Improvement Center (CIMMYT) has been col- laborating with the Ethiopian Institute of Agricultural Research (EIAR) in the development and dissemination of improved wheat varieties. This long-standing partnership has led to the development of about 44 improved bread wheat vari- eties with associated agronomic and crop protection practices.

1.2 Statement of the problem

It is recognized that substantial efforts are being exerted by stakeholders towards achieving a minimum yield gap through addressing constraints related to production. Matters related to the end-use quality of wheat has been given little atten- tion while wheat varieties often perform differently with respect to their abilities to meet consumer preferences. Varieties can possess certain characteristics that would make them preferable for a given end-use than others (Morris, 2002). For instance, wheat that is suitable for bread making has hard texture, more protein, more gluten, higher zeleny sedimentation value, higher farinograph water absorption, good milling quality etc. Conversely, wheat with soft texture, low protein, low farinograph absorption results in poor bread baking performance. Soft wheat varieties are destined for cakes, cookies and other pastry products.

Furthermore, the color of flour is one of the key indicators of quality and therefore white flour is produced through the process of gradual reduction (commercial milling) to separate bran and germ from the white-colored endosperm. The popularity of white (refined) flour lies in its high sensory appeal and the fact that it results in good bread baking performance compared to whole-grain flour. However, the adverse health consequences of white flour are also well recognized (Marquart et al., 2002). Conversely, rural households and a significant propor- tion of the urban ones consume wheat-based foods made from the whole grain. Although it is advisable to continue the consumption of wheat as a nutrient- dense and healthy whole grain product, it is necessary to improve the baking performance of whole-grain wheat flour. Therefore, there is a need to compromise between minimizing the adverse health effect of refined flour and improving the technological performance of whole-grain flour.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to determine the technological and physicochemical characterization of bread wheat varieties grown in Ethiopia

1.3.2 Specific Objectives

- To investigate the chemical composition of bread wheat varieties grown in Ethiopia
- To determine physical properties of grain and flour of different wheat varieties
- To assess the milling performance of bread wheat varieties grown in Ethiopia

1.4 Significance of the study

The findings of this study will be helpful to agricultural researchers who are engaged in variety development. They will consider technological properties as one criterion during variety development and release. The information generated will also be significant for processors, consumers, and policy makers to distinguish among varieties based on technological properties. Besides, the findings will also serve as basis for further research in technological quality to be carried out in depth and breadth.

1.5 Scope of the Study

The study has aimed at technological and physicochemical characterization of 1 3 wheat varieties grown on the same location and year by Adet Agricultural research center, Amhara Region Agricultural Research Institute, Adet.

2 Literature review

2.1 Classification of wheat

Wheat is one of the cereals used extensively in many parts of the world for the preparation of bread and many bakery products (Fincher and Stone, 1986). In its various food forms, wheat provides a large proportion of the world's nutrition. It is the most important cereal crop in the world (Pena et al., 2006) which is the principal source of energy, protein and dietary fiber for a major portion of the world's population.

The diploid (monococcum) einkorn wheat: Einkorn (*Triticum monococcum ssp. monococcum* L.) is an ancestral diploid wheat, related to bread (*T. aestivum ssp. aestivum*) and durum (*T. turgidum ssp. durum*) wheats. Einkorn was key in the advance and development of agriculture and a significant food source for thousands of years, before it was replaced by the more productive polyploid wheats during the Eneolithic period (Hidalgo et al., 2006). Einkorn is known for its high protein and yellow pigment contents besides its low allergenicity (Hidalgo et al., 2006). Besides, it is also believed to be an excellent genomic source of traits such as disease resistance, yellow pigment content, etc., for bread and durum wheats Abdel-All et al. (1995); Cooper (2015); Zaharieva and Monneveux (2014).

The tetraploids (Triticum turgidum), durum and emmer wheat: Tetraploid wheats are genetically and morphologically diverse (Matsuoka, 2011). Tet- raploid wheats have played a key role in human history. Durum wheat (*Triticum durum*) is the primary wheat for pasta and semolina production and the second most cultivated wheat after bread wheat (*Triticum aestivum* L.). Emmer wheat (*T. turgidum subsp. dicoccon*), although a 'relic' crop today, is used for bread making, animal feed and as a genetic resource for the improvement of bread and durum wheat varieties (Teklu et al., 2007). Durum wheat, *T. turgidum*, is valued for its high gluten content and widely used for pasta, bulgar, couscous and some bread flours. Semolina is coarsely ground durum wheat. Durum wheat is a distinct species, expressing a phenomenon known as tetraploidy, a condition that renders it with 4 copies of each chromosome in its genome.

Hexaploid (Triticum aestivum), bread wheat: Common wheat (*Triticum aestivum* L.) evolved through natural hybridization and chromosome doubling between *T. turgidum ssp. durum* Desf. MacKey, a cultivated allotetraploid, and *Aegilops tauschii* Coss. A diploid goat grasses. Since its arrival, common wheat has become a popular staple crop, not only because it adapts well to different vernalization and photoperiod conditions, but also because it grows more aggressively than its progenitors under salt, low pH, aluminum, and frost conditions. In addition, it has enhanced resistance to pathogens as well as versatile end products (Matsuoka, 2011). It is the major wheat species grown throughout the world, accounting for about 95% of the million tons of wheat which are grown annually (Shewry and Hey, 2015).

2.2 History of Bread Wheat

Wheat is believed to have originated in Southwestern Asia. Some of the earliest remains of the crop have been found in Syria, Jordan, and Turkey. Primitive relatives of present-day wheat have been discovered in some of the oldest excavations of the world in eastern Iraq, which date back to 9,000 years. Other archeological findings show that bread wheat was grown in the Nile Valley about 5,000 B.C. as well as in India, China and even England at about the same time. Wheat was first grown in the United States in 1602 on an island off the Massachusetts coast. Human beings have depended upon the wheat plant for themselves and their beasts for thousands of years. A global wheat failure would be a disaster that few nations could survive for even one year (Gibson and Benson, 2002).

Bread Wheat evolved through years of cultivation in the southern Caspian plains. This evolution was accelerated by an expanding geographical range of cultivation and by human selection, and had produced bread wheat as early as the sixth millennium BC. Modern varieties are selections caused by natural mutation starting with emmer wheat up to husk less modern wheat. Cytological and cytogenetic evidences showed that wheat consists of diploid, tetraploid and hexaploid (two, four and six sets of chromosomes respectively) species with a basic chromo- some set of x=7. Three genomes designated as A, B (G), and D was involved in the formation of the polyploidy series (Angus and Bonjean, 2001). *T. urartu* and *Aegilops squarossa* (syn. *Triticum tauschii*) are the diploid progenitors of the A and D genomes, respectively. It is believed that *T. monococcum* naturally hybridized with the yet unknown B- genome donor to give rise to the tetraploid emmer group. Emmer wheat in turn hybridized with *A. Squarossa* and a spontaneous chromosome doubling of the triploid resulted in the formation of hexaploid wheat (Angus and Bonjean, 2001). Within the tetraploid group, cultivated em- mer (*T. dicoccum*), which arose from the wild *T. dicoccoides*, was the first to be domesticated. The other forms, such as *T. durum*, *T. turgidum* and *T. polonicum* might have originated from cultivated emmer through mutation or accumulation of mutations that reduced the toughness of the glumes to a point at which free threshing was attained (Kimber and Sears, 1987).

2.3 Anatomy and flour types of wheat kernel

A kernel of wheat is a dry, one-seeded fruit. Wheat kernel has three major components, namely bran, endosperm, and germ (Figure 1).

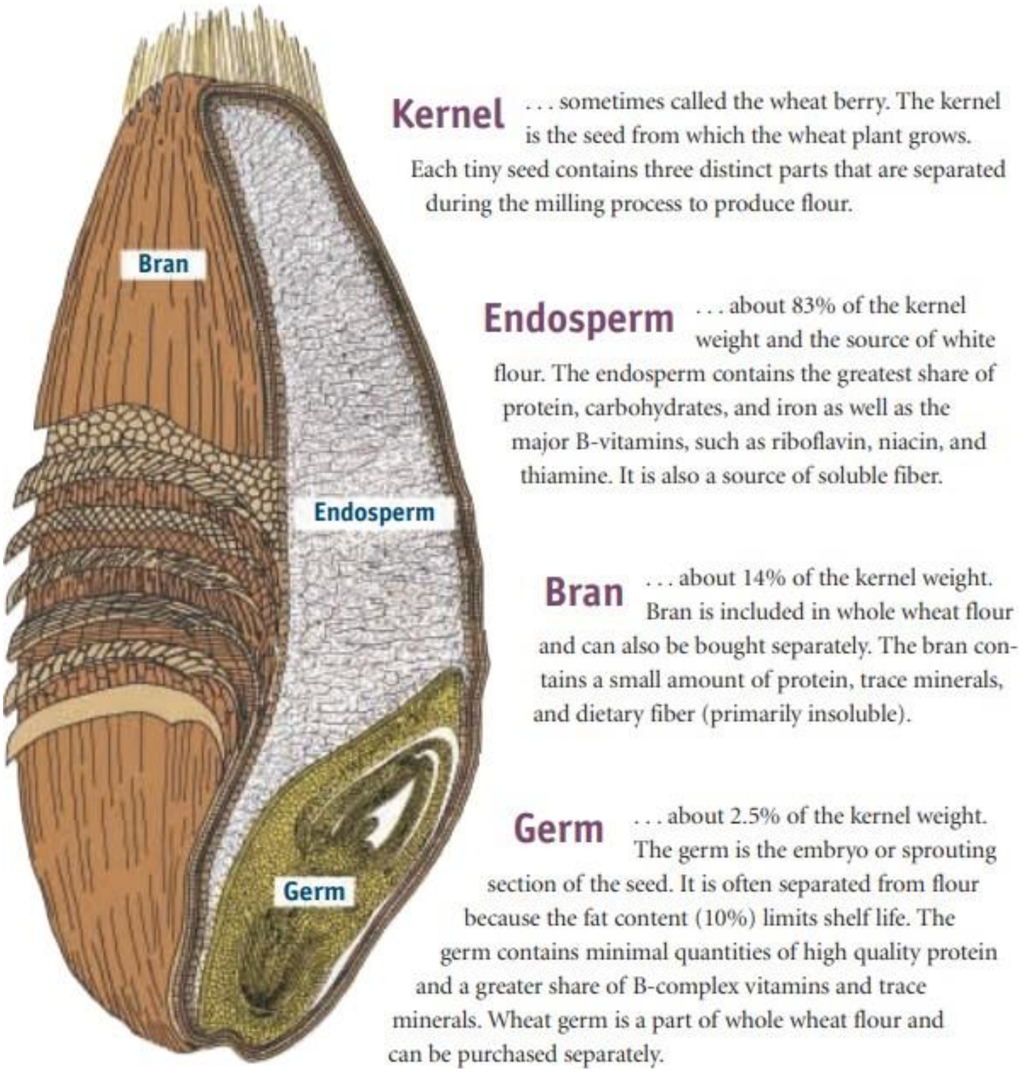

Figure 1: Anatomy of wheat kernel.
Picture downloaded from http://nationalfestivalofbreads.com

The pericarp and the outermost tissues of the seed, including the aleurone layer, compose the bran. There is no natural line of cleavage between bran and starchy endosperm. This fact accounts for some of the difficulties encountered in separating the two during flour milling. The germ is, structurally, a separate entity; a separation of germ and endosperm should require no breaking of cell walls (Bradbury et al., 1956). The bran is the outermost layer of the kernel, making up about 14.5% of total kernel weight whereas he endosperm accounts for the majority of the kernel weight – 83%. The germ, the smallest part of the kernel, makes up about 2.5% of total weight. The modern milling process is a gradual reduction of the wheat kernels through a process of grinding and sifting. This process targets separation of bran and germ from endosperm. The success of such milling process is measured by the purity of the endosperm particle in the final flour without significant contamination with bran particles. On the other hand, whole wheat flour is made from the entire kernel components to be in- cluded in the final product. Both whole and refined wheat flours have their pros and cons. Refined flour has superior baking performance and sensory appeal due to the fact that it is made of pure endosperm fraction of the kernel, which contains the gluten forming proteins with less bran contamination. The white color of flour is often considered as a consumer attraction. However, the refined flour is devoid of essential nutrients that are concentrated in the bran and germ components. In the case of whole wheat flour, a nutrient dense flour is a great advantage despite its usually unacceptable color and poorer baking performance caused by fiber's weakening effect on gluten, which in turn, is manifested in a reduced loaf volume and lack of fluffiness of bread. Nowadays, there is a growing consumer interest in bakery products that offer health benefits as a result of the presence of bioactive components (Haros et al., 2006). As pointed out by Marquart et al. (2002), whole-grain wheat flour presents certain nutritional ad- vantages over refined wheat flour, as during the milling process, some nutrients, such as fibres, proteins and vitamins, are retained in the bran and germ fraction.

Bioactive compounds in whole grains can act independently or synergistically to reduce the risk of various diseases. Phenolic compounds present antioxid- ant activity and reduce the concentration of low density cholesterol in the blood (Menga et al., 2010; Schmiele et al., 2012). The anticarcinogenic and antioxidant effects of phytic acid is considered to be an active component with anticarcino- genic effects, protecting the tissues against oxidative reactions (Buri et al., 2004; Wu et al., 2009). Besides, the phytosterols present in the germ, are also related to a reduction in the risks of certain types of cancer (Simha, 2005). Fibres in- crease faecal volume and thus reduce its permanence time in the intestine, which in turn, reduces the risk of colon cancer. Fibers retard digestion and nutrient absorption, decreasing the glycaemic index (Buri et al., 2004).

2.4 Production and Productivity of Wheat in Ethiopia

The major types of wheat grown in Ethiopia consist of: Bread wheat (*Triticum aestivum*), Durum wheat (*Triticum turgidum durum*) and Emmer wheat (*Triticum turgidum dicoccoides*). Emmer wheat is the wild progenitor of the domesticated durum and bread wheat varieties. Bread wheat account for about half of the area planted, and is generally grown in the highland and semi-highland areas of the

Oromia, Tigray, SNNP, and Amhara regions. Durum wheat covers about 40% of the national wheat area. A small amount of emmer wheat is also grown, primarily in the Oromia region (Bergh et al., 2019). Emmer wheat is commonly used in the form of different food preparations that are traditionally recommended for mothers as a special diet after child birth and used for healing of broken bones faster in Ethiopia (Melese et al., 2016). The main wheat growing areas of Ethiopia are the highlands of the central, south-east and northwest parts of the country. In terms of regional contribution, the production of wheat from Oromia (57.5%), Amhara (30.25%), SNNP (7.3%) and Tigray (4.6%) and (0.35%) from the other region (Central Statistical Agency, 2018). According to CSA, there are 4.2 mil- lion wheat farmers in Ethiopia, and live in Oromia (40.6%), Amhara (39%), SNNP (12.47%), Tigray (7.4%) and less than 1% of wheat farmers live in other regions of Ethiopia (Central Statistical Agency, 2018). In the same year, the av- erage largest wheat area per farm was 0.43 ha/farmer in Oromia region where as the smallest was recorded in Tigray (0.19 ha/farmer). The majorities of the farm- ers are smallholder farmers; and are producing mostly for own consumption and supplying only small marketed surplus (Kelemu and Negatu, 2016). Although wheat production in the country is dominated by smallholders, 3-5% of wheat production land is cultivated by commercial farms (Minot et al., 2019). To in- crease wheat production and productivity and thereby to substitute importation, the Ministry of Agriculture (MoA), in collaboration with its key stakeholders, has recently launched an initiative to produce wheat in three lowland basins of the country, namely Awash (Oromia and Afar regions), Wabeshebelle (Somali Region), and Omo (SNNP) basins. In those locations, wheat production was not previously practiced but demonstrated to be successful during 2018/2019 (personal communication).

2.5 Distribution of Wheat Production in Ethiopia

The main factors influencing the distribution of wheat production in Ethiopia are rainfall and altitude. Wheat grows best at temperatures between 7°C and 21°C and with rainfall between 750 mm/year and 1600 mm/year. Since altitude strongly influences the temperature in Ethiopia, most wheat is grown at an alti- tude of 1500 meters above sea level and above. For this reason, wheat is grown on the central plateau in the regions of Oromia, Amhara, Tigray, and the SNNP. In fact, less than 1 percent of the wheat area is outside these four regions (Central Statistical Agency, 2018). Wheat yields are highest in Oromia (3.27 t/ha), which has the important wheat surplus zones of Bale and Arsi with prime growing con- ditions. Wheat yields are lower in SNNP (2.93 t/ha) and Amhara (2.79 t/ha). In Tigray, wheat yields are just 2.18 t/ha, as a result of the low rainfall and poor soils in some parts of the region. As would be expected, wheat area roughly de- termines wheat production, although there are some variations because of yield differences. For example, Oromia accounts for 40.6 percent of production, which is even more than its share of area because of the relatively high yields in that region. In contrast, Amhara represents 39 percent of production, somewhat be- low its share of the national wheat area. SNNP account for just 12.47percent and Tigray account for just 7.4 percent of the national wheat production (Central Statistical Agency, 2018).

2.6 Wheat varieties and Production in Ethiopia

One of the most important inputs in agriculture is seed. Seeds form the foundation of all agriculture. Without seeds there is no next season's crop. The genetic traits embodied within seeds reflect and determine the nature of farming systems dependent on them. The genetic and physical characteristics of seed determine the productivity in line with the use of other agricultural inputs and improved cultural practices within the farming system. Improving the genetic and physical properties of seed can trigger yield increase and lead to improvement in the ag- ricultural production and food security. In order for seed to act as a catalyst in agricultural transformation, however improved seed has to be made available to a broad base of farmers on continuing base. Many released varieties have never been widely disseminated (Walelign, 2008). The use of good quality seed of adopted and improved varieties is widely recognized as fundamental to ensure increased crop production and productivity. This fact is even more important in view of the increasingly diminishing area of cultivable land, declining soil fertility and ever-growing population; those facts increase the importance of pro- motion and use of good quality seed as a means to intensify food production. The potential benefits from the distribution of good quality seed of improved varieties are enormous, and the availability of quality seed of wide range of vari- eties and crops to the farmers is the key to achieve food security. Enhanced pro- ductivity, higher harvest index, reduced risks from pest and disease pressure, and higher incomes are some of the direct benefits potentially accrued to the farmers (Hughes, 2008). Basic seed for cereals is produced by respective research centers of EIAR and RARIs, the ESE, OSE and ASE, and licensed private seed companies. Seed producers are both public and private. The public seed production is dominated by Ethiopian Seed Enterprise (ESE) and since 2008 regional seed enterprises (RSEs) have come into the picture, at present there are two RSEs, Oromia Seed Enterprise (OSE) and Amhara Seed Enterprise (ASE). There are about 30 licensed private seed companies mainly involved in the production of seed (Alemu, 2011). The agricultural research system has been engaged in ad- aptation and generation of different improved varieties for most of the cereal crops. Since the start of formal crop improvement programmes in early 1950s, there has been strong exchange of cereal germ plasm especially through a close collaboration with International Agricultural Research Institutes (CGIAR cen- ters). For example, the Ethiopian wheat and maize improvement programmes has been collaborating with the International Maize and Wheat Improvement Center (CIMMYT), which has resulted in release of considerable number of varieties. The supply of any seed material depends on the availability of seed from the formal and the informal sectors and their ability to develop and provide seeds of the cultivars needed by the local producers. The Ethiopian formal seed sector is composed of the Ethiopian Institute of Agricultural Research (EIAR) and Universities (as crop breeding bodies) and the Ethiopian Seed Enterprise (ESE) (as seed multiplier and supplier). Unlike the formal sector where there is clear distinction between cultivar development and seed production and supply, in the informal seed sector both, the production and the supply ends are linked, as farmers are the ones who manage both. It is largely recognized in Ethiopia that farmers can obtain seed from the formal (seed companies/enterprises, agricultural research centers and universities) as well as the informal (local or traditional including farmers' saved seed, local markets exchanges, etc. (Molla, 2006). The national wheat area coverage is over 1.02 million hectares from which 14.1 million quintals are produced annually (Legesse et al., 2003). Wheat is one of the major cereal crops grown in Ethiopia. It is grown in the highlands at altitudes ranging from 1500 masl to 3000 masl, situated between 6-16^{o} N and 35- 42^{o}E; however, the most suitable agro-ecological zones for wheat production fall between 1900 and 2700 masl where the annual rainfall ranges between 600 and 2000 mm. Small-scale farmers who rely on rainfall and traditional methods of production are the main wheat producers in Ethiopia (Molla, 2006). It is grown successfully under a wide range of soil conditions, but it is best adapted to fertile, well-drained silt and clay loam soils. It can also be grown successfully under a wide range of rainfall and temperature conditions. In addition, it can withstand areas quite well; yet it grows successfully in hot climates if the humidity is not too high. In Ethiopia, there are two types of wheat grown: bread wheat (*Triticum aestivum*) and durum wheat (*Triticum durum*). Durum wheat is indigenous and the most dominant type of wheat grown, while, bread wheat is believed to be of recent introduction, perhaps brought-in by Portuguese explorers in the 18th century (Arega, 2009).

2.7 Physicochemical Characterization

The physical characteristics of grain are important as they are indicative of potential processing quality. In many countries, physical characteristics are used to determine how a grain will be segregated and stored. Wheat quality can best be described in terms of end-use, milling, and baking & rheology. Main physical properties of wheat that influence quality of wheat are grain weight, hardness, grain size & diameter, and color (Kent, 1994).

Protein is the component in wheat flour that makes the greatest contribution to the typical flour properties. Wheat proteins are responsible for the unique Visco - elastic properties of bread dough (Sluimer, 2005). Kyomugisha (2002) reported that the protein content of wheat is highly affected by environmental conditions, grain yield and available nitrogen as well as the variety genotype. The percent- age of grain protein may be considered as a useful criterion for establishing the economic value of wheat. Wheat gluten is the main flour component responsible for bread quality. Gluten, the protein of wheat, is a gray, tough, elastic sub- stance, insoluble in water. On account of its great power of expansion, it holds the gas developed in bread dough by fermentation, which otherwise would es- cape (Schoenfeld and Ioannidis, 2013). The protein content of wheat varies from 8 to 16%, depending on variety and environmental factors such as soil type and location (Cauvain et al., 2007).

Technological quality of wheat is determined by the sum of different flour prop- erties which influence the properties of the dough and its behavior during pro- cessing and ultimately the final product. It is determined by various chemical, physical and rheological tests (Živančev et al., 2009). The protein content and structure are the most important factors determining the quality of the flour where higher protein content causes higher quality of the final product (Unbehend et al., 2003). The rheological evaluation of wheat flour is of vital importance to the bakery industry, helping to predict dough processing characteristics and final product quality (Haros et al., 2006).

The brightness of white flour is important to both millers and their customers. UK millers examine the natural pigmentation of the flour and use a variety of techniques to measure this. Bright white flour is a positive attribute. Yellow is not desirable and grey flour is unacceptable.

3 Materials and Methods

3.1 Wheat varieties and source

Samples of 13 bread wheat (*Triticum aestivum*) varieties (Alidoro, Danda'a, Densa, Dinknesh, Gassay, Guna, King Bird, Lemu, Ogolcho, Senkegna, Shor- ima, Taye and Tsehaye) were collected from Adet Agricultural Research Center, Amhara Region Agricultural Research Institute (ARARI), Adet, Ethiopia. The varieties investigated have been released in the years shown in Table 1, although information regarding production, area coverage and distribution is not available to the best of my knowledge. The samples were harvested in the same year (2019/20), season, and location. The samples were packed in plastic bags and placed in cooling boxes during transportation to the laboratory in Bahir Dar Institute of Technology where it was stored in refrigerator at 4^{O}C until needed for analysis.

Table 1: Release date of wheat varieties

Variety	Year of release	Growth habit	Semidwarf (Rht gene)
Dinknesh	2007	Spring	Yes
Guna	2001	Spring	Yes
Alidoro	2007	Spring	Yes
Densa	2002	Spring	Yes
Shorima	2011	Spring	Unknown
Senkegna	2005	Spring	Yes
Ogolcho	2012	Spring	Yes
Danda	2010	Spring	Yes
Lemu	2016	No info	No info
Kingbird	2015	No info	No info
Tsehay	2011	Spring	Yes
Gassay	2007	No info	No info
Taye	2005	Spring	No

Source: http://http://wheatatlas.org/country/varieties/ETH/0

3.2 Experimental design

The experiment was conducted in a completely randomized design (CRD) of one factor (variety or flour particle size category). Measurements were made in triplicate or quadruplicate.

3.3 Data collected

3.3.1 Chemical characteristics of wheat varieties

Protein, starch, moisture, wet gluten, and Zeleny values of wheat grains were determined using USDA-GISPA (2006) approved method: NIRT (Near Infrared Transmittance) using Infratec 1241 grain analyzer (Foss Analytical, 3400 Hilleroed, Denmark). The analysis was carried out at the grain quality laboratory of the Amhara Region Agricultural Research Institute, Bahir Dar, Ethiopia. Near-Infrared Transmittance (NIRT) determination is a spectrophotometric determination of a sample's constituents by measuring the amount of light transmitted through a sample at specific wavelengths in the near-infrared region of the spectrum. The NIRT grain analyzer measurements are made in a transmittance mode using the lower wavelength range, 570 – 1050 nm, (unlike the reflectance measurements between 1100 – 2500 nm). The higher energy level of the light in the lower range allows for deeper penetration into the kernels, thus not only the surface but also the inner part of the kernel is measured. All of this allows a larger sample volume when transmittance is used, thereby giving a superior representation of the sample analyzed (FOSS, 2012).

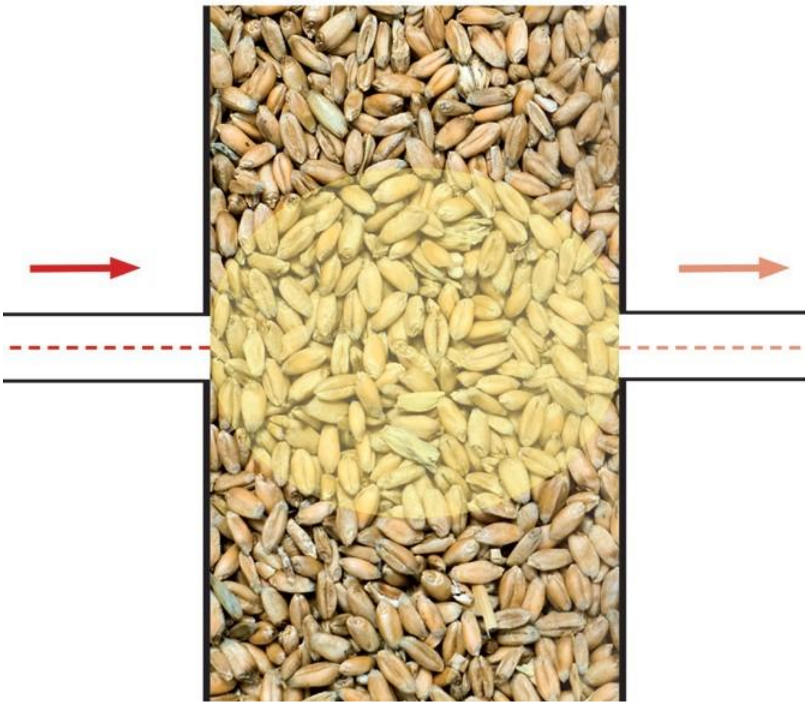

Figure 2: Transmittance of near infrared radiation through wheat grain. *Source:* FOSS (2012)

About 500 grams of wheat was cleaned by using a combination of sieves and winnowing to free the wheat from any dockage and other foreign material. All of the cleaned wheat was poured into the hopper of the NIRT grain analyzer. The wheat grain was then allowed to pass through the 18 mm sample cell where it interacts with NIR radiation (Figure 2). Results were displayed on the screen as average of the entire sample.

3.3.2 *Single kernel characteristics of wheat varieties*

Kernel hardness index, kernel weight and kernel diameter were determined us- ing Single Kernel Characterization System (SKCS, Perten Instruments North America Inc., Springfield, Illinois, USA) based on development by Martin et al. (1993) and previously published procedure (Kalsa et al., 2019). The wheat ker- nel samples were cleaned by removing broken kernels, weed seeds, and other foreign material, and 12 to 16 g of sample was used for SKCS analysis. The instrument analyzes 300 kernels individually for kernel weight, diameter, moisture content, and hardness. The SKCS analysis was carried out at the Food Science Laboratory in the Kulumsa Agricultural Research Center. The design principle of the SKCS 4100 (Figure 3) is based on sequential separation by means of an indented wheel (singulator) with the aid of a vacuum, of a sample of grain into individual seeds that are individually weighed and then crushed between a toothed rotor and a crescent at the rate of two seeds per second. The seed diameter and moisture content are also recorded. The sequence of measurements performed by the SKCS 4100 includes weight (mg) measured as the electrical force required to return the boat, into which the individual seeds are dropped, to its original horizontal position. This force is proportional to the mass of the seed. The measurement is calibrated against mass determined using an analytical balance for single seeds with weights of 12–80 mg (Osborne and Anderssen, 2003).

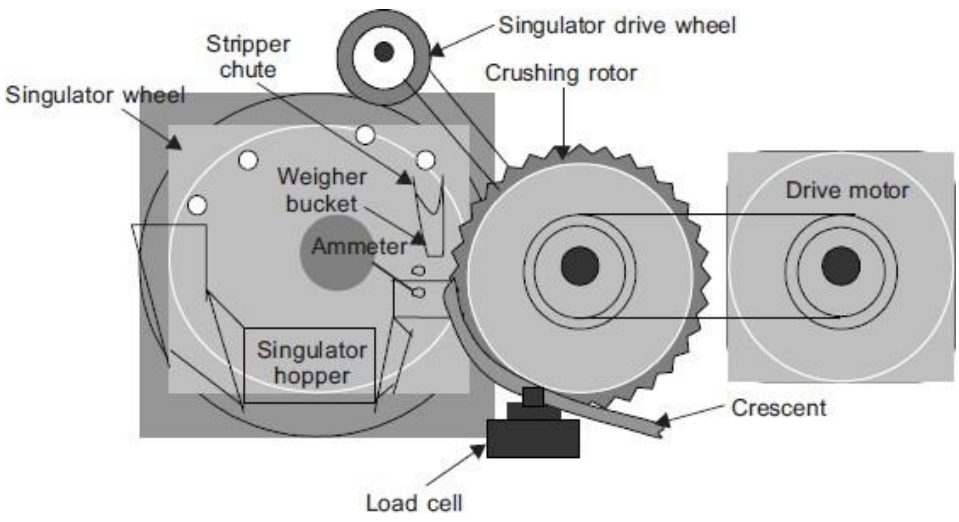

Figure 3: Operating mechanism of Single Kernel Characterization System (SKCS 4100). *Source:* Osborne and Anderssen (2003)

Diameter (mm) is measured as the size of the gap formed between the crescent and the rotor at engagement. The position of the engagement, and thereby the size of the gap, is determined by the number of data scan intervals performed between engagement and exit. Moisture content (%) of each seed is regressed with the (natural) logarithm of electrical conductance and force terms (Osborne and Anderssen, 2003).

For analysis procedures requiring ground samples, wheat grain was ground into flour using bench- top laboratory hammer mill (Sinograin, Sichuan, China) with an installed sieve of 0.5 mm (500 µm) size.

3.3.3 *Milling of grain into flour*

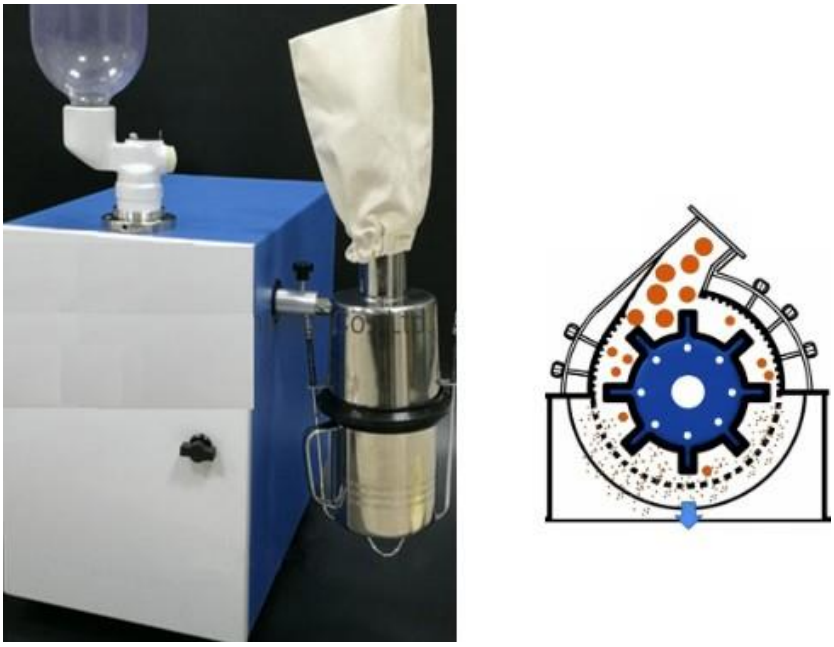

Figure 4: Laboratory hammer mill

The hammer mill is a grinding chamber containing a horizontal rotating shaft on which hammers are mounted (Figure 4). The hammers are fixed to the central rotor. The rotor is spun at a high speed inside the grinding chamber while wheat grain is fed into a feed hopper. The grain will crush, shatter, or pulverize upon hammer impact, collisions with the walls of the grinding chamber, and particle on particle impacts. Perforated metal screens covering the discharge opening of the mill retain coarse material for further grinding, while allowing properly sized materials to pass as finished product.

3.3.4 *Farinograph properties of wheat varieties*

Water absorption, dough development time, dough stability, and degree of softening of whole-wheat flour were measured according to AACC (2011) us- ing the 300 g bowl of an electronic Farinograph (Figure 5) (toposun, Model: TPS-JMLD, Shanghai, China).

Farinographs measure and record the resistance to deformation of a flour/water dough against the mixing action of blades over time and at a specific speed (rpm) and temperature.

Figure 5: Farinograph instrument installed in the food safety laboratory, Institute of Technology, Bahir Dar University

Dough resistance is expressed as motor torque, in dimensionless units known as

Farinograph or Brabender Units (FU or BU). During the test, the dough is developed and further broken down. The farinograph is used to estimate the water absorption of flours, the relative mixing time, the stability to overmixing, and rheological properties of the dough during mixing. Farinograph water absorp- tion indicates the amount of water to be added to a flour in order to bring the consistency of the dough to 500 farinogram units (FU, Figure 6).

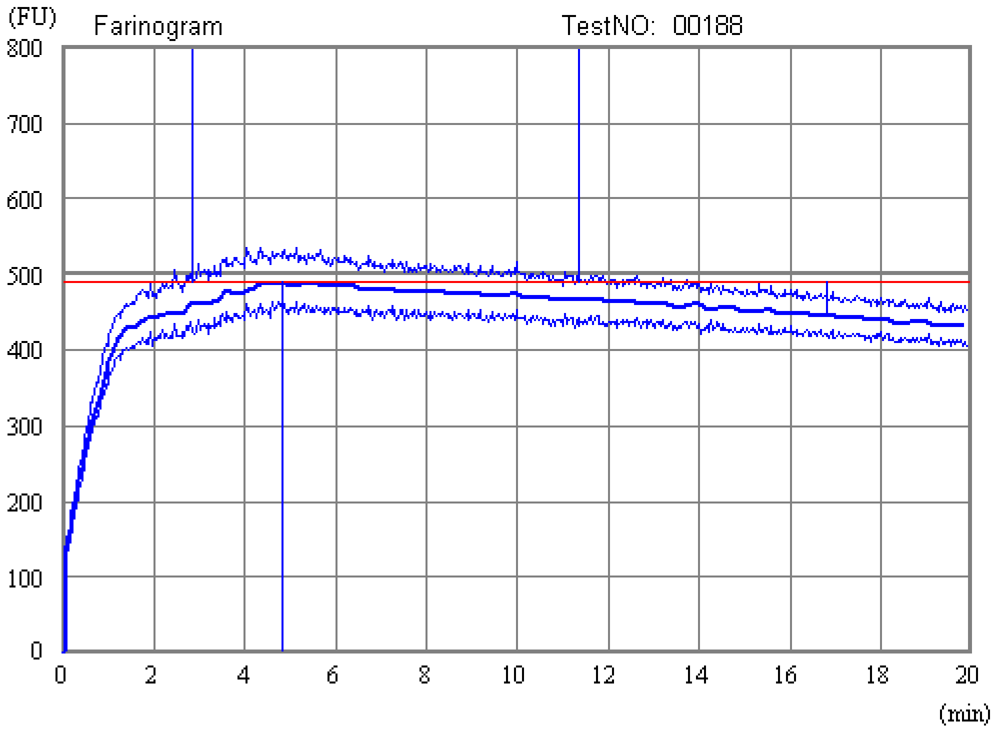

Figure 6: Farinogram showing key data points of farinograph dough analysis.

Farinograph is used to estimate the water absorption of flours, the relative mixing time, the stability to overmixing, and rheological properties of the dough during mixing. Dough development time provides the time (in minutes) between the origin (time zero) of the curve and its maximum (peak). Stronger flours with higher protein content have a longer development time than weaker flours with equivalent particle size distribution. Stability is the difference in minutes between the arrival time (the time at which the top of the curve reaches the 500-FU line) and departure time (the time at which the top of the curve falls below the 500-BU line). It is a measurement of how well a flour resists overmixing. Stronger flours are usually more stable than weaker ones. Degree of softening of dough meas- ures the difference in FUs between the top of the curve at the optimum and the point on the curve 12 minutes later (Figure 6).

3.3.5 *Particle size distribution of flours of wheat varieties*

Particle size distribution was carried out by sieve analysis (FRITSCH GmbH, Oberstein, Germany) shown in Figure 7. The sieve shaker separates wheat flour particles by passing them through a series of sieves stacked in the order of decreasing aperture size from top to bottom. The sieves used were 500 µm, 425 µm, 355 µm, 250 µm, 180 µm, 150 µm, 125 µm, 90 µm, and the bottom pan (< 90µm). The empty weight of each sieve was recorded before sieving. To assist the flow of flour through the stack of sieves, a steel ball (about 5 mm diameter) were placed on each sieve. The impact force the steel balls exert on the sieve surfaces prevented the clogging of sieve apertures and the caking of flour particles. The stack of sieves was shaken for 10 min, after which the mass of flour retained on each sieve was recorded. Percentage mass fraction was calculated by dividing the mass of flour retained on a sieve with the mass of the whole grain flour, and multiplying by 100.

Figure 7: Particle size analyzer.

3.3.6 *Determination of color of flours*

Color of flour fractions was determined using Spectrophotometer (Konica-Minolta, Model CM-600d, Japan). The spectrophotometer (Figure 8) displayed values for L* (brightness or whiteness), a* (redness to greenness) and b* (yellowness to blueness). In the present study, the L*- value was the most important measurement in relation to our objectives. With the objective to offset the in-

Figure 8: Spectrophotometer used for flour color measurement.

herent color differences among varieties, a change in color of flour of a given particle size range was calculated relative to the color of its whole grain:

$$\text{Relative color change \%} = \frac{L^*PS - L^*WGF}{L^*WGF} \times 100,$$ where

L*PS = L* value of a given particle size, and

L*WGF = L* value of whole grain flour.

3.4 Data analysis

A triplicate/quadruplicate data was analyzed using one-way ANOVA. When ANOVA shows significant difference among the treatments ($P < 0.05$), treatment means were separated using Tukey's Honest Significance Difference (HSD) test at 5% level of significance. Tukey's HSD was preferred to Least Significant Difference (LSD) test because of the fact that HSD is a better option when minimizeing family wise error rate (Type I error) is targeted. Correlations were conducted using the Pearson method. Data were analyzed using R version 3.5.0 (R Core Team, 2018). Graphs were plotted using Sigma Plot, version 12.5 (Anonymous, 2013).

4 Results and discussion

4.1 Physicochemical characteristics

The chemical characteristics of the bread wheat varieties are presented in Table 2. The chemical properties differed significantly ($P < 0.05$) among the varieties of wheat. Protein content was in the range of 10.3 to 13.2%. The variety *Dinknesh* showed the highest protein content, whereas *Taye*, had the least protein among the tested varieties. Starch content was in the range between 64.8 – 68.3%, with the variety *Dinknesh* exhibiting the lowest starch content and that of *Gassay* the highest starch content. Similarly, wet gluten and zeleny sedimentation values range from 20.7 to 29.3% and 24.9 to 39.5%, respectively. Highest and lowest wet gluten content was shown by the varieties *Dinknesh* and *Taye*, respectively. *Guna* showed the highest zeleny sedimentation while *Tsehaye* exhibited the low- est value. Color (L* value) of the whole-grain flour ranged from 77.0 (*Guna*) to 122.9 (*Shorima*) (Table 2).

Table 2: Physicochemical characteristics of the wheat varieties (Mean ± SD)

Variety	Moisture (%)	Protein (% db.)	Starch (%db.)	Wet Gluten (%)	Zeleny (%)	Flour color (L*- value)
Dinknesh	12.3 ± 0.2[c]	13.2 ± 0.3[a]	64.8 ± 0.1[e]	29.3 ± 0.9[a]	35.4 ± 1.2[b]	118.5 ± 0.7[b]
Guna	12.3 ± 0.2[c]	12.5 ± 0.1[b]	66.3 ± 0.2[d]	27.5 ± 0.1[b]	39.5 ± 0.5[a]	77.0 ± 0.3[h]
Alidoro	11.7 ± 0.1[d]	12.2 ± 0.2[bc]	67.6 ± 0.5[ab]	26.8 ± 0.4[bc]	30.6 ± 1.3[d]	118.6 ± 0.2[b]
Densa	12.3 ± 0.1[c]	12.1 ± 0.2[bc]	66.0 ± 0.5[d]	26.2 ± 0.6[bc]	34.7 ± 0.9[b]	78.2 ± 0.4[gh]
Shorima	12.4 ± 0.1[bc]	11.9 ± 0.2[c]	67.8 ± 0.2[ab]	25.8 ± 0.8[c]	33.4 ± 0.4[cd]	122.9 ± 0.6[a]
Senkegna	12.1 ± 0.1[cd]	11.8 ± 0.2[cd]	67.3 ± 0.3[bc]	25.5 ± 0.6[c]	31.9 ± 0.5[de]	81.7 ± 0.4[cd]
Ogolcho	10.8 ± 0.3[f]	11.4 ± 0.3[de]	66.4 ± 0.4[cd]	21.4 ± 1.0[de]	30.2 ± 0.5[e]	79.8 ± 0.3[ef]
Danda	10.2 ± 0.1[g]	11.3 ± 0.2[e]	66.2 ± 0.2[d]	22.2 ± 0.5[de]	30.6 ± 0.7[e]	81.1 ± 0.3[de]
Lemu	10.9 ± 0.2[f]	11.3 ± 0.1[e]	67.3 ± 0.3[bc]	25.5 ± 0.6[c]	31.9 ± 0.5[de]	122.6 ± 0.4[a]
Kingbird	11.7 ± 0.1[e]	10.9 ± 0.1[ef]	67.7 ± 0.4[ab]	21.4 ± 0.7[de]	30.5 ± 0.2[e]	80.2 ± 0.8[ef]
Tsehay	12.9 ± 0.1[a]	10.8 ± 0.1[fg]	68.0 ± 0.4[ab]	22.6 ± 0.7[d]	24.9 ± 0.4[g]	79.4 ± 0.2[fg]
Gassay	12.7 ± 0.2[ab]	10.5 ± 0.2[fg]	68.3 ± 0.6[a]	21.7 ± 0.7[de]	26.0 ± 1.0[fg]	122.8 ± 0.4[a]
Taye	11.6 ± 0.1[e]	10.3 ± 0.3[g]	67.8 ± 0.2[ab]	20.7 ± 0.3[e]	27.4 ± 0.7[f]	82.9 ± 0.6[c]
$F_{12, 39}$	**125.3**	**70.8**	**31.8**	**77.3**	**75.4**	**6416**
P-value	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

The technological performance of wheat grain is predominantly influenced by the quality and quantity of protein. Protein content is a primary factor used to characterize wheat. However, protein content is not enough to assess the functional property of wheat grain. Gluten properties need to be considered along with the protein content to judge the technological quality of wheat (BAŞLAR and Ertugay, 2011). The protein content of the tested wheat varieties were higher than the minimum 11.0% limit set by WFP (2013), except for the varieties *King Bird*, *Tsehaye*, *Gassay*, and *Taye*, which had lower protein than the 11.0% limit. Additionally, the wet gluten content of the tested wheat varieties of *Dinknesh*, *Guna*, *Alidoro*, *Densa*, *Shorima*, *Senkegna*, and *Lemu* fulfilled the 25% minimum wet gluten content, while *Ogolcho, Danda'a, King Bird, Tsehaye, Gassay*, and *Taye* had wet gluten contents below that limit (WFP, 2013). However, the zeleny sedimentation values of the tested wheat varieties were found to comply with the 25% minimum level, except for the variety *Tsehaye* (ICRC, 2020).

The single kernel characteristics, kernel weight, hardness index, and diameter were significantly affected by variety (Table 3). Kernel weight ranged from 28.12 g for the variety *Lemu* to 38.17 g for *Dinknesh*. Highest grain hardness index was recorded by the variety *Guna* (70.1%), whereas the lowest hardness was observed by *Taye* (19.1%). Similarly, grain diameter was in the range from 2.52 (*Lemu*) to 2.89 (*Dinknesh*). Grain moisture ranged from 10.2% (*Danda*) to 12.9% (*Tsehaye*).

The correlation among the different physicochemical variables of wheat is shown in Table 4. Protein showed a significant and positive correlation with zeleny sedimentation value, wet gluten content, and kernel hardness index, while it did a significant and negative correlation with starch content. Kernel weight showed a significant and direct relationship only with kernel diameter. Kernel weight and kernel diameter were not significantly correlated with protein and starch contents (Table 4).

Table 3: Single kernel characteristics of the wheat varieties (Mean ± SD)

Variety	Kernel weight(gm)	Hardness index (%)	Diameter(mm)
Guna	34.82 ± 0.89[bc]	70.1 ± 1.5[a]	2.73 ± 0.04[b]
Alidoro	33.63 ± 1.3[bcd]	30.8 ± 1.2[h]	2.67 ± 0.03[bc]
Densa	29.8 ± 0.4[gh]	65.0 ± 0.5[b]	2.53 ± 0.02[de]
Shorima	33.27 ± 0.40[cd]	30.1 ± 0.7[h]	2.74 ± 0.04[b]
Senkegna	30.20 ± 0.05[fg]	47.5 ± 0.5[de]	2.62 ± 0.06[cd]
Ogolcho	31.21 ± 0.53[efg]	47.2 ± 0.1[de]	2.56 ± 0.03[cd]
Danda	35.48 ± 0.96[b]	47.8 ± 2.0[de]	2.87 ± 0.04[a]
Lemu	28.12 ± 0.44[h]	46.4 ± 0.3[de]	2.52 ± 0.05[e]
Kingbird	31.86 ± 0.51[def]	35.4 ± 1.2[g]	2.68 ± 0.02[bc]
Tsehay	34.03 ± 0.77[bc]	43.7 ± 1.2[f]	2.59 ± 0.03[cde]
Gassay	33.00 ± 1.04[cde]	55.2 ± 0.6[c]	2.69 ± 0.03[bc]
Taye	30.83 ± 0.28[fg]	19.1 ± 1.2[i]	2.68 ± 0.04[bc]
$F_{12, 39}$	**43.3**	**488.4**	**30.0**
P-value	**< 0.001**	**< 0.001**	**< 0.001**

A multiple linear regression was calculated to predict wet gluten and zeleny sedimentation values of wheat grains based on their protein content and kernel hardness values of the wheat varieties. Wet gluten content and Zeleny sedimentation value of the wheat grains can be predicted using a linear regression model (Table 5).

Table 4: Correlation coefficients among physicochemical parameters.

Variable	Protein (%)	Kernel weight (mg)	Hardness index (%)	Diameter (mm)	Starch (%)	Wet gluten (%)
Protein (%)						
Kernel weight (mg)	0.30[NS]					
Hardness index (%)	0.35[*]	0.09[NS]				
Diameter (mm)	0.20[NS]	0.82[***]	-0.08[NS]			
Starch (%)	-0.63[***]	-0.3[NS]	-0.49[***]	-0.26[NS]		
Wet gluten (%)	0.69[***]	0.22[NS]	0.40[*]	0.11[NS]	-0.24[NS]	
Zeleny sedimentation	0.82[***]	0.11[NS]	0.47[**]	0.17[NS]	-0.58[***]	0.56[***]

Grain hardness is used as key determinant to classify wheat types and end use quality (Campbell et al., 1999; Morris, 2002). The fact that protein content showed a significant positive correlation with kernel hardness index, wet gluten,

Table 5: Multiple linear regression analysis of the effects of protein and kernel hardness on wet gluten and zeleny values.

Variable	Wet gluten (%)	Zeleny sedimentation
Intercept	-3.1 ± 5.0^{NS}	$-13.6 \pm 5.3^{*}$
Protein (%)	$2.3 \pm 0.5^{***}$	$3.7 \pm 0.5^{***}$
Hardness index (%)	0.04 ± 0.2^{NS}	$0.06 \pm 0.03^{*}$
Adj. R^2	**0.47**	**0.69**
$F_{2, 35}$	**17.7**	**41.8**
P-value	**< 0.01**	**< 0.001**

and zeleny sedimentation (Table 4) is in good agreement with the report made by Kaur et al. (2013) and Pasha et al. (2007). The inverse relationship between protein and starch contents observed in the current investigation (Table 4) is in line with Maningat et al. (2009). In this regard, the variety *Dinknesh* had the highest protein, wet gluten, and the least starch, whereas its zeleny value belongs to varieties with highest values. On the other hand, varieties such as *Taye exhibited* the least protein, wet gluten, zeleny, and hardness values. An SKCS hardness index value of less than 10 indicates very soft wheat. Results of 40 - 46 would be intermediate between soft and hard types and values above 46 are termed hard. Biscuit wheat needs to be soft milling (SKCS typically 10 - 45), whereas bread wheat should be hard milling (SKCS typically 50 - 80) (McVittie et al., 2005).

4.2 Particle size distribution and flour color

Table 6 depicts the flour lightness as affected by particle size of the whole wheat flour. The color of flour was significantly ($P < 0.05$) affected by particle size of flour, regardless of variety. In all cases, the color tended to be lighter as the particle size decreased (Table 6).

Table 6: Effect of particle size on color of flour for each variety.

	Wheat variety												
Sieve size (μm)	**Alidoro**	**Danda**	**Densa**	**Dinknesh**	**Gassay**	**Guna**	**Lemu**	**Ogolcho**	**Senkegna**	**Shorima**	**Taye**	**Tsehaye**	**King bird**
500	99.1±1.0^{f}	72.7±1.4^{f}	65.7±0.5^{g}	100.1±0.5^{f}	108.8±0.5^{e}	63.2±0.6^{h}	109.1±1.3^{f}	69.6±1.2^{e}	71.2±0.7^{f}	107.3±2.4^{f}	72.8±1.2^{e}	64.1±0.4^{h}	72.5±1.0^{e}
425	99.9±1.1^{f}	72.6±0.2^{f}	66.0±1.1^{g}	99.1±0.5^{f}	108.8±0.2^{e}	63.7±0.3^{gh}	110.1±1.0^{f}	71.3±0.7^{de}	68.9±0.9^{g}	108.0±1.1^{ef}	72.2±0.3^{e}	63.9±1.0^{h}	71.8±0.3^{e}
335	101.9±0.7^{f}	73.3±0.4^{f}	69.7±0.4^{f}	100.4±0.7^{f}	108.3±1.4^{e}	65.0±0.6^{g}	108.1±0.9^{f}	70.1±1.8^{e}	70.1±0.8^{fg}	107.8±0.3^{f}	71.9±1.1^{e}	66.0±0.6^{g}	72.7±0.3^{e}
250	105.8±1.0^{e}	77.4±1.3^{e}	71.6±1.3^{ef}	105.6±0.4^{e}	110.9±0.6^{e}	69.0±0.6^{f}	113.5±0.2^{e}	73.0±2.7^{de}	73.5±0.4^{e}	111.9±1.5^{e}	75.6±0.7^{d}	71.2±0.8^{f}	74.1±0.9^{de}
180	107.9±1.7^{e}	80.2±0.5^{d}	73.8±1.9^{e}	113.0±2.4^{d}	117.6±2.2^{d}	74.2±0.4^{e}	118.1±1.5^{d}	74.7±0.7^{d}	78.6±0.2^{d}	119.2±1.4^{d}	79.6±1.0^{c}	77.8±0.6^{e}	76.3±0.8^{cd}
150	114.2±1.7^{d}	78.3±0.8^{de}	78.5±1.0^{d}	117.9±1.6^{c}	123.5±1.7^{c}	77.5±1.0^{d}	122.3±0.3^{c}	78.5±0.6^{c}	83.3±0.2^{c}	123.0±2.4^{cd}	82.0±0.7^{c}	81.0±0.4^{d}	79.0±2.1^{c}
125	125.3±0.9^{c}	82.7±0.4^{c}	81.5±0.4^{c}	125.0±0.3^{b}	125.5±0.5^{c}	79.9±0.7^{c}	124.3±0.7^{c}	83.7±0.3^{b}	84.5±0.1^{c}	125.9±0.6^{bc}	87.0±1.1^{b}	83.5±0.6^{c}	82.9±0.6^{b}
90	130.2±0.3^{b}	86.3±0.1^{b}	84.6±0.5^{b}	131.1±0.3^{a}	131.7±0.3^{b}	84.6±0.8^{b}	130.8±0.5^{b}	85.7±0.4^{ab}	87.7±0.4^{b}	129.0±0.3^{b}	88.1±0.9^{ab}	86.1±0.4^{b}	87.7±0.2^{a}
< 90	136.7±0.6^{a}	89.7±0.1^{a}	88.2±0.2^{a}	132.3±0.5^{a}	136.4±0.3^{a}	88.0±0.2^{a}	135.7±0.4^{a}	88.8±0.4^{a}	90.5±1.1^{a}	136.0±0.3^{a}	90.5±0.6^{a}	89.5±0.5^{a}	88.5±1.2^{a}
$F_{8, 18}$	**500.5**	**216.8**	**204.4**	**511.1**	**286.2**	**723.4**	**394.6**	**105.5**	**490.6**	**172.6**	**194.4**	**754.2**	**129.8**
***P*-value**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

*Means followed by the same superscript letters in the same column are not significantly different at P=0.05.

Figure 9 highlights the changes in mass fraction and flour whiteness of each variety across three particle size groups, namely > 425 µm, 250-425 µm, and < 250 µm.

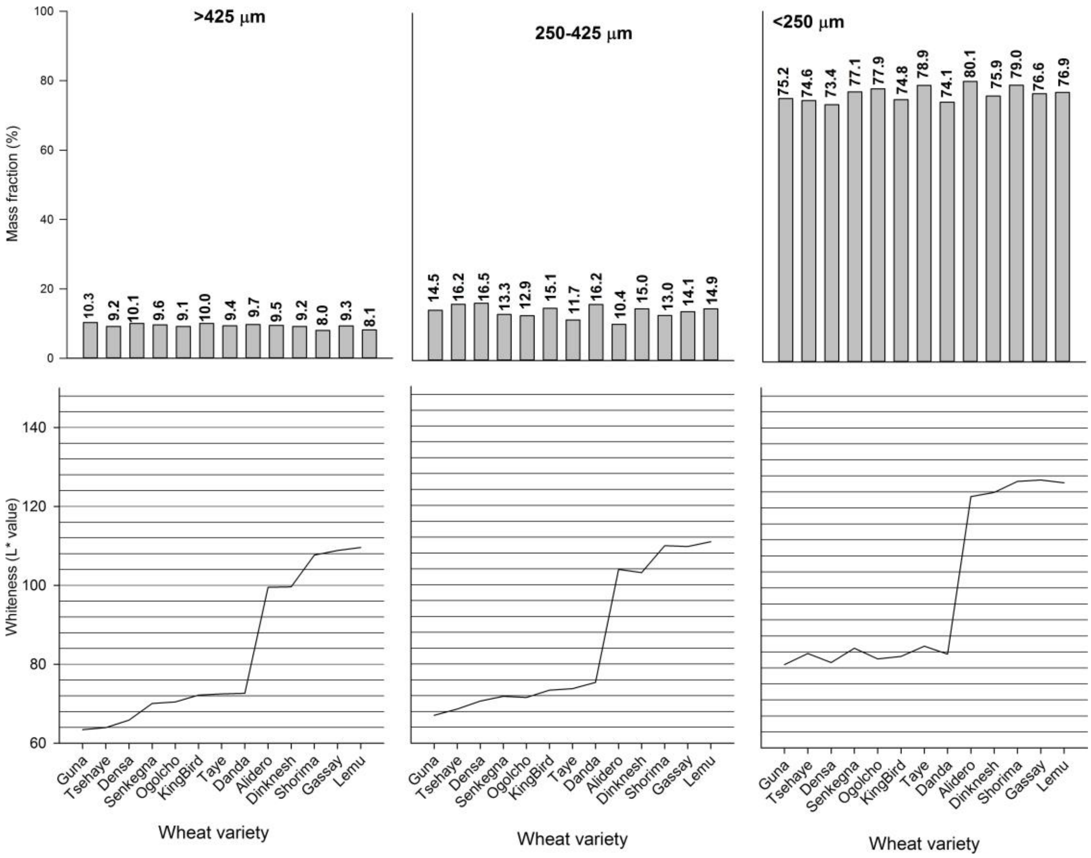

Figure 9: Mass fraction and color of flours of different particle size ranges of flour from different wheat varieties.

As flour particle decreased, a corresponding increase in mass fraction was observed (Figure 9). Although the direction of change in color was similar for all varieties, the magnitude of change showed differences among the variety because of the inherent differences in color. As one can see from Table 2, the wheat varieties were significantly different in flour color (in terms of lightness/darkness).

The colors of flour fraction of > 425 µm and 250-425 µm were darker than the whole grain flours of each wheat variety. However, the flour fraction with particle size of < 250 µm was lighter (whiter) than the whole grain flour regardless of wheat variety (Figure 10). Within each of the > 425 µm, 250-425 µm, and < 250 µm particle size groups, wheat variety affected flour color significantly with an $F_{12, 26}$-values of 31.4, 12.4, and 89.3, respectively, and *P*- values of < 0.001 in all the three cases. In the case of particle size > 425 µm, highest darkening (a negative relative percentage color change) was observed in the variety *Tsehaye* whereas varieties *Danda'a, Kingbird, and Lemu* showed least darken- ing compared to their whole grain counterparts. Similarly, in the 250-425 µm particle size category, the darkening of flour relative to the whole grain counter- part of each variety was highest in varieties *Dinknesh and Tsehaye* and lowest in that of *Danda* (Figure 10). A different direction of change of flour color was seen in the particle size category < 250µm. In this category, the most whitening of flour color, relative to the whole grain counterpart (relative change in color), was recorded in the variety *Tsehaye* while whitening was lowest in that of *Danda* (Figure 10).

Fractionating whole grain flour by particle size resulted in an increasing trend of flour whiteness as particle size was decreasing. Although this trend was observed in all varieties, the magnitude of change in whiteness differed across varieties. For example, *Tsehaye* variety was among the few varieties that achieved highest whiteness level in the < 250 µm category, while *Danda* of the same particle size category belonged to few other varieties that performed least in whiteness level. The larger flour fraction (> 250 µm) of the variety *Tsehaye* was significantly darker than the same flour fraction of the variety *Danda*, implying that the darker the flour of the larger particle size fraction is, the whiter will be the remaining flour with finer particle size (Figure 11). This partitioning of flour color

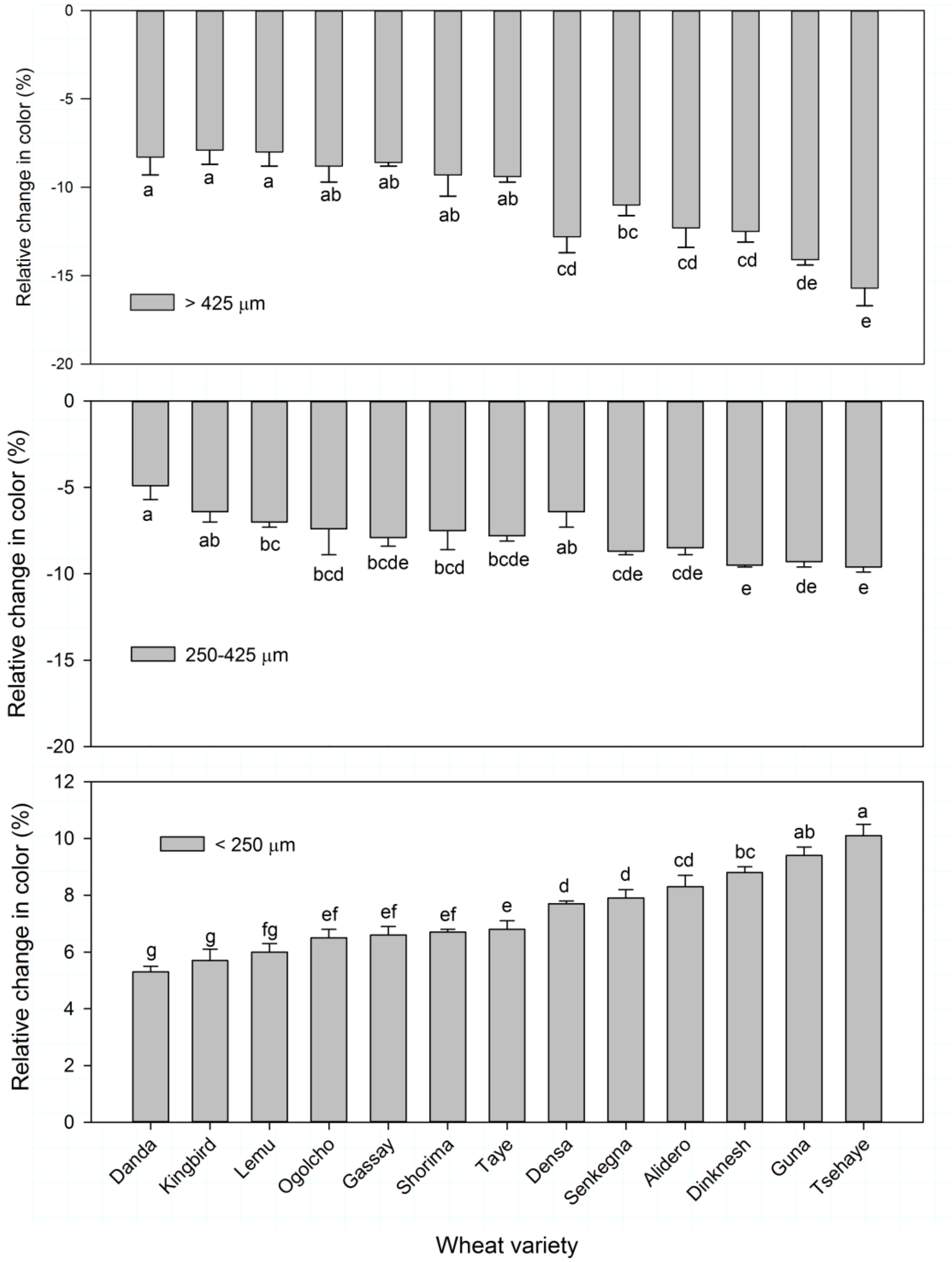

Figure 10: Relative change of flour color as a function of particle size.
Bars with the same letter(s) within each particle size category are not significantly different

across particle sizes, with finer components being whiter than the coarser ones, might be associated with the fact that bran components are generally less mellow compared to the endosperm particles. Thus, it is recognized that the darker bran components end up in the coarser fractions while more of the whiter endosperm tend to be easily pulverized. The browner (dark) color of bran fraction compared to the endosperm is recognized to be associated with the fact that the bran fraction of wheat seed contains higher concentrations of phenolic acids, flavonoids and yellow pigments (Žilić et al., 2012). Besides, differences in L*-value

of whole wheat flour among the tested varieties was highly significant (Table 1).

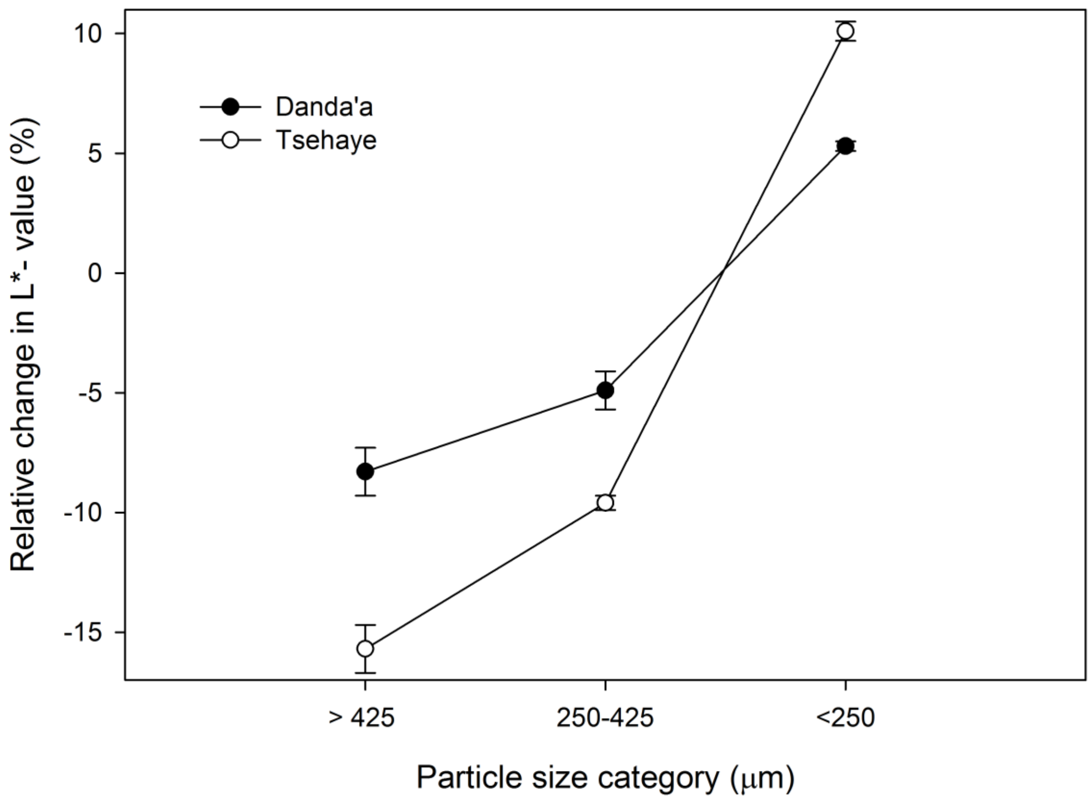

Figure 11: Comparison of two wheat varieties with highest and lowest relative color change values across particle size category

4.3 Farinograph properties

The farinograph properties of flour from the different varieties is shown on Table 7. The farinograph properties were significantly ($P < 0.05$) affected by wheat variety. Among the varieties tested, a higher water absorption was ob- served by the varieties *Guna*, *Densa*, and *Dinknesh*, whereas the variety *Alidoro* showed lower farinograph water absorption. Dough development time was in the range from 4.9 min (*Senkegna*) to 8.4 min (*Tsehaye*). Similarly, dough stability ranged between 4.2 min (*Dinknesh*) to 10.6 min (*Alidoro*). Regarding the degree of softening, it ranged from 36.3 FU to 83.0 FU observed by the varieties *Alidoro* and *Densa*, respectively.

Table 7: Farinograph properties of flour obtained from different wheat varieties.

Variety	Water absorption	Development time	Dough stability	Degree of softening
Guna	64.3 ± 0.2^{a}	6.9 ± 0.9^{ab}	6.2 ± 0.6^{de}	71.0 ± 7.6^{ab}
Densa	63.7 ± 0.5^{a}	6.9 ± 1.9^{ab}	6.7 ± 1.5^{bcde}	83.0 ± 8.5^{a}
Dinknesh	63.7 ± 0.4^{a}	5.0 ± 0.5^{b}	4.2 ± 0.4^{e}	55.3 ± 1.0^{bcd}
Shorima	60.0 ± 0.1^{b}	6.8 ± 0.4^{ab}	10.4 ± 1.4^{a}	37.7 ± 2.5^{d}
Danda	59.6 ± 1.0^{bc}	5.2 ± 0.2^{b}	8.5 ± 2.1^{abcd}	46.3 ± 10.6^{cd}
Kingbird	59.6 ± 0.3^{bc}	7.3 ± 0.3^{ab}	9.9 ± 2.2^{abc}	41.0 ± 7.9^{cd}
Tsehay	59.6 ± 0.5^{bc}	8.4 ± 1.1^{a}	7.5 ± 0.3^{abcde}	*
Senkegna	59.1 ± 0.4^{bc}	4.9 ± 0.5^{b}	5.1 ± 0.6^{de}	60.3 ± 10.4^{bc}
Ogolcho	59.0 ± 0.1^{bc}	6.5 ± 0.3^{ab}	8.7 ± 0.3^{abcd}	42.3 ± 1.2^{cd}
Lemu	58.8 ± 0.3^{bcd}	6.9 ± 0.4^{ab}	10.0 ± 1.3^{ab}	46.3 ± 6.4^{cd}
Taye	58.7 ± 0.1^{cd}	5.7 ± 0.6^{b}	6.3 ± 0.6^{cde}	53.7 ± 5.5^{bcd}
Alidoro	57.7 ± 0.1^{d}	6.1 ± 1.5^{ab}	10.6 ± 1.5^{a}	36.3 ± 2.1^{d}
$F_{11, 24}$	**88.3**	**4.2**	**9.1**	**12.4**
P-value	**0.000**	**0.002**	**0.000**	**0.000**

Means followed by the same letters are not significantly different ($P > 0.05$) by Tukey's HSD test.

* The farinograph recorder works for 20 minutes and Degree of Softening is the Farinogram Units recorded 12 minutes after Dough Development Time. For wheat flours having Dough Development Time of more than 8 minutes (like variety *Tsehaye*), the Degree of Softening cannot be recorded.

The varietal differences in farinograph properties observed among the varieties tested in the present study have significant implications in predicting technological properties, such as baking qualities. An acceptable farinograph water absorption of flours for baking bread is mostly higher or equal to 60% (Khan, 2016). In this regard, varieties such as *Guna*, *Densa*, *Dinknesh*, and *Shorima had* higher than 60% water absorption. The average dough development time of straight grade white flour (75% extraction) is suggested to be 8.3 min (Baker- pedia, 2020). However, the fact that Bakerpedia (2020) used a refined flour with less bran content than our whole grain flour might be the reason for the higher development time reported by those authors. The values of dough stability and degree of softening are generally acceptable when the former is higher and the latter is lower. Still they have more significance in providing information to ad- just mixing time. Generally, higher flour water absorption, slower development, and higher stability during mixing (relative to values among varieties) is desir- able to bakers (Iqbal et al., 2015; Sahin et al., 2019; Faměra et al., 2004; Barrera et al., 2007).

Water absorption showed a significant positive correlation with grain hardness ($r = 0.75$, $t = 6.6$, $P < 0.001$) and with protein ($r = 0.57$, $t = 4.1$, $P < 0.001$). Yamamoto et al. (1996) reported that wheat flour with higher protein and dam- aged starch content has higher farinograph water absorption. It is well recog- nized that hard wheat produces higher proportion of damaged starch during milling (Sapirstein et al., 2007; Barrera et al., 2007). This was confirmed in the present study by looking at *Taye* and *Guna* varieties having the lowest and highest kernel hardness values, respectively, among the tested varieties (Table 3). *Taye* variety had the highest kernel hardness index, protein, and water absorption. More proportion of particles (> 90 µm) were observed by *Guna* than *Taye*, whereas the proportion of finer particles were higher in case of *Taye than* that of *Guna* (Figure 12). As a wheat with low hardness, the variety *Taye* was more friable and hence had more fine particles with expectation of less starch damage level. More starch damage was expected by the variety *Guna*, which had high hardness index value.

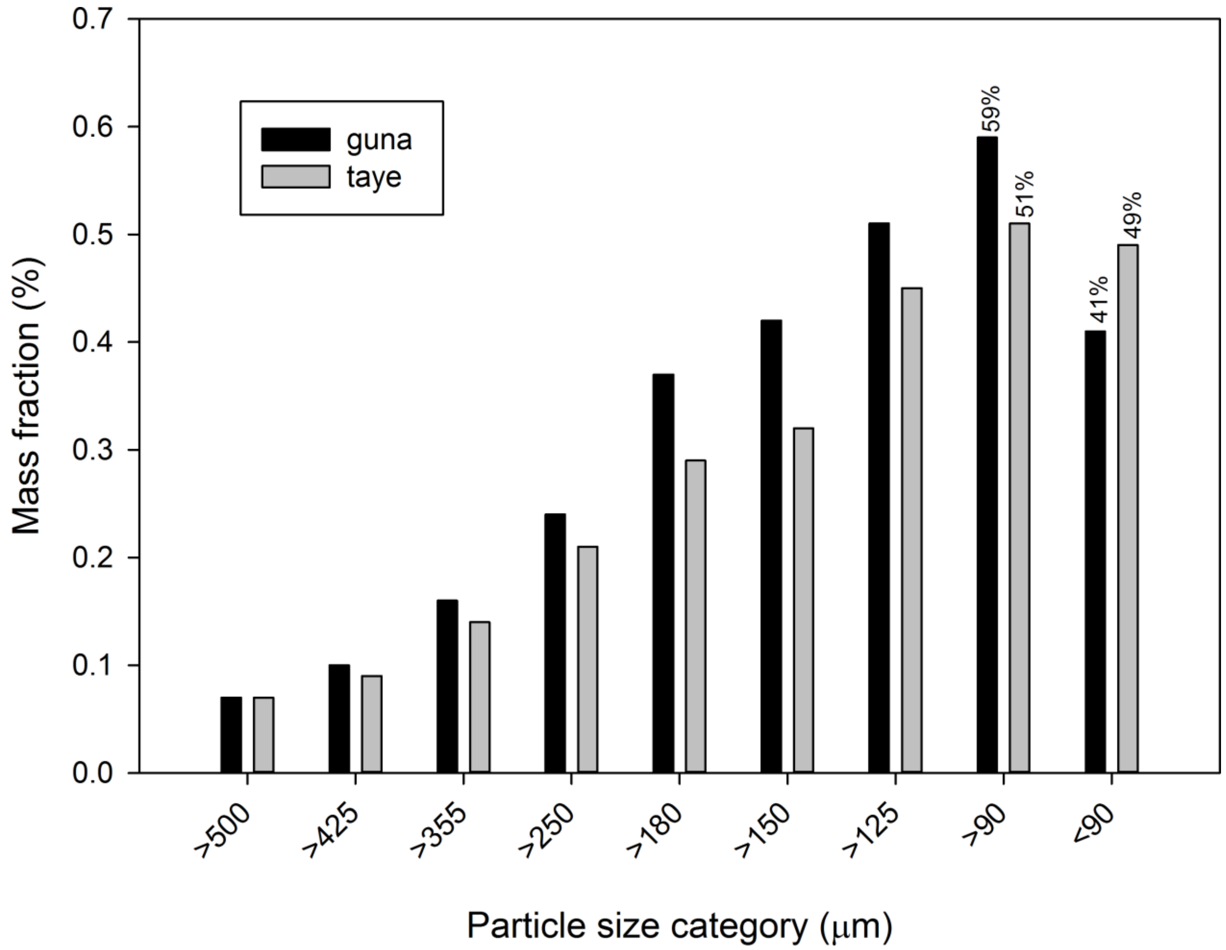

Figure 12: Mass fraction of *Guna* (hard) and *taye* (soft) varieties based on particle size groups.

Damaged starch should be high enough for yeast activity and gas production in baked good formulations that do not require sugars. However, the damaged starch level should not be so high in order to avoid dough handling problems

(Barrera et al., 2007). Sapirstein et al. (2007) pointed out that there was a close relationship between gas production by yeast and damaged starch level ($r = 0.94$).

Flour water absorption was negatively correlated with dough stability (r = -0.53, *df* = 35, P <0.001) and positively with degree of softening (r = 0.67, df = 35, P <0.001). These relationships among farinograph data is in line with the re- port made by Kaur et al. (2013), who pointed out that flours with higher water absorption showed lower dough stability and high degree of softening.

4.3.1 Effect of particle size on Farinogram properties

Figure 13 shows that particle size has a significant effect on farinograph properties of wheat flour, except for dough development time. Water absorption of particle size category < 90 µm flour was lowest whereas dough stability of flour of the same particle size category was highest of the studied particle size groups (Figure 13).

To assess the effect of particle size on farinograph properties of wheat flour, segregation of the whole wheat flour into categories of flours from a single variety (*Shorima*) was made based on particle size (Figure 13). Farinograph water absorption of flour with finer particle size was lower than that of coarser flours (Figure 13). This result contradicts with the report given by Sapirstein et al. (2007) who suggested that finer particles exhibited more water absorption than the courser ones. The difference in the findings could be attributed to the fact that Sapirstein et al. (2007) used durum wheat (hard wheat), which results in

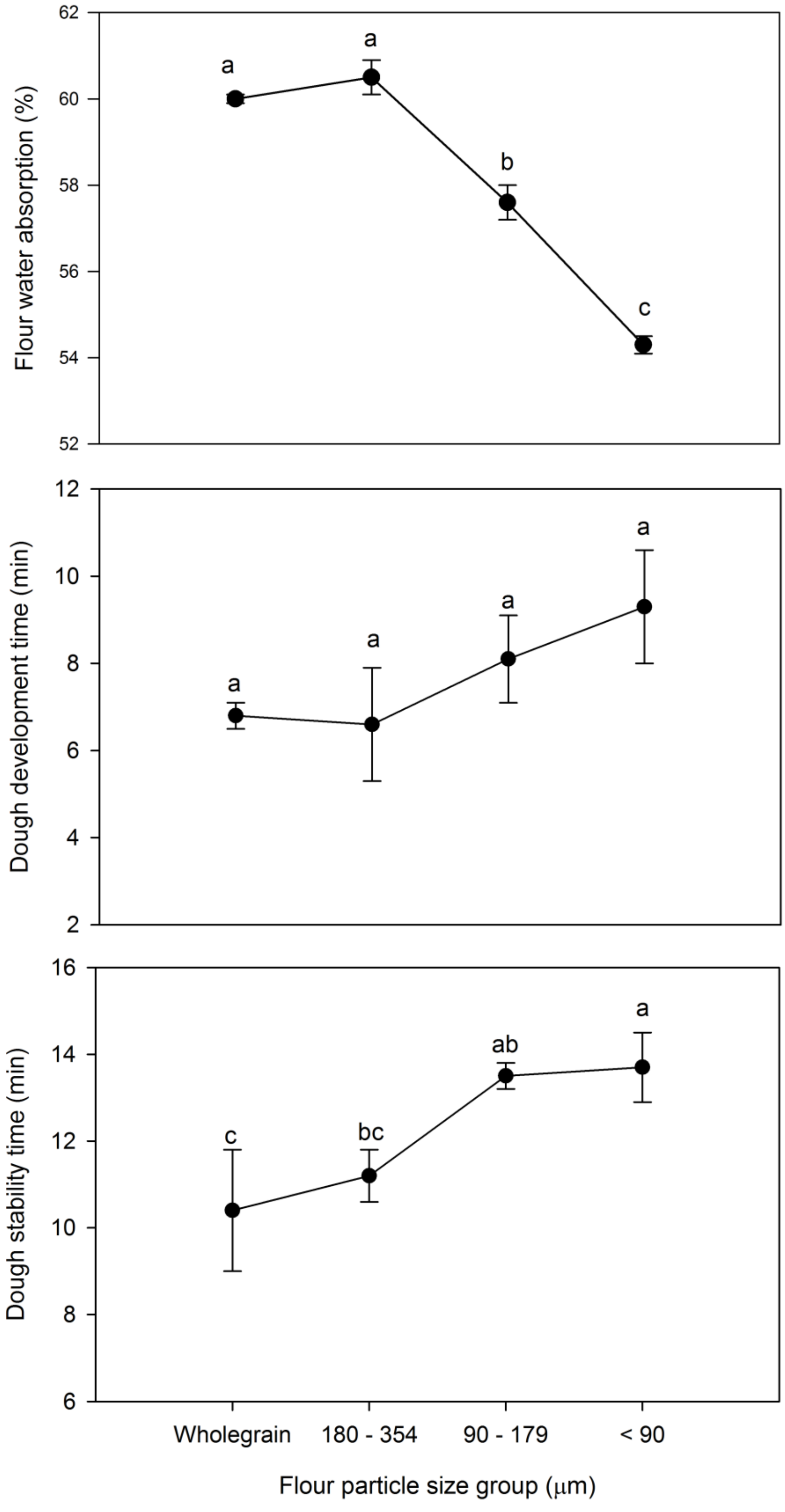

Figure 13: Farinograph properties of wheat flour of variety *Shorima* with different particle size groups. Means with the same letters are not significantly different

flour with high starch damage during milling. In our case, the variety used for this purpose (*Shorima*) was soft (Table 3) and hence less starch damage is ex- pected compared to the durum wheat used by Sapirstein et al. (2007). Dough stability of flour of the present study showed an increasing trend with decreasing particle size. This inverse trends of relationship between the farinograph water absorption and dough stability is in line with our finding pointed out in the above paragraph. However, it contradicted with the findings of Sapirstein et al. (2007) who reported that dough made of finer particle flours were less stable compared to their courser counterparts. Again, the high damaged starch level reported by those authors was responsible for the less dough stability they observed on finer flour doughs. It was speculated by Sapirstein et al. (2007) that damaged starch granules were incapable of holding all of the water they absorbed initially.

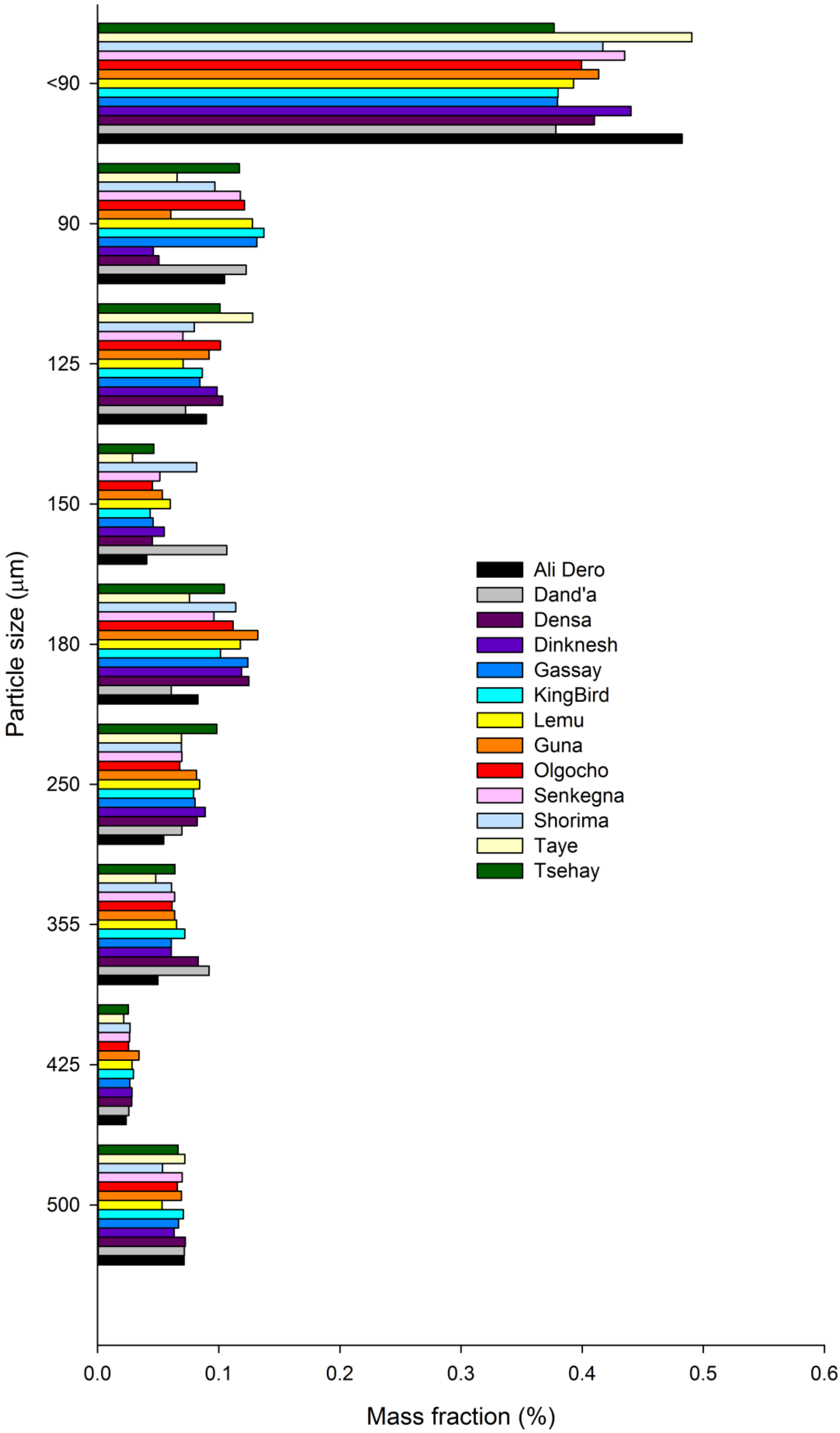

Figure 14: Mass fraction of flour of different particle size groups.

5 Conclusion and recommendation

5.1 Conclusion

Thirteen Ethiopian wheat varieties were evaluated for their physicochemical and technological properties. The SKCS differentiates between hard and soft wheats and gives an indication of their likely milling characteristics. Based on the hardness index values and other characteristics, such as protein content, zeleny val ues, wet-gluten content, farinographic water absorption, and proportion of finer flour particles, the wheat varieties were classified. Accordingly, *Taye, Shorima*, and *Alidoro* varieties were found to be categorized under the soft category (suit- able for biscuits, cakes etc.) whereas *Densa*, *Guna*, and *Dinknesh* varieties lied under the hard wheat category (suitable for bread), the remaining having inter- mediate characteristics.

Segregation of course and fine flour particles improved the color and technological performance of the finer particles. However, varieties were disproportionately affected by the particle size segregation. For instance, the variety *Tsehaye* resulted in a flour with highest lightness in color whereas that of *Danda'a* resulted in the least lightness.

5.2 Recommendation

Taking into consideration the commonly targeted extraction rate of 75% in commercial milling, it is recommended to sort out coarser fraction of 15-20% of whole wheat flour (Figure 14) to improve the baking performance and sensory appeal of bread. This will also allow some of the finer bran and aleurone layer particles to remain in the final product (unlike in the case of commercial white flour production) to benefit the consumers from their health perspective.

Reinforcing the variety characterization information generated by the present study is necessary by conducting further research of the same across location and seasons.

Conducting baking performance test of the wheat varieties need to be among the future research priorities so as to consolidate available information towards obtaining the bigger picture of the characteristics of the wheat varieties.

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