THE EFFECT OF THE VISCOSITY OF READY TO BAKE TEFF BATTER ON THE WEIGHT AND OTHER QUALITIES OF INJERA

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This is to certify that the thesis prepared by Teshome Assefa entitled *The effect of the viscosity of ready to bake teff batter on the weight and other qualities of injera submitted* in partial fulfillment of the requirements for the Degree of Master of Science Food science and Nutrition complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Some processing parameters like viscosity, fermentation time, baking time and other have an effect on the overall quality of injera. In this study, experiments were conducted to determine how viscosity affects weight of injera, which is an important injera criteria especially in the Injera bakery sectors. In the process of baking injera viscosity and weight of injera are the parameters which have impacts on the economic value in addition to other quality attributes of injera. The aim of this thesis work is to investigate whether there is correlation between viscosity of the batter ready to bake and the weight of injera. The raw materials Kuncho-white Teff (DZ-Cr-387), Magna-white Teff (DZ-01-196) and Asgori-brown Teff (DZ-01-99) grain varieties were collected from Debrezeit Agricultural Research Center (DZARC). Experimentation and processing of data were performed to study the correlation on the characteristics of batter and injera. The amylose content of the Kuncho-white Teff (DZ-Cr-387) (22.53%) was higher whereas the Magna-white Teff (DZ-01-196) (19.87%) the lowest. The pH of the batter was 3.86 – 4.11 while the pH for injera was 4.00 – 4.19. The maximum viscosity 24859m.Pa.S, 2083m.Pa.S and 16600m.Pa.S was showed by Asgori-brown Teff (DZ-01-99) at V1, V2 and V3 respectively. 17640m.Pa.S, 14632m.Pa.S and 10683m.Pa.S were the minimum viscosities respectively. From the Asgori-brown Teff (DZ-01-99) the highest weight of injera was- obtained for the whole viscosity category compared to the other teff and blended teff flour. The variable viscosity was found strongly correlated with the weight of injera ($r = 0.947$, $P \neq 0.00$) with significant values. The regression curve for the variables viscosity and weigh was Y= 90.829x - 15131, R^2 0.9149. The regression curve for each varieties was found Y = 190.96x – 49308, r2 = 0.9868 [Teff white (DZ-Cr-387)], Y = 192.36x – 47037, r20.968 [Teff White (DZ-01-196)], Y = 91.511x – 15566,r2 0.9956 [Teff brown (DZ-01-99)], Y= 91.01x-1030, r2 0.998 (Teff white (DZ-Cr-387)-Rice), Y= 139.78x – 31796, r2 0.9829 (Teff white (DZ-01-196)-Rice). Based on the results obtained it could be concluded the viscosity of the batter strongly correlated with the weight of injera.

Key words: Injera, Viscosity, Weight, pH, total starch, pasting profile

DEDICATION

I would like to dedicate this thesis work for my wife; Aster Geremew and my two beloved Kids Asher Teshome and Abigail Teshome.

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Abbreviations and Acronyms

LAB: Lactic acid bacteria

EPS: Exopolysaccharides

ESA: Ethiopian Standard Agency

CSA: Central statistics Agency

EHNRI: Ethiopian Health and Nutrition Research Institute

RVA: Rapid visco analyzer

PCA: Principal component analysis

cP: Centipoise

mPa.s: Pascal-second

DZARC: Debrezeit Agricultural Research Center

DZ: Debrezeit

Cr: Crossed

RVA: Rapid visco analyser

PV: peak viscosity

TV: Trough viscosity

FV: Final viscosity

BV: Breadown viscosity

SV: Setback viscosity

WHC: water holding capacity

STD: Standard deviation

CHAPTER 1
INTRODUCTION

1.1 Background

Teff [*Eragrostis tef* (Zucc.) Trotter] is a tropical cereal cultivated as a major grain crop over most parts of Ethiopia (Bultosa, et al. 2002). Since ancient time nearly about 100BC people in Ethiopia start cultivating and domesticating the teff cereal (Campo, et al. 2016). There are different varieties and cultivars which could be cultivated at different regions of the country depending on the environment and altitudes for different purposes (Tadesse, 2009; CSA, 2011). The common varieties which are popular among the society are Kaye (red/brown) teff, sergega (mixed), Kuncho (white) teff , Magna (supper white) and many more differently named according to the region. Scientifically based on some modification and other parameters teffs of different cultivars are named like DZ-01-196, DZ-01-99, DZ-01-1681, DZ-Cr-37 and many more (Bultosa and Taylor, 2004). These and many others kind of cultivars which are cultivated in Ethiopia are mainly used for the purpose of either home consumption or commercial.

Teff is preferable seed for making of fermented traditionally processed injera (soft, spongy, sour, circular flatbread with honeycomb on the upper surface) and is staple food for the majority of Ethiopians (Bultosa, et al. 2002; Bultosa, et al. 2008 and Abebe and Ronda, 2014). Almost in all parts of the country of Ethiopia; injera contributes 2/3rd of the major meal part served with different sauces (Dijkstra and Polman, 2008). This traditional fermented injera could be made of either from teff whole grain or other grains. Some will also tend to blend teff with other cereals for many reasons. Among these cereals which are used for blending or used for making injera are wheat, sorghum, barely, rice and millets (Yetneberk, et al. 2005; Hrušková, et al. 2013). Teff is preferably selected for its unique quality compared to any other cereals in making injera with all the required qualities attributes (Bultosa, et al. 2008). Teff is not limited for injera making but it has also many other applications such as a whole grain teff or flour used in the traditional fermented liquors, *atemit* and other food stuffs.

The teff batter is prepared from teff flour by mixing water and starter culture under a natural fermentation process (Yetneberk, et al. 2005; Bultosa, 2007). The teff flour has many health benefits for its fibers contents especially for diabetes. The traditional fermentation processes have different stages and involves some crucial steps that absolutely affects the overall quality of injera. Some of the quality impacts due to the process on the final product injera are like sourness, texture, eyes on injera, fold ability, probiotic loads and other (Yetneberk, et al. 2005; Attuquayefio, 2014). So injera making from teff flour or other cereals flour is a multistage long process where it needs some experienced/skillful person in addition optimized process of the steps.

The final product injera is obtained by baking the sour batter which is completely fermented in two stages and its viscosity or thickening manually determined or corrected with continuous addition of water (Ashagrie and Abate, 2012). Actually the thickening of batter depends on the purpose of the final product and varies from home to home (local observation). Viscosity has impact and significant effects on many final products qualities (Attuquayefio, 2014). In the process of baking injera the final viscosity of batter has influence on some qualities of injera like weight, number and size of eyes on injera and others (Attuquayefio, 2014). There are still some limitations and difficulties associated with the process of baking in order to have good quality of injera for the purpose of marketing or household consumptions.

On the other hand, literatures have clearly showed that viscosity of batter depends on some factors like the amount of water added, the nature and type of starch, gelatinization and even fermentation process (Yetneberk, et al. 2005; Bultosa, 2007). The viscosity variation of starch-based cereal dough has effects on the viscoelastic behaviour, the texture, keep ability and nutritional performance of finished products during backing (Ronda, et al. 2005; Waterschoot, et al. 2015). Starch has a major role for this viscosity changes and its pasting properties explains a lot about its nature and has subsequent impact on finished product quality (Abebe, et al. 2015). Pasting properties of flours involves some processes like swelling, deformation, fragmentation, and solubilization.

Viscosity is one of the fundamental characteristics of liquid products with a defined flowing nature (Hidayanto, et al. 2010). It is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress (White and Corfield, 2006). In everyday terms (and for fluids only), viscosity is "thickness" or "internal friction". Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity (White, and Corfield, 2006). Viscosity is dependent on temperature, shear rate, pressure, the type and composition of the material

(Hidayanto, et al. 2010). Therefore, measurement of viscosity has significant importance on the quality of fluids/liquids. Accurate knowledge of viscosity is necessary for various industrial liquid products and helps to distinguish or related directly with quality of the final products. In, specially, food processing; knowing the viscosity of the product will be beneficial in which viscosity indicates consistence, pour-ability, and firmness to define product quality (Hidayanto et al., 2010).

1.2 Statement of the problem

Teff, in Ethiopia is a major food grain, mainly used to make injera, a traditional fermented indigenous Ethiopian flatten soft pancake which is one of the staple foods (Yetneberk, et al. 2005). The people are dependent on this cereal either for preparing their basic meal or as a source of income. It is clear that the process of baking injera is absolutely traditional and has involved several steps with long process (Stewart and Getachew, 1962). In most homes and in some injera bakeries, teff batter and starter culture and backing process has not been modified or improved. The amount of fermented teff batter ready to bake is traditionally guessed and manually rotated in a circular way on the *mitade* (local) until it completely covers the *mitade* (Stewart and Getachew, 1962); (Ashagrie and Abate, 2012).

The amount of water that will be added to make ready for baking will be guessed and traditionally added by looking the flow of pouring. These been for several centuries practiced and is still continued. Most different researches carried on the study of nutritional value, health benefits, genetic mapping whereas with respect to the effect of viscosity of batter limited works are available (Dijkstra and Polman, 2008). These traditional ways of baking injera has its own impacts on the sensory attributes. Whereas traditional ways of determining the teff batter ready to bake has mostly negative impacts on the physical quality of the final product and the weight of injera to have (ESA, 2013). Now a days the Ethiopian standard authority has set some requirements that injera from teff has to fulfill like the weight, thickness and appearance (ESA, 2013). So there are some difficulties finding the exact viscosity of the batter especially in those who are in the injera bakery sectors which causes difficulties in attaining the weight of injera. The problem is mainly there is no standards about the amount and the viscosity of the teff batter ready to bake for obtaining the desired weight of injera. Injera baking above or below the specified standard weight leads the manufacturers to waste their resources. This can be controlled by adjusting the viscosity of teff batter at the time of baking. The weight of injera variation is a big problem encountered during baking for almost all injera bakeries. Baking of injera at appropriate viscosity of batter will help the bakeries to save their resources from wasting. Uncontrolled viscosity of teff batter will result sometimes high or low weight of injera.

1.3 Significance of the study

- The study will provide significant information about the possible apparent viscosity of the teff batter which will help to control the weight of injera.
- The study will show how the viscosity and the weight of injera are correlated.
- The study will show how the varieties and blending with certain cereals have different viscosities.
- The study will help and find out best fit model for a consistent weight in the manufacturing of injera.
- The findings will help the producers to save their resources from the uncontrolled wasting and fulfillment of the regulatory requirements.
- The study and findings will help to create a technology that will improve the injera manufacturing within the standard.
- The study will help to create a suitable and easily applicable means with respect to viscosity and weight per ml of ready to back teff batter for a consistent weight in injera making

1.4 Objectives of the study

1.4.1 General objective

To study the correlation of viscosity of ready to bake teff batter with weight of injera and design a model based on the viscosity for different variety of teff flour, and blended teff with rice.

1.4.2 Specific objectives

- To evaluate the effect of viscosity on the weight of injera for different varieties of teff and blended teff flour,
- To assess the viscosity of the batter used for baking injera and weight of injera from different households
- To correlate the viscosity of batter and weight of injera collected from different households
- To design a model from correlation curve for the viscosity vs weight of injera
- To determine the prediction of a model from a regression curve between the actual viscosity and a theoretical one.

CHAPTER 2

LITERATURE REVIEW

2.1 Teff grain and injera

Tef [*Eragrostis tef* (Zucc.) Trotter] is a tropical cereal cultivated as a major grain crop over most part of Ethiopia (Bultosa et al., 2002). Even though Ethiopia is believed to be the origin of teff; there are many other countries which cultivated or domesticated for different purposes. Some of the countries which cultivate teff are South Africa, Australia, Eritrea, south-eastern Sudan, some parts of Europe and North America (Adebowale, et al. 2011). Among these mentioned countries some of them cultivated the teff for the purpose of making food stuff whereas others do for the animal feeds especially for horse (Adebowale, et al. 2011). There are many researches carried on teff for its high nutritional profile and health benefits regardless of using it for horse/cattle feeds (Adebowale et al. 2011).

There are many different varieties or cultivars of teff found and cultivated in different regions of Ethiopia (Tadesse, 2009; CSA, 2011). The commonly Cultivars of varieties which are popular among the society are Kaye (red/brown) teff, sergega (mixed), Kuncho (white) teff , magna (supper white), (Tadesse, 2009). Scientifically based on some modification and other parameters teffs of different cultivars are named like DZ-01-196, DZ-01-99, DZ-01-1681, DZ-Cr-37 (Bultosa and Taylor, 2004). When we are considering regions of cultivation, environmental and harvesting period we found some kinds of local naming such as GeaLamie, Dabi, ShewaGimira, Beten, Bunign, Albaa, Ada and Enatit (Tadesse, 2009). These and many others kinds of cultivars are cultivated for the purpose of either home consumptions or for sale.

Tropical cereal crop Teff [*Eragrostis tef* (Zucc.) Trotter] has become most popular and attracts many researchers for its many unique characteristics. Some of teff unique characteristics are its high quality of nutritional profile, starch's structure and nature, probiotics load and its applications for various food items (Bultosa and Taylor, 2004; Attuquayefio, 2014). Teff is widely consumed here in Ethiopia as a major source of food for most societies and preferred for making injera (Bultosa, 2007, Attuquayefio, 2014). They used the cereal mostly for making injera from teff flour alone or by mixing other flour. Teff grain is not limited for injera making but also teff whole grain is used for different other food items including fermented traditional local spirit, in the mixture for preparation of grudes and porridge (Bultosa and Taylor, 2004).

2.2 Characteristics of injera

Teff is a preferable grain for making of injera (soft, spongy, sour, circular flatbread with honeycomb on the upper surface) from its flour by traditionally fermenting the flour (Bultosa, et al. 2002; Abebe and Ronda, 2014). Almost in all parts of the country; injera contributes 2/3rd of their major daily dish (Dijkstra and Polman, 2008). The traditional fermented injera is made of either from teff flour or other cereal flour. Some will also tend to blend teff with other cereals for many reasons. Among these cereals which are used for blending or used for making injera are like wheat, sorghum, barely, rice and millets and many more (Stewart and Getachew, 1962; Yetneberk, et al. 2005; Hrušková, et al. 2013). Teff is selected for its unique quality compared to any other cereals in making injera either for household purposes or market (Bultosa, et al. 2008). Injera from teff has elastic in nature, foldable or roll able, unique texture and good sensory attributes (Attuquayefio, 2014).

2.2.1. Fermentation of Teff flour

Teff grain is milled to flour by disk attrition mill, with local milles (Abebe, et al. 2015). Usually the flour particle size varies on the interest of person who milled teff grain for injera making. Therefore the major starting components of fermentation are teff flour, water and *irsho* (starter culture). The traditional fermentation processes of teff flour begins with adding water to teff flour and mixing or kneading it with a starter called *irsho*. This kneading process varies even from home to home depending on the varieties of teff by observing the injera textural qualities (local interview). There is actually little information on mixing and its effect on the texture of injera.

There are different studies on injera reported by varying the amounts of tef flour to water ratio in teff fermentation. The teff flour, water and *irsho* are usually mixed in different proportions. Some of the flour to water proportion mentioned are like 1:1 was used by Abraha et al., (2013), 1:1.6 was used by Girma et al., (2013), 1:2 was used by Ashagrie and Abate, (2012; Girma et al., (2013).

Fermentation is the process of micro-flora (LAB) activities on the starch/carbohydrates of most cereals especially in gluten free cereals by producing different EPS Wolter et al., (2014) and more CO2 gases. The fermentation stages of teff flour for injera making have two stages which are independently processed (Ashagrie and Abate, 2012; Mezemir, 2015). The first fermentation stage is where the dough will be left to ferment for 48 – 72hrs. The second fermentation started after *absit* is added on the first fermented dough and lasts for 2- 4hrs Ashagrie and Abate, (2012); Attuquayefio, (2014). Some literatures conducted on injera has showed that fermentation time is affected by the altitude of the area, the amount of the *irsho*, temperature of the environment and the container used (Mezemir, 2015).

Figure 2.2.1: Fermented batter of teff flour during the work

2.2.2 Baking of injera

Baking injera is the final process of the fermented teff flour batter which was kept for 2 to 3 days and adding of some amount of water before commencing baking (Ashagrie and Abate, 2012). In general baking is the process where heat is transferred from the hot pan to the surface of the food baked on it as a result moisture continuously removed out. So the changes in temperature and moisture conditions between the food material and the hot pan develops desirable characteristics (color, texture, and flavor) of the food as cooking proceeds (Getenet, 2011). In most literatures which discussed about injera baking does not involve or mentioned baking temperature ranges. But according to the work of Tekle, (2011), the surface temperature of the baking pan of conventional electric *mitad* is indicted to be between 180 – 220^{o}C.

Injera baking process on hot circular electric plate is a short period process due to many untouched reasons. After the batter is poured in a circular manner on the hot pan, the pan will be covered and left for 2 to 3 minutes to be steam cooked (Ashagrie and Abate, 2012). Then the baked injera will be removed from the pan and collected in the so called *messob* (a cylindrical container with a flat bottom and made of grass).

Baking temperature of injera has been seen from literatures varies and have no a standard and defined limit. Baking has significant effects on the texture, moisture and shelf life of injera.

Figure 2.2.2: Baking of injera

2.2.3 Eye formation of injera

One of the quality attributes of injera is the honeycomb-like eye formed on one side during baking. These eyes differ in sizes and numbers from injera to injera depending on many factors associated with. Different researches showed the naturally leavened sour injera have a variable porous structure produced by a fermentation process (Attuquayefio, 2014). The small gas nuclei holes (eyes) on the surface of injera are formed due to the release of CO2 gases during baking. These gases are produced spontaneously during fermentation by LAB presented in the dough and starter culture (Abraha, et al. 2013).

There are different factors that affect the quality, size and number of eyes on injera. According to different studies on injera these factors are mentioned as fermentation process, *absits* quantity and quality, viscosity, temperature and baking time and fermentation period (Stewart and Getachew, 1962; Dijkstra and Polman, 2008). In the thesis work Attuquayefio, (2014) indicated that the gas bubbles formed during fermentation creates nuclei like hole due to the evolving of carbon dioxide. These air sacs in the batters will try to find out a way to escape by the temperature of baking which in turn leaves a hole like structure called the honeycomb-like eye (Stewart and Getachew, 1962). Usually it is said that the quality and appearance of the eyes affects the textural quality of injera. Therefore there are not enough studies on the factors associated with the quality and number of eyes on injera.

Figure 2.2.3: The honeycomb eyes of injera

The determination of the number of the eyes could be by using different techniques. The simplest one is by taking defined unit area from four randomly selected part of injera and manually counts the eyes (Dijkstra and Polman, 2008). Then the number of eyes counted will be divided by the area of the sample. There are some difficulties on the determination of the number of eyes to confidently report since no defined specification on the number of eyes per unit area of injera (Gamboa and van Ekris, 2008). According to Cherinet, (1988) eyes are neither too few nor too numerous, they should rather be deep, interlocked with thin cross-walls between them and evenly distributed. In his study he mentioned that the number of eyes is about 11-15 per cm^2.

2.2.4 Weight of injera

The consumption of injera has increased drastically not only domestic only but also in other parts of the world (Yetneberk, et al. 2005; Baye, 2014). This consumption creates an opportunity for the producers to increase their market. Therefore, for this and many other reasons; standard is set by the Ethiopian Standard Agency (ESA, 2013). According to the specification, injera should have an average weight of not less than 310gm based on the consumers' interest (ESA, 2013).

There is a limitation on literatures about factors associated with the weight of injera. Actually the in-consistency in weight of injera could be due to some factors like viscosity of the batter ready to bake, temperature of baking pan, and the time of baking. The weight of injera is measured with a digital balance.

2.3 Nutritional profile of teff grain and injera

2.3.1 Nutritional profile of Teff grain

Teff [Eragrostis tef (Zucc.)Trotter] grain becomes very attractive cereal especially in the Western world for its health and nutritional benefits (Abebe et al., 2015). This importance has triggered many researchers to investigate all about the grain teff and its unique characteristics. There are many reports and researches that show the nutritional packages like the purity of protein, amino acids, carbohydrate, starch, vitamins, minerals, and lipids in brown teff (Baye, 2014; Campo et al., 2016; Inglett et al., 2016). Teff has an attractive nutritional profile with amount of minerals including calcium, iron, magnesium, phosphorus, potassium, and zinc. It is also rich in vitamins, such as thiamin (B1), riboflavin (B2), vitamin A and K (USDA Nutrient Database, 2014). On the other hand grain teff can provide about 11% protein, 73% carbohydrate, 3% crude fibre, 2.5% fat and 2.8% ash (Bultosa and Taylor, 2004). The type of proteins in teff grain are easily digestible, and the essential amino acid profile is regarded as well balanced which makes it preferable in its lysine content than other cereals (Bultosa and Taylor, 2004). Grain teff is preferable as a functional food for celiac patients for its gluten free properties (Bergamo et al., 2011)

2.3.2 Nutritional profile of injera

Table 2.3.2 Nutritional value of teff injera adopted from ESA ES 3786-2013 injera Specification.

S.No	Types of nutrients	Nutrient composition per 100g of teff *injera*
1	Energy, *Cal*	145.0 – 155.9
2	Protein, *g*	3.0 – 3.8
2.1	Gluten	ND*
3	Total carbohydrate, *g*	31.9 – 34.0
3.1	Crude fiber, *g*	1.0 – 1.8
4	Fat, *g*	0.6 – 0.7
5	Minerals (Total ash), *g*	0.7 – 1.7
5.1	Calcium (Ca), *mg*	50.0 – 68.0
5.2	Phosphorus (P), *mg*	100.0 – 115.0
5.3	Iron (Fe), *mg*	7.0 – 14.7
5.4	Zinc (Zn), *mg*	1.5 – 1.7

According to the work of Mehta et al., (2012), fermentation has impacts on the food flavor and nutritional values. Fermentation is the process created by the microbial (LAB) activities on the starch of the flours. Some macro nutrients like protein decrease remarkable in the fermented teff while minerals improved in their availability (Urga et al., 1997). In addition, fermentation plays a key role in reducing the inhibitors contents of teff and increase the bioavailability of minerals (Urga et al., 1997; Umeta et al., 2005).

2.4 Main components of teff and fermented teff flour

2.4.1 Starch

Starch is a widely known polysaccharide of glucose polymers formed by amylose and amylopectin chains. These main components of many cereal including teff are macromolecular polymers of α,D-glucose (Bultosa et al., 2008; Yu et al., 2014). Cereals functionality and their properties will vary based on the nature and structure of these components (Bultosa et al., 2002; Yu et al., 2014). The starch properties of many cereals are influenced by the ratio of amylose to amylopectin which affects their physicochemical properties. In most crops starch contains 20–30% amylose and 70–80% amylopectin. Teff starch has small granules (2–6 µm) and slightly differs in their properties as compared to other tropical cereals (e.g. maize) (Bultosa and Taylor, 2004).

The color, viscosity, texture and rheological properties of many cooked or fried starchy foods are affected by the interaction of starch with protein or changing in the structure due to thermal or bacterial or other process (Bultosa and Taylor, 2004; Abebe and Ronda, 2014). Teff flour, in the study of Abebe et al., (2015) and Bultosa et al., (2002) has high water absorption capacity which relates to the higher degree of swelling of the teff starches, which have a small and uniform granule size, providing larger surface area. On the other hand Bultosa and Taylor, (2004) indicted that the gel firmness and the intermolecular forces in teff starches are comparatively higher and stronger than the maize's. These have a contribution for the elasticity of injera which is not breakable easily when it is folded. In the study by Yu et al., (2014) these two major components of starch of cereals have significant correlation with the intrinsic viscosity. According to Bultosa, (2007), teff flour starch showed less thickening ability and more shear tolerance compared to maize starch.

The starch of teff flour has been explained and discussed in various literatures about the unusual and potentially useful properties for better resistance to shear rates, extreme pH and other factors on the on the qualities associated with product (Bultosa et al., 2002; Bultosa, 2007; D'Silva et al., 2011; Yu et al., 2014). In different literatures the size of starch granules of many cereals are reported as ranging from 1µm (e.g. rice, amaranth, and quinoa starch) to more than 100 µm (e.g. potato and canna starch) (Dhital et al., 2015). There are also some studies on the general properties of starches and their contents of the components related that undergo some changes as exposed to some process. This nature of the starches differ from cereals to cereals in structures and helps to behave differently when they are exposed to some changes for instance the teff starch comparably differs from that of maize as it has lower peak and setback viscosities (D'Silva et al., 2011). As reported by Abebe and Ronda, (2014) the starch content of the cereals ranged between 66.9% (for whole wheat flour) and 87.7% (rice flour) and the starch contents of the teff were found to be significantly higher than that of the whole wheat flour and lower than both refined wheat and rice flours.

At present there are some more studies on teff starch which has been shown some unusual and potentially useful properties. A study conducted by Bultosa et al., (2002) and Bultosa and Taylor, (2004) on starch of teff has clearly indicated that the starch granules are small (2 - 6 mm) in size. Teff starch also has lower peak and setback viscosities than maize starch which indirectly affects their water holding capacity (Bultosa et al., 2002).The physico-chemical properties of teff starch has attracted many researchers about its great potential to be used in a broad/wide range of food applications. A research conducted by Bultosa et al., (2002) showed that teff starch has slow retro-gradation tendency compared to other cereals where it could have or put a potentially positive impact on shelf life of baked products. Therefore these and other many reasons have made teff much preferred for making the traditional Ethiopian flatbread injera in terms of flavor quality, texture and softness.

There are some studies which showed the tendencies of starches of cereals to be damaged by different reasons especially during milling (Ali et al., 2014; Abebe et al., 2015). These damaged starches have impacts on the overall rheological properties and on the final products (Yetneberk et al., 2005 and Bultosa, 2007). According to some studies teff starch granules are found to be less exposed to have damaged starch (DS) during milling or processes of making injera; because they are much smaller/short in sizes compared to wheat or maize. The DS has actually some good or bad impacts on the quality of the final starchy products and dough for they have high water absorbing ability which will influence on the viscosity (Bultosa, and Taylor, 2004).

Teff starch also undergoes changes in the arrangements of its components due to the processes as a result these changes will influence the texture, elasticity and other properties of the batters and injera (Yetneberk et al., 2005; Bultosa, 2007). In the process of baking injera; *absit* (pre-gelatinized starch) added to the teff batter after primary fermentation to enhance the texture of injera. According to Taylor, (2008), the increased viscosity of the teff batter resulting from cooked *absit* seems to enable it to better hold the carbon dioxide produced during fermentation. In the work of Zannini et al., (2012) and Wolter et al., (2014) stated that starch gelatinization could play also an important role in gluten-free formulation because of the ability of starch pastes to trap air bubbles that aid the gas-holding capacity of batter. In another study by Taylor, (2008) there is an indication of the effect of viscosity on teff batter due to the cooked *absit* to the better holding of carbon dioxide produced during fermentation. Viscosity of batter has the overall effect on the eye formation and the weight of injera.

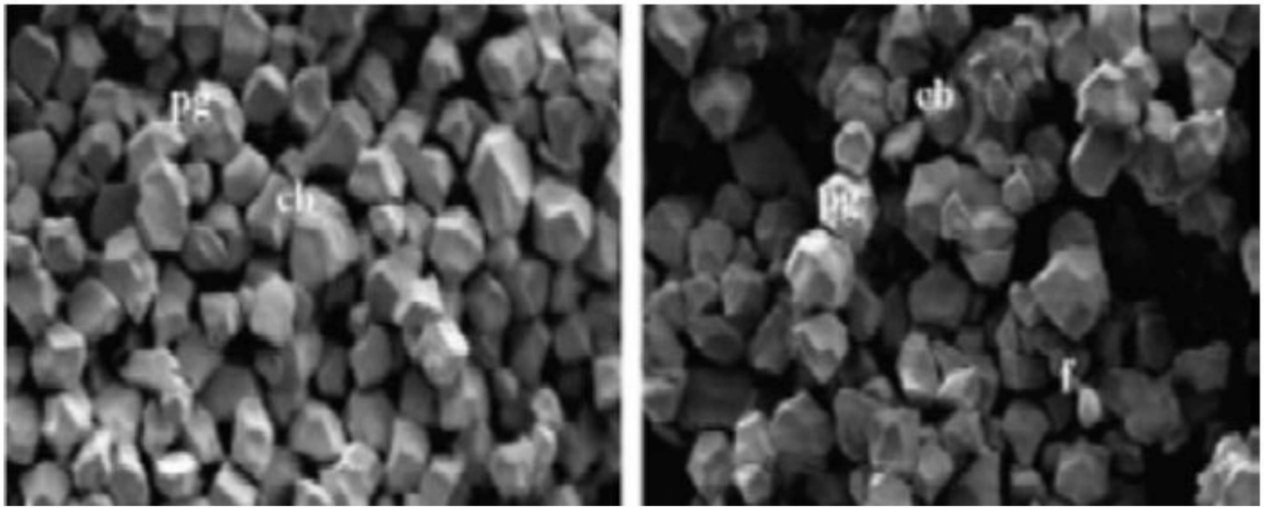

Figure 2.4.1: Individual starch granules of teff. Where: pg: polygonal shape starch granules. Pb: protein bodies and f: fibre. (From Bultosa et al., 2002).

2.4.1.1 Components of starch: Amylose and Amylopectin

Amylose is an α-(1→4)-linked glucose polymer with a few long-chain branches linked together by α-(1→6) glycosidic bonds. Its molecular weight ranges between 10^5 and 10^6 g mol^{-1} (Roger et al., 1996). Amylose is one of the crucial component of starch that affects the nutritional and other properties like susceptibility to enzymatic hydrolysis, gelling and pasting behavior (French et al., 1984). The higher amylose content in starch have been shown to have lower digestibility or better nutritional value. It was indicated frequently that the properties of starches will be easily predicted by analyzing the amylose content. Amylopectin is the other component of starch composed of very large, highly branched polysaccharide that ranges from $3x10^5$ to $3x10^6$ glucose units Zobel, (1988). It is composed by large number of short-chain of α-(1,4)-linked D-glucopyranosyl residues which are interlinked by α-(1,6) linkages Zobel, (1988). It has molecular weight higher than ($\sim10^8$) g mol^{-1}.

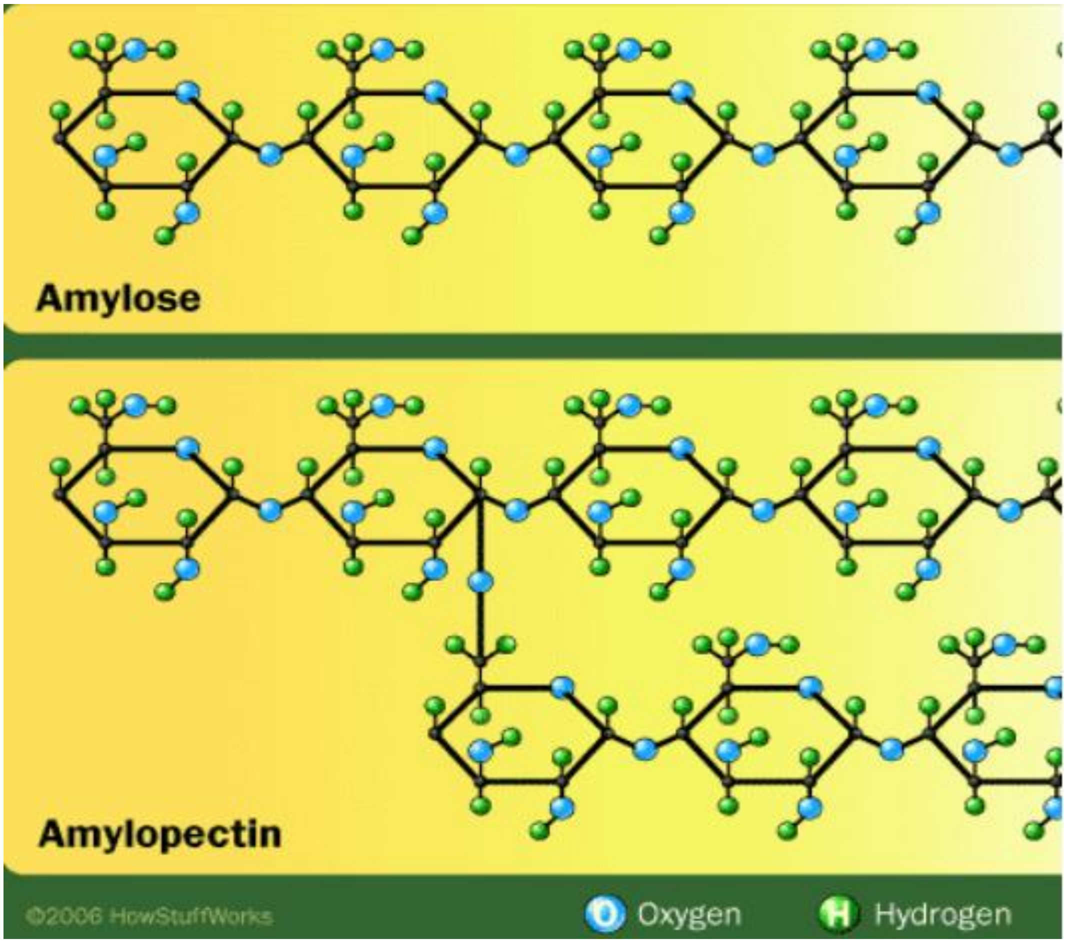

Figure 2.4.1.1: Starch components, amylase and amylopectin adopted from Dijkstra, A. and Polman, B., 2008

Amylose is an essential structural component of the bread making because of its rapid reterogrdation determines the final quality of the products. Due to these factors flours with waxy starches containing no amylose or from waxy wheat were mentioned as unsuitable for bread making for they yield breads with very poor crumb characteristics (Morrison, 1995).

High-amylose (linear) starches re-associate during the process more readily than high-amylopectin (branched) starches. However, there are some controlling factors which reduces the re-association extents like the mineral contents and amylose-lipid interactions (Ronda et al., 2011). In the work of Bultosa et al., (2002) the amylose content of teff flours have impacts on their pasting properties giving that the higher amylose contents results in higher CPV.

2.4.2 Protein

There are few cereals with the absence of a protein storage called gluten which help the cereals flour to have elasticity nature but a problem with respect to health. Teff flour is one of the so called gluten free flour where its elasticity is not due to gluten (Baye, 2014; Inglett et al., 2016). Gluten is the primary structural protein component which contributes and provides structure texture and other qualities in wheat-based bakery products (Goesaert et al., 2005). The kind of protein indicated in the study by Goesaert et al., (2005) in wheat and other cereals is gluten which is mostly from two subunits gliadin and glutenin. As reported by Goesaert et al., (2005) the low-molecular weight gliadins are associated with the viscosity whereas the high-molecular weight glutenins are related with elasticity of the wheat based dough. On the other hand the viscoelasticity nature of dough especially from wheat related is to the extent or degree of di-sulfide bonds (Dong and Hoseney, 1995).

Teff have a good and significant amino acid fractions even without gluten (Baye, 2014; Inglett et al., 2016). According to Adebowale et al., (2011) prolamin protein is the major protein storage and reported that it is more hydrophilic, less polymerized and has lower thermal stability (Baye, 2014). The prolamines, non-gluten protein in nature, are an easily digestible kind of protein and have no impact of elasticity texture of the teff dough (Hrušková et al., 2013). However the teff dough has different nature in texture and elasticity due to the absence of gluten. Even different studies indicated that the nature of the protein in teff have a good water holding capacity. Teff protein prolamins are more hydrophilic, less polymerized, less cross-linked by disulfide bonding and have lower thermal stability (Adebowale et al., 2011). According to these studies the crosslinking of disulfide bonds of prolamin in teff is still unknown or undiscovered at which its interaction could be responsible for elasticity of injera. On the other hand difference in the nature and properties of protein in teff will clearly make teff selective for a good quality in the final product injera (Adebowale et al., 2011).

2.4.3 Exopolysahaccharides

The enzymatic activity during fermentation by the lactic acid bacteria (LAB) produces a wide variety of long-chain sugar polymers called exopolysaccharides (EPS) dextran (Moroni et al., 2011). These dextran are varied in their chemical composition, structure and physical properties

(Moroni et al., 2011). In teff and quinoa sourdough glucooligosaccharides (GlcOS), amixture of PSO (panose- series oligosaccharides) and isomalto-oligosaccharides, were formed during fermentation (Wolter et al., 2014). The formation of dextran during fermentation positively influenced dough rheology producing softening effects especially in buckwheat and teff sourdoughs (Wolter et al., 2014). The concentration of EPS produced correlated with amount of protein, fermentable sugars (glucose, maltose, fructose and sucrose), and mineral contents in quinoa flour.

In the study by Wolter et al., (2014), teff flour is much better and highest in sucrose levels (113 mmol/kg flour) as compared with other gluten free cereals like Quinoa and Wheat flour. Whereas, the same researchers report Quinoa contains highest amount of maltose (158mmol), approximately twice as much as buckwheat flour.

2.5 Viscosity

2.5.1 What is viscosity?

Viscosity is one of the intrinsic characteristics of liquids which are dependent on the nature of the amount of substance dissolved. Viscosity can be one of the descriptive properties of final products of processing foods or other industrial liquid products (Bourne, 2002). It is described as the measurement of internal resistance of fluids to flow which is being deformed by either shear stress or tensile stress at specified temperature (White and Corfield, 2006). The concept is vital and important parameters in the wide ranges of industrialized process foods in liquids and semi-solid forms. Viscosity is a determinant tool in the food processing industries like Juice, beverages, sauce, sugar, dairy and others many more. On the other hand in paint, pharmaceuticals and oil manufacturing industries viscosity has an important role for the good grade of products. In general fluids viscosity measurement depends or varies on the factors like temperature, pressure and the type/composition of the material (Hidayanto et al., 2010).

2.5.2 Measurements of Viscosity

The measurements of fluids viscosity are in two different ways namely Dynamic (Absolute) Viscosity and Kinematic Viscosity (Bourne, 2002.). An accurate measurement of viscosity is very important in industries for many reasons. The viscosity measurement depends on temperature, pressure and the type and composition of the material. It may also depend on the shear rate and can change with time by the process of flow itself. For special systems the viscosity is influenced by external electrical fields (Hidayanto et al., 2010). Both viscometer and rheometer are the sophisticated scientific instruments used for measuring fluids rheological characteristics as the function of viscosity vs. shear rate and viscosity vs. temperature (Bourne, 2002). Many studies indicated that the starch based foods are subjected to Rapid-visco Analyzer (RVA) for the measurement of their apparent viscosity Acosta-Osorio et al., (2011) and provides information of water- starch interaction.

I. Dynamic (Absolute) Viscosity

Dynamic Viscosity is defined as the resistance of fluids to flow, or the fluid's resistance to be deformed when they are subjected to a force (White and Corfield, 2006; Bourn, 2002). Dynamic viscosity is commonly reported in Centipoise (cP) and therefore the SI unit is the Pascal-second (Pa·s), which is equivalent to N·s/m2, or kg/(m·s). The cgs unit is the poise (P), named after Jean Louis Marie Poiseuille and more commonly used in many standards as centipoise (cP).

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1 cP = 1 mPa·s = 0.001 Pa·s. the relationship between SI units and CGS Units

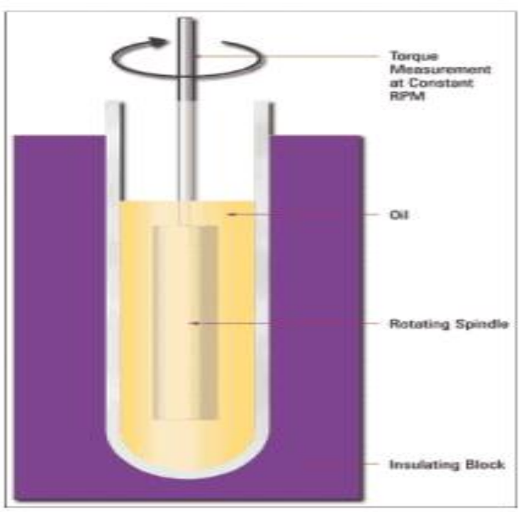


Figure 2.5.2I: Brookfield Rotary Viscometer

II. ***Kinematic Viscosity***

The Kinematic viscosity is defined as a fluid's resistance to flow and measured by noting the time required by a fluid sample to travel through a capillary under the gravitational force. This kind of viscosity measurement is used by most laboratories worldwide. The time taken is noted and converted into Kinematic Viscosity and reported in Centistoke units (cSt). Therefore 1cSt = 1 mm^2/s. The two measurements, Dynamic and Kinematic Viscosity, can be used interchangeably as shown the formula below:

Dynamic Viscosity (cP) = Kinematic Viscosity (cSt) x Fluid Density (kg/m3)

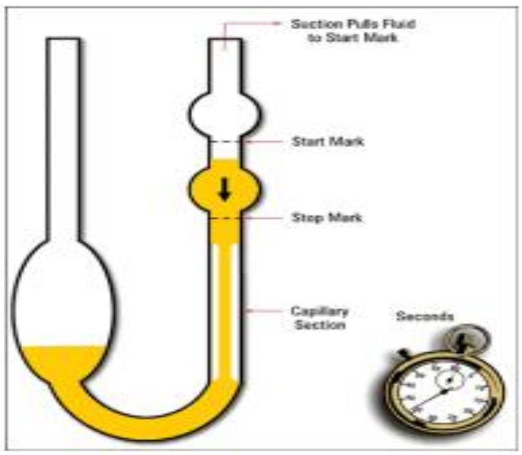


Figure 2.5.2II: Ostwald viscometer for kinematic viscosity

2.5.3 Categories of viscosity

Viscosity of fluid is generally classified into two by the characteristics they behave when the shear stress are applied as

1. Newtonian and
2. Non – Newtonian viscosity.

2.5.3.1 Newtonian viscosity

The liquid will behave Newtonian viscosity when the shear rate (D) is linearly proportional to shear stress (τ).The proportionality coefficient η (called viscosity) is constant in the case of Newtonian liquids (lecture). Fluids like water and most gases behave Newtonian viscosity for they have constant viscosity throughout the course (Bourne, 2002). The relationships explained in graphical representation as below.

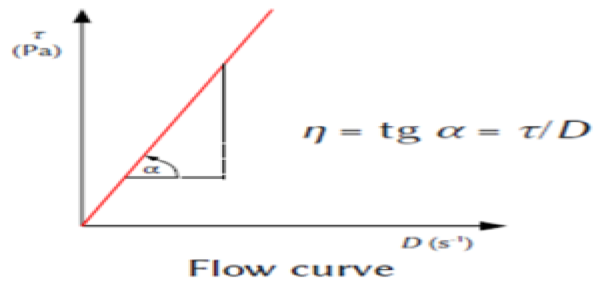


Figure 2.5.3.1 Graphical representation of Newtonian viscosity

2.5.3.2 Non- Newtonian viscosity

Some other liquids behave in a complicated way when the shear stress is applied to them. The kind of viscosity observed from these kinds of liquids are called Non – Newtonian viscosity. The relation between shear stress and shear rate is not linear for these liquids rather fluids exhibit a variety of different correlations between shear stress and shear rate (Bourne, 2002). Viscosity for such liquids varies with the shear: $\eta = f(\tau)$ or $\eta = f(D)$. From different literatures it is clear that cereals and most viscous materials exhibit a non-Newtonian behavior (Acosta-Osorio et al., 2011). Based on the behavior of the viscosity of Non-Newtonian liquids will be classified into two according to the structural changes of the particles or molecules of the liquids within; Shear – thinning and Shear-Thickening (lecture).

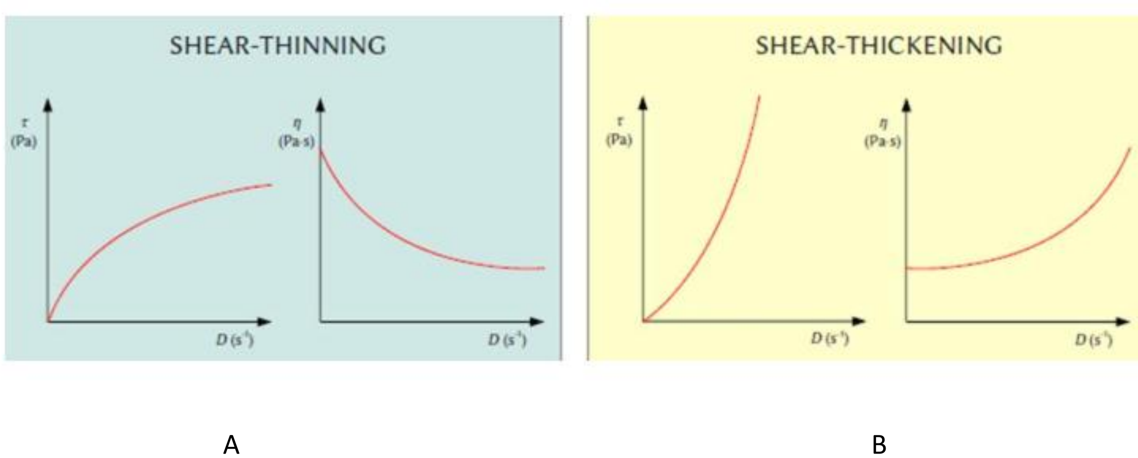


Figure 2.5.3.2: The two graphical representation for Non Newtonian Viscosity
A: for shear thinning and B: for shear thickening

I. ***Shear-thinning behavior***

Shear-thinning behavior for liquids will be observed when structural changes of the particles or molecules are caused due to the forces applied for a change in viscosity; in ordering manner. The arrangement of the particles or molecules of solutions/mixture of liquids have the forms of orientation, ordering, disaggregation, deformation, elongation.

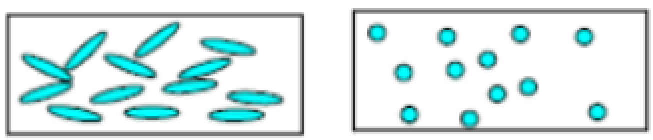


Figure 2.5.3.2Ia: Fluids system particle or molecule arrangement at rest adopted from Viscosity.pdf

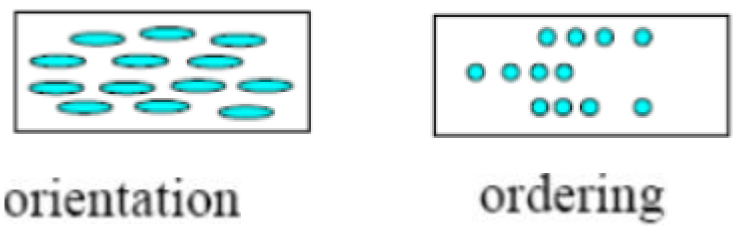


Figure 2.5.3.2Ib: Fluids system particle or molecule arrangement during flowing

II. ***Shear-thickening behavior***

Shear-thickening behavior for liquids will be observed when structural changes of the molecules or particles are caused due to the forces applied for a changes in viscosity; in disordering manner (Triantafillopoulos, 1988).

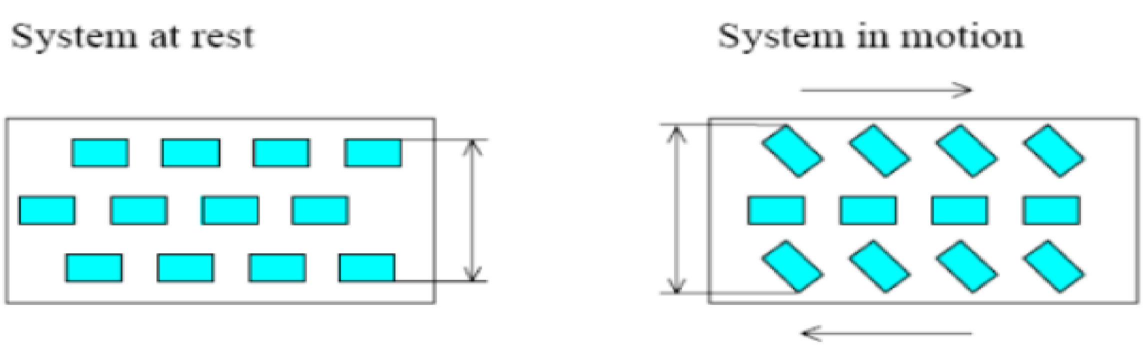


Figure 2.5.3.2II Graphical representation of shear thickening

2.6. Viscosity of batters

Dough consistency of any flour plays an important role in the final over all products quality. In the study of Pauwels, (2013) on wheat bread explained that low moisture, high viscosity dough yielded lower specific loaf volume while high moisture, low viscosity dough showed an increased specific loaf volume. The viscosity of the teff batter and its effects on the quality of injera has not been studied intensively just like on others aspects of teff (Attuquayefio, 2014). There are different factors that influence the viscosity of the teff batter like the starch content, proteins content and behavior of gel formed during *abist* preparation and baking (Hrušková et al., 2013; Abebe et al., 2015; Abebe and Ronda, 2014). Teff starch pastes or batter show Non-Newtonian behavior of viscosity, i.e. stress thinning for almost all starchy products falls in this category of viscosity. Teff starch paste showed stress max which will decrease as the temperature varies from 25^{o}C to 90^{o}C. It shows that higher at 25^{o}C than at 90^{o}C. The variation of the stress are due to the formation of hydrogen bonds at lower temperature that stabilize and strengthen the matrix, causing the stiffness of gels (Bultosa, 2007; D'Silva et al., 2011and Abebe and Ronda, 2014). According to Abebe and Ronda, (2014) research for Rheological and textural properties of teff grain are found that the effect of temperature and concentration on gel maximum stress is highly dependent on the cereal type.

Teff batter is therefore exhibit shear-thinning or non-Newtonian behavior due to their starch's tendencies to have less shear stress and thickening ability as reported by (Bultosa, 2007). In other studies conducted on sorghum by Schober et al., (2007) reported that fermentation has an impact on the starch nature which will affect the rheology properties of the teff batter as a whole. Actually there are research gaps on this process of fermentation impacts on the teff batters characteristics. Hamada et al., (2013) have compared the viscosity of rice flour and wheat flour dough to find out the gelatinization effects on the rheological properties of the dough and indicated that viscosity of rice dough is greater than the wheat dough. In addition, Admassu, (2006) also found injera generally requires a batter mixture that is viscous enough (200-1500)cP to retain leavening gasses while cooking and to give a good finished product injera. Therefore, there are some research findings about the teff flour rheological properties which help to conclude that the viscosity and visco-elasticity nature of the teff batters not dependent only on the amount of water added to make it thin but also the nature of starch and other components of teff. Considering the effect that the viscosities of batters ready to bake have on the weight of injera, it will be very crucial to determine that the viscosity of teff batter before baking. This is very important step in ensuring that good quality of injera with a consistency of weight to be produced.

2.7 Impact of Visco-metric properties on food quality

The visco-metric properties of cereals is explained by their pasting profiles based on the nature and content of the starch. This properties of starchy flour of both cereals with gluten and gluten free have been studied to measure their dough or batter consistency for the desired quality attributes of the products. The measurement of pasting profiles (gelatinization, pasting, and setback properties) using Rapid Visco Analyser as a function of shear and temperature on the viscosity of starches and flour determines the overall quality of the final products (Collar, 2016). There are different techniques for finding out the visco-meteric properties of the cereal flour for the preparation of formulation with the desired quality of final products. It has been worked out so far intensively and changed the quality dimension of the products in the bakery world. The RVA, amylograph, farinograph and rheometer are widely used for the measurement of viscomet ric properties of the flours.

The viscosity of the batter discussed as the controlling factors for the final cake volume due to bubbles movement inside the batter (Baixauli et al., 2008). In the other work done by Lakshminarayan et al., (2006), the air bubbles will be prevented from out of the batter as the viscosity of the cake batter is sufficiently high. According to Pauwels, (2013) the effect of viscosity (batter consistency) was mentioned as one of the controlling parameter on the specific volume of baked loaf. The measurement of dough consistency especially in the baking of bread was indicated as a crucial step and has a role in final product quality. On the other hand in wheat bread baking as mentioned by Pauwels, (2013), the bread quality will drastically be affected by the amount of water added. On wheat bread, he mentioned as correlated the viscosity of dough for the formulation inversely with the specific loaf volume of bread. However, according to Pauwels, (2013) work showed that the size and shape of breads were influenced by the initial batter viscosity which results in breads with the smaller loaves, flatter top crusts and less rounded edges between upper and side crusts. The bread baked with batters of higher viscosity will produce valleys and small holes created on the crusts of samples developed weak cell structures that might collapse during baking (Pauwels, 2013).

On the other hand in the study of Attuquayefio, (2014) the significance of the apparent viscosity effects had mentioned ($p<0.05$) on the number of eyes formed on *injera*. In her summarizing on the effects of viscosity of batter on the nature of eyes on injera, may be by the degree of the gelatinization of the surrounding wall of the eyes. On the other hand the same author has mentioned that the apparent viscosity of the teff batters has effects on the elasticity and thickness of the *injera*. As the apparent viscosity of the teff batters ready to bake injera increased the elasticity modules of injera also tends to increased directly (Attuquayefio, 2014).

2.8 Weight per ml of teff batters

Weight per ml is the expression of relative density of liquids against density of water determined by pycnometer which is a very precise method (Hare and Ngan, 1998). In the measurement of weight per milliliter of fluids distilled water at a defined temperature is used. The pycnometer is glass flask with a close-fitting ground glass stopper with a capillary hole through it and has defined volume. The capillary fine hole helps for releasing a spare liquid after closing a top-filled pycnometer and allows to obtained a given volume of measured working liquid with a high accuracy (Noureddini et al., 1992).

Figure 2.8: Pycnometer

CHAPTER 3
MATERIALS AND METHODS

3.1 Raw material collection and sample preparation

The raw materials kuncho-white Teff (DZ-Cr-387), magna-white Teff (DZ-01-196) and Asgori-brown Teff (DZ-01-99) grain varieties were collected from Debrezeit Agricultural Research Center (DZARC). Additional quantity of each variety were collected from farmers associations. All the varieties were harvested in the year 2016. Rice was obtained from markets for the purpose of flour blending. All the collected raw materials were stored carefully until the appropriate and respective laboratory analysis were conducted.

3.1.1 Raw materials preparation

All the Teff varieties and rice grains were cleaned, milled into fine flour using small-scale commercial mill house. Each teff variety and rice were milled avoiding mix up by cleaning the mill using enough amount from each variety. Following milling, the flour was collected separately with labeled poly bags until the treatments was conducted.

3.1.2 Experiment location

The baking process of injera, viscosity measurements, pH measurements for injera and batter, weight of injera, diameter, and weight per ml, Number of honey comb eye on injera count and WHC were done at Ethiopian Public Health Institute (EPHI). The other tests like moisture content of injera, flour and Batter were conducted at College of Natural Sciences Addis Ababa University Center for Food Science and Nutrition. Amylose content, percentage of starch and pasting profile of teff flour using RVA were conducted in Queensland University laboratory of Centre for Nutrition and Food Sciences, St Lucia QLD 4072, Australia.

3.2 Experimental frame work of the research

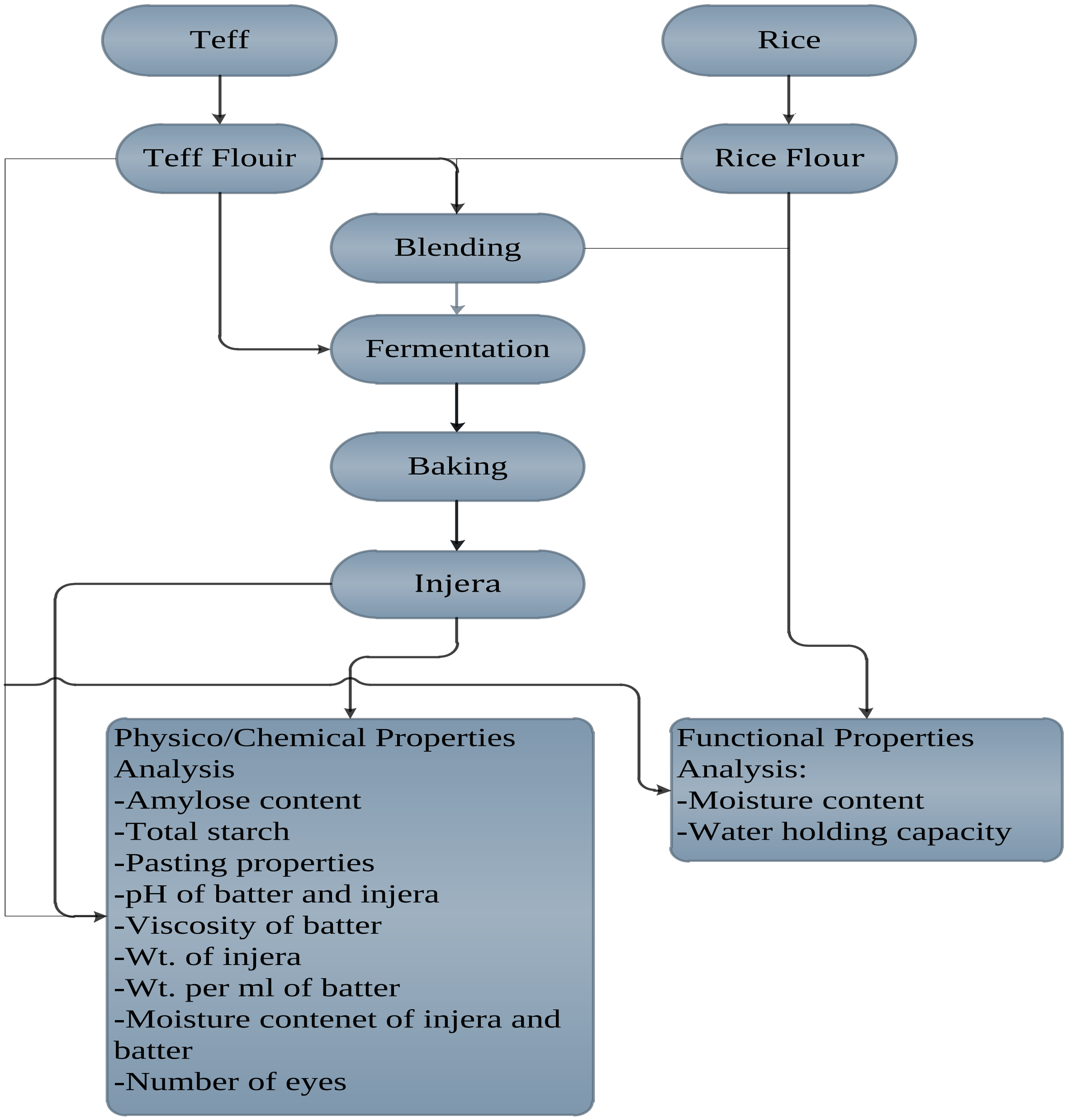


Figure 3.2: Experimental frame work of the research work

3.3 Processing methods

3.3.1 Flour preparation and blend formulation

3.3.1.1 Flour preparation from teff

The teff grains sample were cleaned manually by sifting and winnowing before milling to remove damaged grains, stones, dusts, light materials, glumes, and stalks, undersized and other extraneous materials. White Teff (DZ-Cr-387), white Teff (DZ-01-196) and brown Teff (DZ-01-99) varieties were milled and ground into fine whole flour using disk attrition mill, with two disks, traditionally used in the cottage teff grain milling house.

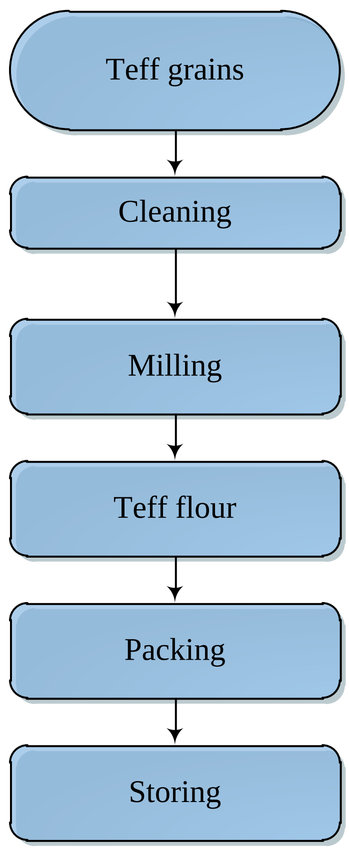


Figure 3.3.1.1 Process flow diagram for the preparation of Teff flour

3.3.1.2 Flour preparation from raw Rice

The Rice samples obtained from commercial market were cleaned manually to remove damaged grains, stones, dusts, light materials, stalks, and other extraneous materials. About 5.0 kilogram of Rice was milled and ground into fine flour using disk attrition mill, with two disks, traditionally used in the cottage milling house which was previously cleansed with enough amount of rice grain.

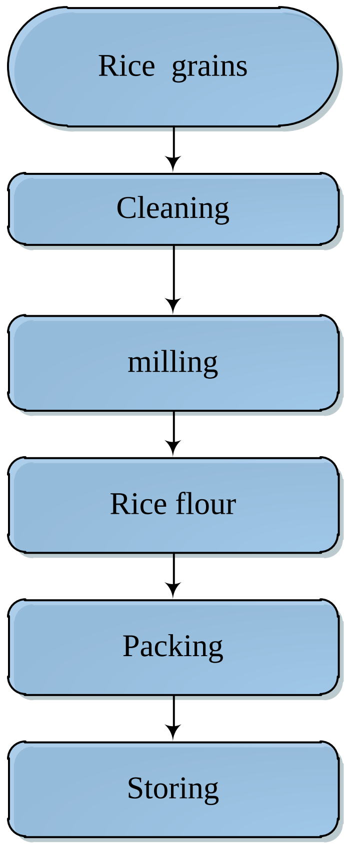


Figure 3.3.1.2 Process flow diagram for the preparation of Rice flour

3.3.1.3 Blended Teff-Rice flour

Blending of flours were done in proportion 70% teff; 30% rice. The flour first blended before making dough by weighing the exact amount of flour.

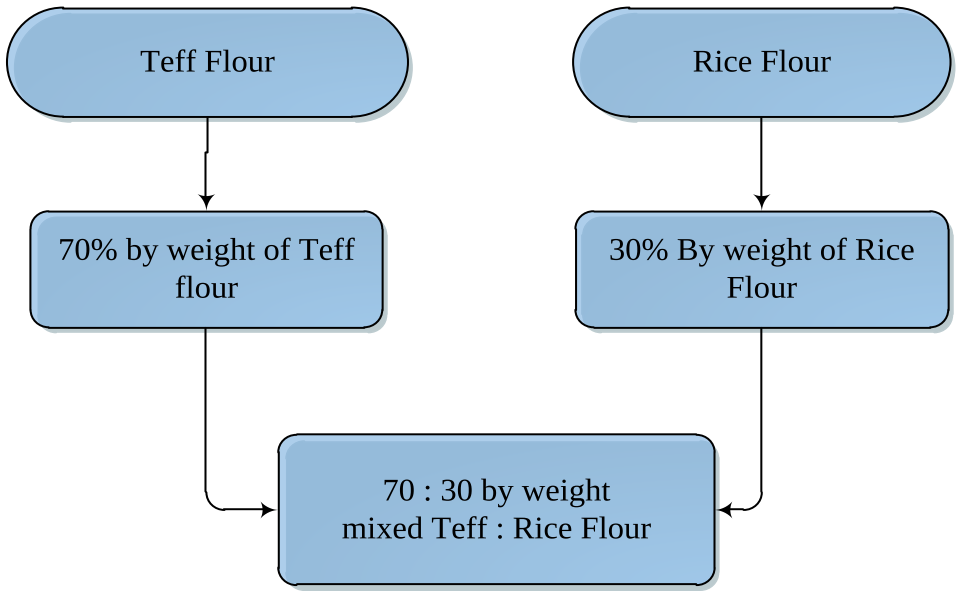


Figure 3.3.1.3: Process flow diagram for the preparation of Blended Teff flour with Rice flour

3.3.2 Fermentation of flour

The flour was fermented separately for each triplicate treatment having 1killogram flour by mixing with clean municipal water in the ratio of 1:2 (w/w) and 16 % of starter culture *(irsho*) which was previously prepared for each variety (Ashagrie and Abate, 2012). The plastic container was used for mixing all the above starting materials. The dough preparation was traditionally and kneaded by hand with continues addition of measured amount of water. The mixture was left to be fermented for 72 hours at ambient temperature (22-26°C). After 72 hours of primary fermentation, the supernatant liquid which was slightly yellowish watery that settled on the surface of the fermented batter was decanted. For every 1 kg of original flour, 200 ml of the fermented mixture was mixed with 400 ml of water and boiled (traditionally known as *'absit'*) using aluminum saucepan on a hot plate with a continues stirring for about 5min. The cooled *absit* (below 50^{o}C) was added to the main part of fermented batter and thoroughly mixed with stirring (Ashagrie and Abate, 2012).

Then the amount of water added to thinning onto the main batter was varied into different measured portion to obtained variable viscosity for each treatment. The batter was covered and left for the second fermentation to occur. As a result after 2 hours the noisy air bubbles due to CO_2 gas was formed which indicates that the fermentation has occurred and lasted (Ashagrie and Abate, 2012; Desiye and Abegaz, 2013). The fermentation process was separately prepared for each three teff varieties and blended teff flour in triplicate.

Figure 3.3.2 Triplicate samples of fermentation of Blended Tef flour.

3.3.3 Baking of injera

Injera was baked from fermented batters which have completed all its process as mentioned in the above method. A plastic beaker (jog) was filled with appropriate amount of batter (fermented dough) and poured out onto the hot clay electric plate, in a circular motion. The baking temperature was between $190^{o}C$ to $210^{o}C$ controlled by checking using thermometer. After 2.5 - 3 minutes with steam cooking injera was removed from the hot clay electric plate, *mitad* (Ashagrie and Abate, 2012). The injera which was baked for each varieties and blended teff flour was collected separately and cooled to room temperature for further analysis.

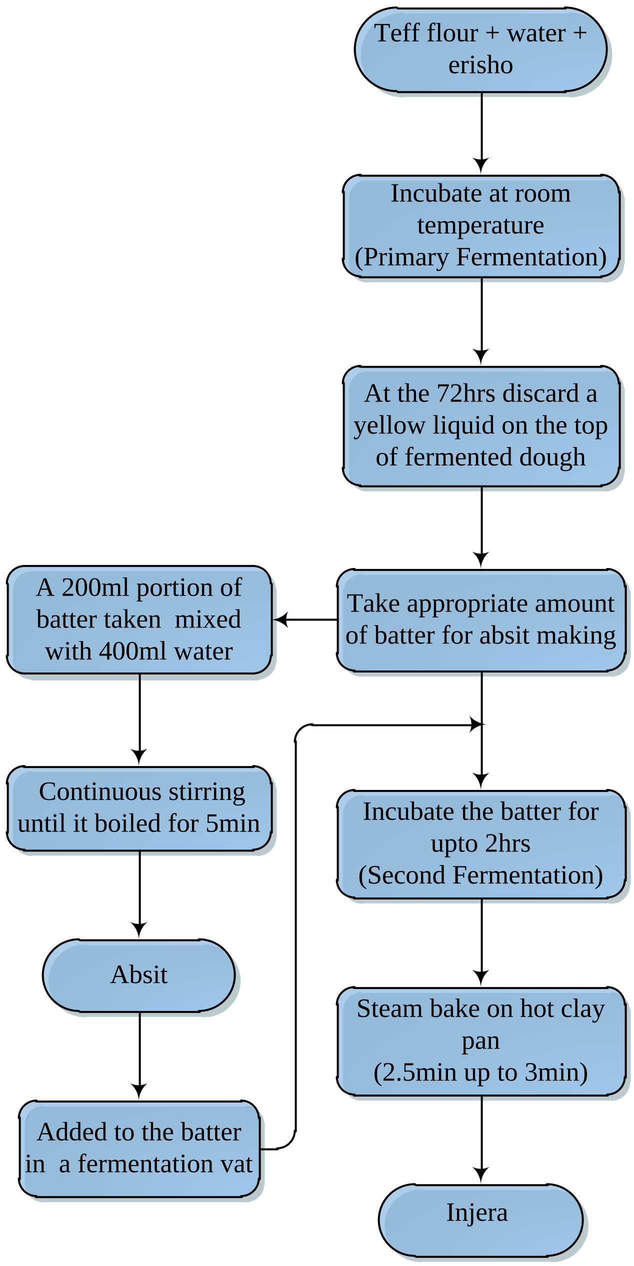


Figure 3.3.3: Injera baking flow chart

3.4 Analysis methods

3.4.1 Functional properties of flour

3.4.1.1 Moisture Content of Flour

The moisture content of the teff flour and blended flour samples (2gm) were determined by drying at a temperature of 115°C using instant moisture analyzer (AND model ML-50, made in Japan). The percentage of the moisture content were displayed on the LCD screen as the whole moisture released off with a peep sound at the end of the process. The sample was analyzed in triplicate.

3.4.1.2 Water Holding capacity (WHC)

The water holding capacity (WHC) of the samples was determined according to Inglett et al., (2016). Each sample (2 g, dry weight) was mixed with 25gm of distilled water in 50 ml capacity of cupped falcon tube. Then the samples were mixed vigorously for 1min to form homogenous suspension using a Vortex stirrer. After mixing, the samples were held for 2 hour and centrifuged at 1,590rpm for 10min using a centrifuge model ROTOFIX-32A (made in Germany). Each treatment was replicated in triplicate. Water holding capacity (WHC) was calculated by the difference between the weight of water added (Wad) and water decanted (Wd) which as reported on dry basis (g of water absorbed /100 g of dry sample) (Inglett et al., 2016).

$$WHC = (Wa - Wd) \qquad \textbf{(3.4.1.2)}$$

Where, Wa weight of water added

Wd weight of water decanted

Figure 3.4.1.2 Centrifuge used in the WHC determination

3.4.2 Physicochemical analysis of flour

3.4.2.1 Amylose content Determination

Amylose content of Teff flour was determined with the Megazyme assay kit (Megazyme, Ireland 2015) according to the assay Procedure stated in k-amyl 106/15. Amylose content was determined from the flour of teff samples by taking 30mg on dried basis. Then the sample was treated according to the k-amyl l06/15 test procedures. The calibration curve was performed using the starch reference sample (with specified Amylose content) and regression equation was designed for the calculation of the samples flour amylose content. After all the necessary procedures and steps was taken to extract the sample according the method the absorbance was measured along with the standard D-glucose controls at the 510nm against the reagent blank. Each sample was treated duplicates. The Amylose content % (w/w) on dry basis was calculated using the formula below.

$$Amylose, \% \text{ (w/w)} = \left(\frac{A \ x \ DF}{Wd-m}\right) x \ \frac{1}{b} \qquad \textbf{(3.4.2.1)}$$

Where, A = absorbance read against the blank control

DF = the dilution factors

Wd = total starch weight on dried basis in the sample

m = the slope from the regression curve

b = the Y- intercept from the regression curve

3.4.2.2 Total Starch

Total starch for three different cultivars teff flour was determined using the Megazyme Total starch Kit (Megazyme, Ireland, 2016) according to the Assay procedure K-TSTA-50A/K-TSTA-100A 08/16 which includes AOAC Method 996.11 and AACC Method 76-13.01. The determination was done on 100.00 ± 1.00 mg of sample flour. All supernatants produced during ethanol washing steps were collected and pooled together and adjusted to 100mL with distilled water. Total supernatant D-glucose was quantified using glucose oxidase and peroxidase, a dye forming system, with spectrophotometer reading at 510 nm according to the Starch Kit procedure. All the necessary steps and procedures was carried out according to the test method. A quality control was performed by using the standard regular maize starch from the Assay kit which has the actual content of starch on its label. A calibration curve was determined for the Glucose by using the GOPOD reagent. The total starch %, w/w, was calculated using the formula below on dried basis. The analyses were performed in triplicate and reported as an average for each sample.

$$Total\ Starch\ \%\ (\text{w/w}) = A\ x\ F\ x\ \frac{FV}{0.1}\ x\ \frac{1}{1000}\ x\ \frac{1}{FW}\ x\ \frac{162}{180}\ x\ 100 \qquad \textbf{(3.4.2.2)}$$

$$= \frac{A\ x\ F\ x\ 0.9}{FW}\ x\ 100$$

Where, A= absorbance read against the blank control

F= Conversion from the absorbance to µg = $\frac{100\mu g\ of\ D-glucose}{absorbance\ for\ 100\mu g\ of\ D-glucose}$

FV= Final concentration of the sample =100ml

0.1 =volume size of diluted sample that being analyzed using GOPOD reagent

1/1000 = Conversion from µg to mg

FW = initial dry flour weight = flour weight x (1 - % moisture content)

162/180 = conversion from free D-glucose to an hydro-D-glucose (as in starch)

3.4.2.3 Pasting properties of teff flour

Pasting was conducted using a Rapid Visco Analyzer (RVA Perten-2017, Australia). A sample 3 g; of a respective teff flour was mixed to form slurry by suspending in distilled water to the total weight of 28 g. Then it was run according to a Standard Condition described by the RVA Perten-2017 manual. The heating and mixing profile for the short pasting condition with an initial stirring speed of 960rpm at 50^{o}C for 30s was used and then stirring speed was reduced to 160 rpm for the entire period thereafter. The temperature was increased at a constant rate of to 95^{o}C and held at this temperature for 3.0 min. The paste samples were then cooled at a constant rate until the temperature reached 50^{o}C at the end of the trial at 13 minutes. Results were analyzed in terms of pasting temperature, peak viscosity, breakdown and setback (difference between final viscosity and trough). All measurements were repeated in duplicate

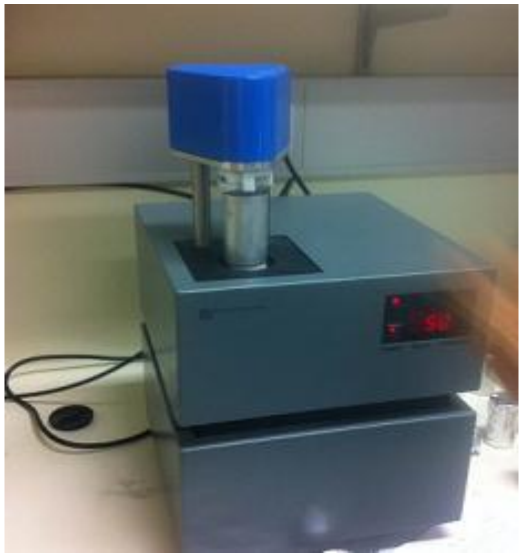


Figure 3.4.2.3: Perten RVA instrument

3.4.3 Physicochemical analysis of the product

3.4.3.1 PH of batter

The pH of the fermented samples ready to bake was measured directly with scientific electronic bench top pH meter of Nine series (model 902 made in China) after calibrating with buffers at pH 4.0 and 7.0. The pH electrode was immersed in the beaker containing the teff batter (fermented), and a stable result was recorded.

3.4.3.2 PH of Injera

Injera sample (10 g) was weighed and mixed with 100 mL of distilled CO2 free water and stirred vigorously. The supernatant solution was decanted into a 250 mL beaker. The supernatant solution PH was measured using scientific electronic bench top pH meter of Nine series (model 902 made in China). The pH electrode was immersed in the beaker containing the supernatant solution, and a stable result was recorded.

3.4.3.3 Viscosity of Batter

In the experiment to see the effect of viscosity on weight of injera, a rotational digital viscometer made of Thermo Scientific (model HAAKE viscotester *E*, R-version V 1.1, made in Spain) was used to analyze the apparent viscosity of the teff batters. The instrument was leveled and the appropriate spindle number R7 with a suitable RPM set. The selected measuring feature was displayed on the LCD of the instrument. The selected and loaded spindle was immersed up to the mark into the beaker containing the sample. The viscosity of the batter was measured just before baking for all the samples by controlling the temperature using water bath at 25 ± 1^{O}C (Xu, Y., et al. 2014).

Figure 3.4.3.3a: Water bath used for temperature control

Figure 3.4.3.3b: *HAAKE* Viscometer used for Viscosity measuring

3.4.3.4 Weight of Injera

The weight of injera was measured for the sample after attained the ambient temperature using the electronic digital mass balance OHAUS (model GT800, made in USA). The measurement for the weight of injera was done for each variety and blended batter in triplicate.

Figure 3.4.3.4 Weight of Injera measuring

3.4.3.5 Weight per ml of batter

Weight per ml of the samples was determined using pycnometer. The digital balance and distilled water were used to determine the sample density. The pycnometer was dried with air oven at 105°C and the weight of empty pycnometer measured (W1). The pycnometer was first filled with distilled water and weighed (W2) and then the pycnometer containing the batter sample (W3) was measured. The result was calculated using the formula below (Noureddini, H., et al., 1992).

$$\text{Weight per ml} = \frac{W3-W1}{W2-W1} \qquad \textbf{(3.4.3.5)}$$

Where, W1 weight of empty pycnometer

W2 weight of pycnometer filled with water

W3 weight of pycnometer filled with sample

3.4.3.6 Moisture Content of Injera

The moisture content of injera samples (2gm) were determined by drying at a temperature of 115°C using instant moisture analyzer (AND model ML-50, made in Japan). The percentage of the moisture content were displayed on the LCD screen as the whole moisture released off with a peep sound at the end of the process. The sample was analyzed in triplicate.

3.4.3.7 Moisture content of Batter

The moisture content of batter samples (2gm) were determined by drying at a temperature of 115ºC using instant moisture analyzer (AND model ML-50, made in Japan). The percentage of the moisture content were displayed on the LCD screen as the whole moisture released off with a peep sound at the end of the process. The sample was analyzed in triplicate.

Figure 3.4.3.7: Instant moisture analyzer

3.4.3.8 Number of eyes on Injera

The number of honeycomb-like or eye on the surface injera was determined by counting the number of eyes on a portion of sample 3cm x 3cm taken from four different parts from full injera. Therefore, the number of eyes was reported as No. of eye/cm2 using the formula mentioned below (Cherinet, 1988).

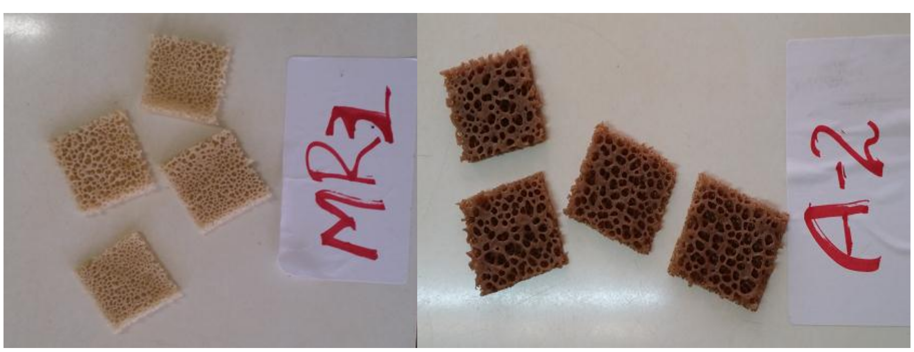


Figure 3.4.3.8: Pieces of injera Portion for eye counting

$$\text{No. of eyes} = \frac{total\ No.of\ eyes\ on\ injera}{3cm\ x\ 3cm\ piece\ of\ injera} \qquad \textbf{(3.4.3.8)}$$

3.4.3.9 Diameter of Injera

The diameter of injera which is related to the size shall not be less than 51cm. therefore the size of teff injera was measured using measuring tape (ESA, 2013).

Figure 3.4.3.9: Injera diameter measurement

3.5 Experimental design and statistical data analysis

Pearson correlation coefficient (r) was calculated between the weight and viscosity measured variables using IBM SPSS statistic version 20.0.0 from the correlation curve. Correlation analysis was used to determine, estimate or predict the strength of the correlation between Viscosity of ready to bake teff batter and weight of injera. Then the model was designed by applying regression Analysis. The XLSTAT 2014.5.03 software was used for the PCA analysis in order to have directionally reduced components.

CHAPTER 4
RESULTS AND DISCUSSION

Some processing parameters like viscosity, fermentation time, baking time and other have an effect on the overall quality of injera. In this study experiments were conducted to determine how viscosity affects weight of injera, which is an important injera condition especially in the manufacturing sectors. The experiments also have a look at different parameters which could have some effects on the overall viscosity of teff batters. The viscosity of teff batter before baking is clearly different from home to home. Therefore the viscosity and weight from different 31 households were collected and measured and were compared in order to be used as a benchmark and also to determine the acceptable model. Some studies like pasting profile, total starch and % of Amylose of the three Cultivars of teff flours were conducted in order to see the change in viscosity of batters is not only from the amount of water added only.

4.1 Measurement of viscosity of batter and weight of injera from different households

It is clear that households use different fermentation process of teff or blended teff flour for injera baking. About 31 households were visited randomly based on their willingness for the observation of the correlation between viscosity and weight of injera. The weight of injera were measured using a portable digital balance when it was completely cooled at room temperature. Then the batter were collected at the time of baking and stored in refrigerator at $4^{O}C$ and then viscosity was measured at the EPHI laboratory using Thermo Scientific HAAKE E viscometer.

The data arrangement (Table 4.1) of viscosity of batter and weight of injera from different households predicts the relation between the two variables. As clearly seen that the weight of injera increased with the viscosity of the batter ready to bake. From the correlation curve (Figure 4.1) the viscosity of batter ready to bake is found to be positively correlated (r^2 = 0.6139) with the weight of injera. From correlation curve between the weight of injera and viscosity of batter collected from different households it was clearly seen that the weight injera related positively with the viscosity of batter.

Table 4.1: Viscosity of ready to bake batter and weight of injera from different Households arranged in ascending order

Households	Viscosity of Batter mPaS	Weight of Ingera (gm)
HH-28	13097	277
HH-29	14325	297
HH-21	14577	289
HH-27	15665	275
HH-25	16008	307
HH-26	16597	282
HH-23	16643	279
HH-2	17974	287
HH-1	18904	293
HH-31	18995	289
HH-14	19478	336
HH-17	19480	313
HH-22	19555	296
HH-12	19790	331
HH-13	20119	356
HH-9	20320	350
HH-18	20341	329
HH-4	20905	309
HH-11	21318	404
HH-30	21349	323
HH-8	21386	387
HH-16	21839	336

HH-19	21875	354
HH-15	22354	359
HH-3	22382	297
HH-7	23075	380
HH-5	23875	363
HH-10	24177	420
HH-6	24693	393
HH-24	24887	359
HH-20	24903	372

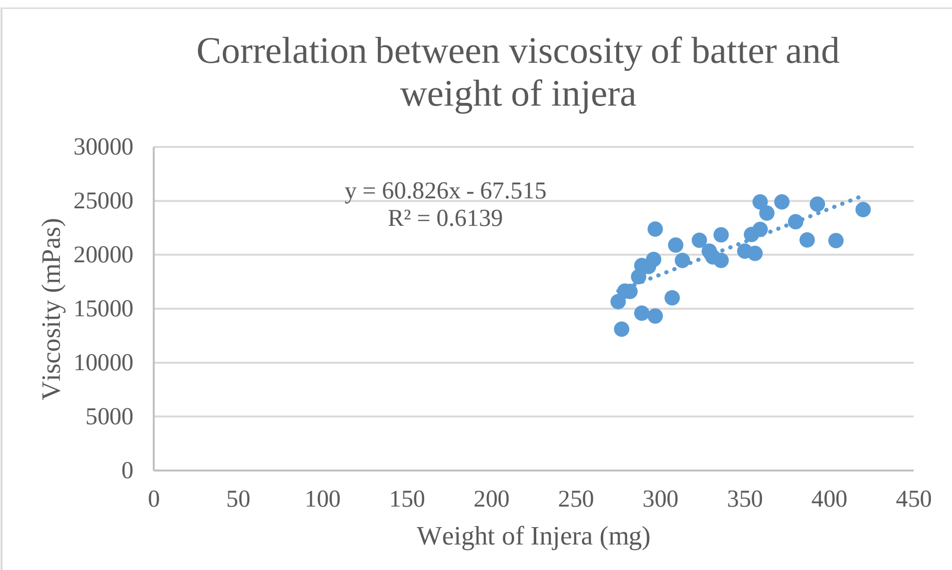


Figure 4.1: the correlation curve for viscosity of batter ready to bake and weight of injera

4.2 Functional Properties of flours

4.2.1 Moisture content of flours

The teff flour moisture content for all the cultivars were analyzed using instant moisture analyzer (model ML-50 brand of AND, made in Japan) and the result found (Table 4.2) ranges from 10.35% to 11.03%. On the other hand Bultosa, (2007) reported the moisture contents of 13 different varieties in the ranges 11.22%-9.30%. On the work of Abebe and Ronda, (2014), Abebe et al., (2015), the moisture contents of DZ-Cr-387 & DZ-01-99 are 10.4% & 10.5% respectively which are not significantly different from the values listed in Table 4.2.1. The moisture content of the flour were not significantly different from the other studies. Therefore, the tests which involves dry basis analysis might be reliable.

Table 4.2.1 Moisture content of flours

Flours	Moisture (%)
Teff-white (DZ-Cr-387)	$10.83^{a} \pm 0.74$
Teff-white (DZ-01-196)	$10.87^{a} \pm 0.17$
Teff-brown (DZ-01-99)	$10.17^{b} \pm 0.17$
Rice	$12.31^{c} \pm 0.09$
Blended Teff (DZ-Cr-387)-Rice	$11.74^{d} \pm 0.05$
Blended Teff (DZ-01-196)-Rice	$11.89^{d} \pm 0.12$

Values with different letters are significantly different (P< 0.05) and are means Of three determinations.

4.2.2 Water holding capacity (WHC)

The hydration properties of the flour is found significantly different (P<0.05) among the varieties as observed from the results (Table 4.2.2). According to the WHC results (Table 4.2.2), Teff-brown (DZ-01-99) has the lowest value 168.84g/100g as compared with the others and Teff-white **(**DZ-Cr-387) has highest 179.43g/100g. In the study conducted by Abebe et al., (2015), Teff-white **(**DZ-Cr-387) variety exhibits higher mean WHC (2.65g/g from mill 2) even as compared with other cereals like wheat and rice. The fiber contents of whole grain teff and particle sizes are some of the reasons which influence to increase the water binding capacity of flours Abebe et al., (2015). On the other hand the mineral contents (Ca & Mg) and protein affects the hydration properties of teff flours due to their interaction and formation of coagulation (Inglett et al., 2016). These interferences on WHC and other factors of the flours might determine the amount of flour to be hydrated. The flours with less hydration capacity requires more flours than the one with high hydration capacity to make dough. The flour with high WHC value might be preferable from economical point of view of the flour. On the other hand the results (Table 4.2.2) of the blended flours showed higher hydration capacity as compared to their respective unblended teff flours.

Table 4.2.2: The mean water holding capacity and moisture content with their STD.

Sample	WHC (g/100g)
Teff-white (DZ-Cr-387)	179.43ab ± 5.61
Teff-white (DZ-01-196)	170.10a ± 3.24
Teff-brown (DZ-01-99)	168.84a ± 8.50
Blended Teff (DZ-Cr-387)-Rice	200.17c ± 11.79
Blended Teff (DZ-01-196)-Rice	194.83bc ± 14.28

Values with different letters are significantly different at 0.05level

4.3 Physicochemical properties of flours

4.3.1 Amylose content of Teff flour

Table 4.3.1: Amylose content of teff flours

Cultivars	Prep	Sample mean Weight (mg)	Absorbance mean (nm)	Moisture (%)	Total starch (%) w/w	Dry starch weight (mg)	Amylose (%) w/w
Teff-white (DZ-Cr-387)	Flour	31.25	0.127	8.87	71.16	20.27	22.53
Teff-brown (DZ-01-99)	Flour	30.40	0.118	10.50	72.97	20.13	20.85
Teff-white (DZ-01-196)	Flour	31.65	0.121	7.41	72.35	21.20	19.87

The determination of amylose content is either from the extracted starch of flours on dried basis or directly using the flours of samples by considering the starch value as a compensation in the sample on dried basis (Bultosa et al., 2008; D'Silva et al., 2011). The amylose content of the three teff cultivars (Table 4.3.1) were significantly different and Teff-white (DZ-Cr-387) has highest amylose value 22.53(%) w/w whereas Teff-white (DZ-01-196) has the least amylose value (19.87%) w/w relatively. In the work of Bultosa et al., (2002) work on 13 different teff varieties, the amylose content from flour was determined by coneA method and the result ranges from 25.8% to 20.0%. Whereas the amylose content selected teff varieties in this work are ranges 22.53% to 19.87%. The result difference might be from the amount of other constituents like protein and moisture contents.

The amylose content are influenced by the moisture and the protein content and its results varies from literature to literature. The nature and content of Amylose has an impacts on the intrinsic properties of the viscosity of the flours (Yu et al., 2014).

4.3.2 Total Starch content

Table 4.3.2: Total starch for the teff flour

Sample Name	Mean Sample weight (mg)	Moisture %	Sample weight on dry basis (mg)	Absorbance mean at 510nm	Total Starch %, w/w
Teff-white (DZ-Cr-387)	100.40	8.87	91.50	0.77	71.16
Teff-brown (DZ-01-99)	100.53	10.50	91.24	0.79	72.97
Teff-white (DZ-01-196)	100.40	7.41	92.96	0.79	72.35

Starch for the three teff varieties were determined calorimetrically from their flours (table 4.3.2). The result of total starch for teff flours were reported by different literatures with a value of around 70%. Therefore those values for the three teff varieties reported in this work (Table 4.3.2) are not significantly different from those values reported by other literatures (Abebe and Ronda, 2014). From the three teff varieties Teff-brown (DZ-01-99) has the highest total starch value 72.97% whereas Teff-white (DZ-Cr-387) has the lowest value 71.16%. In the work of Abebe and Ronda, (2014) the total starch content reported for Teff-brown (DZ-01-99) and Teff-white (DZ-Cr-387) 75.5% without significant difference between them. A quality control sample maize starch of known starch content was analyzed with the sample for validating the Con A method.

4.3.3 Pasting Properties of starch

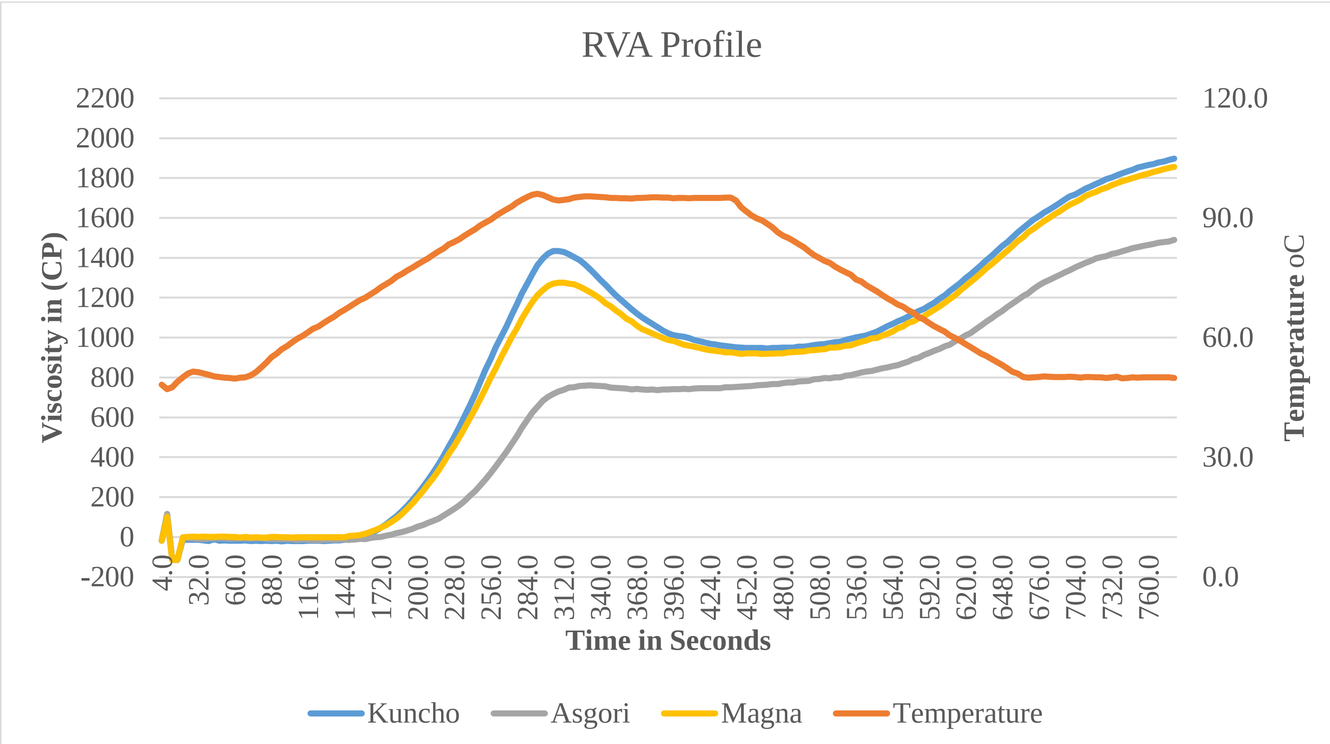


Figure: 4.3.3: Pasting profile of different varieties of teff flour

Pasting properties of the three teff flours was analyzed with RVA pertain model for it has a significant implication of the starch properties over the temperature which is characterized by the viscosity it exhibits. Pasting characteristics of all the three varieties teff flour were investigated using the RVA in order to summarize how the viscosities vary. Therefore, the pasting properties of each varieties are graphically (figure 4.3.3) explained according to their difference in their viscosities against pasting temperature and pasting time. The pasting temperature, peak time, Peak temperature, peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown viscosity (BV) and setback viscosity (SV) were calculated from the pasting curve. The results are reported in Table 4.3.

Table: 4.3.3: The pasting profile parameters of the three teff varieties analyzed by RVA

	Teff-white (DZ-Cr-387)	Teff-brown (DZ-01-99)	Teff-white (DZ-01-196)
Pasting temp (^oC)	72.7[a]	78.4[b]	72.6[a]
Peak Viscosity (cP)	1434.5[a]	759.5[b]	1275[c]
Final Viscosity (cP)	1897.5[a]	1490.5[b]	1855.5[a]
(Hot Past) Trough viscosity (TV)	947.5[a]	736.5[b]	917[a]
Breakdown Viscosity (cP)	487[a]	23[b]	358[c]
Setback from trough (cP)	950[a]	754.5[b]	938.5[a]
Peak Time (secds)	308[a]	332[b]	312[a]
Peak Temperature (^oC)	94.4[a]	95.5[a]	94.5[a]

The mean Values of the above pasting profiles with different letters are significantly different at 0.05level.

From the three teff varieties the Teff-brown (DZ-01-99) has shown significantly different in most pasting profiles than the other two varieties. The Teff-brown (DZ-01-99) (Table 4.3.3) has higher in pasting time, peak time and peak temperature respectively. Pasting temperature of the Teff-brown (DZ-01-99) showed highest pasting temperature 78.4^oC which means an approximate gelatinization temperature of Teff-white (DZ-01-196) 72.6oC and Tef-white (DZ-Cr-387) having the pasting temperature 72.7^oC respectively. The report by Bultosa, (2007) from the work by Brabender Amylograph has shown the pasting temperature of 13 teff varieties ranges in (75.9 - 67.7)^oC. Specifically the Teff-brown (DZ-01-99) has a value of 73.7^oC whereas Teff-white (DZ-01-196) has a value of 72.6^oC in the report. By the same Author in 2002 the peak temperature for Teff-brown (DZ-01-99) reported 74.2 ^oC. So the results obtained in this study might be due to the same reason that differs from the other studies. Therefore the highest pasting temperature could be due to the starch particle size from milling, or from RVA running parameter.

The other pasting profile result were the peak viscosity (PV) which is one of the basic characteristics of most starches. In this work (Table 4.3.3) the peak viscosities of the three teff varieties were compared. The Teff-brown (DZ-01-99) has the lowest PV value 759.5cP whereas on the other hand the other two white teff; Teff-white (DZ-01-196) and Teff-white (DZ-Cr-387) has 1275cP and 1430cP respectively. Teff-brown (DZ-01-99) reported with the lowest PV in the work of (Bultosa, 2007) which was from its extracted starch. When we compare the two white teff with their PV values in this work Teff-white (DZ-Cr-387) (1430cP) has highest. The PV predicts some defined properties of the flour and affected by the thickening ability, water holding capacity of starchy flours, granule size, molecular structure of amylopectin, cross-linking, and starch - water concentration, lipids, residual proteins and RVA operating conditions (Bultosa, 2007; Ali et al., 2014; Abebe et al., 2015; Truong et al., 2017).

The final viscosity (FV) for the three Teff varieties was compared and Teff-white (DZ-01-196) and Teff-white (DZ-Cr-387) has FV with a little difference of 42.0cP. Whereas the other Teff variety Teff-brown (DZ-01-99) has a significantly lower FV value 1490.5cP from the two white Teff (Table 4.3.3). On the work of Abebe et al., (2015) the final viscosity value for Teff-white (DZ-Cr-387) is higher than that of Teff-brown (DZ-01-99) in both milling type flour. In this work also the Teff-white (DZ-Cr-387) has the highest FV value 1897.5cP which is 42.0cP higher than the Teff-white (DZ-01-196). The change in FV (Table 4.3.3) between the three Teff varieties might indicate slow re-association of starch molecules at 50°C after cooling from 95°C and as a result causes an increase in the viscosity. Abebe et al., (2015) explained that the final viscosity (FV) did not influenced by the teff cultivar type. Final viscosity shows the ability of the material (flour) to form a viscous paste due to the retrogradation process of soluble amylose as the temperature cools down (Ali et al., 2014, Abebe et al., 2015). However, the final viscosity was explained by the same author to be influenced by the effect of milling which is the particle size where it was not considered in this work. The variation of results between the teff varieties in this study might be due to the above reasons.

Trough viscosity (TV), the other RVA profile, obtained for the teff flours (Figure 4.3.3). The TV indicates the minimum apparent viscosity value of hot paste recorded upon continuous shear thinning of the gelatinized system at high temperature for 192secs (Ali et al., 2014). The TV reflects the degree of the disintegration of the swollen systems and alignments of amylose and other linear flour components in the direction of the shear (Bultosa, 2007). There is no much difference observed (Table 4.3.3) between the two white teff even in their TV values except having a difference 30.5cP. The other teff variety Teff-brown (DZ-01-99) has a significant difference in the TV value 736.5cP than the white Teff; Teff-white (DZ-01-196) and Teff-white (DZ-Cr-387) – 917cP and 947.5cP respectively.

The setback viscosity (SBV) of the flour (Table 4.3.3) were obtained from the RVA chart (figure 4.3.3). The apparent viscosity values are the difference of TV from the FV. The setback viscosities for the Teff-white (DZ-01-196) and Teff-white (DZ-Cr-387) were found to be almost insignificantly different in their values 938.5cP and 950cP respectively. On the other hand the Teff-brown (DZ-01-99) setback viscosity was 754.5cP which was lowest and quite different from the two white Teff. In the work of (Bultosa et al., 2002) the Teff-brown (DZ-01-99) was reported with the minimum SBV value. The SBV is an indication of the gel syneresis which is likely to take place based on the starch nature and degree of retrogradation as the temperature goes cool down (Bultosa et al., 2002). In other words the SBV shows how the viscosity of the paste the teff flour suspensions recovered as the temperature cools down (Abebe et al., 2015). The same author explained that the gel syneresis formation in teff starch is lower than maize and other cereals starch.

The breakdown viscosity (BV) of the flour (Table 4.3.3) were obtained from the RVA chart (Figure 4.3.3). The apparent viscosity values for the three Teff varieties were obtained by the difference of TV from the PV. The breakdown viscosity (BV) values (Table 4.3.3) for the three teff verities were significantly different. The breakdown viscosity (BV) of Teff-brown (DZ-01-99) (23cP) was the lowest whereas the Teff-white (DZ-Cr-387) the highest BV value 487cP. The low breakdown viscosity values indicated the low swelling ability of the teff flour and the high of values also indicated the high swelling ability. The breakdown viscosity (BV) is an indication of holding strength of starch which is to hold more water. It also indicates that the ability of starch resist temperature and require longer baking time (Ali et al., 2014, Pongjaruvat et al., 2014).

4.4 Physicochemical Analysis of Injera and batter

4.4.1 pH of injera and batter

The sourness test of traditionally fermented Ethiopian injera is one of the sensory attributes impacted by pH due to changes in Lactic acid concentration during fermentation (Yigzaw et al., 2004; Uraga and Narasimha, 1997). The literature by Uraga and Narasimha, 1997 on the 96 hrs fermentation conducted the pH value is reported to be 3.83. The pH reading (Table 4.2.2) measured immediately at the time of baking was slightly varies among the varieties and according to viscosity changes. Even disregarding pH changes due to viscosity of the batter, it can be observed the overall lowest pH values (Table 4.2.2) for Blended Teff (DZ-Cr-387)-Rice and relatively highest for Teff-white (DZ-01-196). In all pH readings (Table 4.2.2) for the batter; it is observed that the slight change observed as the viscosity varies within the same variety.

Urga et al., (1997) reported that the pH was totally dependent on the lactic acid content in the fermented batter at the day of baking and showed that the decrease in value as the fermentation time increased (Attuquayefio, 2014; Urga et al., 1997). The contribution of moisture content, amylose content and starches contents of the starting materials are significant in affecting the pH value during the fermentation process due to the amount of fermentable sugars (Sahlin, 1999). On the other hand pH readings for the fermented batters are affected by the buffering effect of the protein content and a relation on the concentration of free amino acids, total nitrogen content (Yigzaw et al., 2004; Urga et al., 1997).

The pH readings (Table 4.2.2) for injera observed the same as that for batter among the teff variety but there was slight increment in pH values compared to the batter for injera. This is due to the decrease in the moisture content by baking caused a change in pH. In the thesis work of Attuquayefio, (2014) the inverse relationship between the pH and moisture content was reported for commercial available injera ranging 3.65 (60.40%) to 4.02 (44.46%). Even the pH readings of injera (Table 4.2.2) for the variable viscosity of batter of the same teff variety; there was variations. In different literatures the pH readings of injera is reported with different figures for variable reasons like fermentation time, the removable supernatant liquids remedies and the amount of back-slope *(erisho*) used (Yigzaw et al., 2004, Urga et al., 1997). All in all the ESA has set the pH of teff injera to be in the range 3.45 to 4.0. As a result the values of pH obtained was no significantly different from the set values of pH by (ESA, 2013).

Table 4.4.1: pH values for Injera and Batter

Sample	pH of Batter	pH of Injera
Tef-white (DZ-Cr-387)	4.01	4.03
	4.02	4.05
	4.05	4.08
Tef-white (DZ-01-196)	4.03	4.13
	4.09	4.15
	4.11	4.19
Tef-brown (DZ-01-99)	3.88	4.03
	3.89	4.06
	3.91	4.08
Blended Teff (DZ-Cr-387)-Rice	3.85	4.00
	3.86	4.03
	3.88	4.05
Blended Teff (DZ-01-196)-Rice	3.92	4.05
	3.90	4.08
	3.94	4.10

4.4.2 Viscosity of Batter

The single apparent viscosity of the batters were measured at the time of baking for each teff varieties and blended flour. Therefore, the Teff-brown (DZ-01-99) shows the highest viscosity (24859mPa.s) within the same viscosity category while the Blended Teff (DZ-01-196)-Rice shows the least viscosity (18697mPa.s) (Appendix A). The two blended Teff (DZ-Cr-387)-Rice and

Blended Teff (DZ-01-196)-Rice flour showed higher viscosity values than their respective teff flour within the same viscosity groups seen in Appendix A. The increase in viscosity value for the blended flour might be due to the starch nature of the rice. Measurements of viscosity for the fermented batters and the paste are quite different due to the structure of the starch and other components of the flour. The viscosity values for the fermented batter were influenced by the *absit* added and due to the amount air bubbles as fermentation takes place (Attuquayefio, 2014). Therefore, there were clear difference on the texture and eyes of injera for each batter with different viscosity. This part of phenomenon is a research gap where it needs an intensive work how viscosity and eyes of injera correlated. On the other hand, a report by Admassu, (2006), the viscosity of batter was indicated to be in the range 200-1500 centipoise for an injera. Therefore, viscosity of batter mixture reported in different work was found variable due to the required quality attributes of the final product.

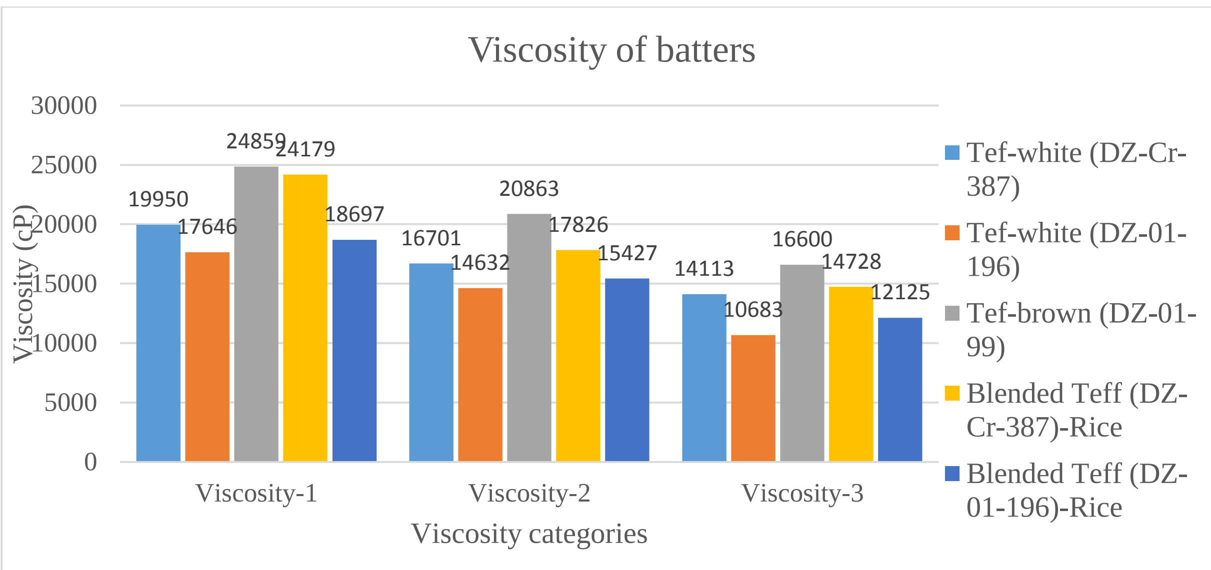


Figure: 4.4.2: The viscosity exhibited by the different teff varieties and blended teff flour

Note: In Viscosity-1 750ml of water used
In viscosity-2 1000ml of water used
In viscosity-3 1250ml of water used

The batters have different viscosity values at the same amount of water added for each batter whereas as the amount of water added increased for each viscosity category the viscosity decreased for the group of batters. So as clearly seen in the Figure 4.4.2 (Viscosity-1, -2, -3), the variable viscosities values showed by the batters might be due to other factors of the flour.

4.4.3 Weight of Injera

The weight of injera was measured for each batters at different viscosity (Annexure 4.4.3). The weight of injera decreased as the viscosity decreased for each flour which was treated under the same conditions by controlling all the other factors. Within the same viscosity category the Teff-brown (DZ-01-99) shows the highest weight while the Teff-white (DZ-Cr-196) the lowest weight observed (Appendix B). The weight of baked products are dependent on the amount of moisture loss during baking, the temperature used for baking, time of baking and the water flour ratio. In this work temperature of hot clay plate *mitad* was continuously checked using a thermometer in order to control and maintain same temperature throughout the baking process (190ºC to 210ºC). The weight of injera all in all varies as the viscosity of the batters varies respectively. This was observed as the two results were correlated accordingly. Regardless of the viscosity and other factors the weight of teff injera has to be 310gm and above based on the customers interest (ESA, 2013).

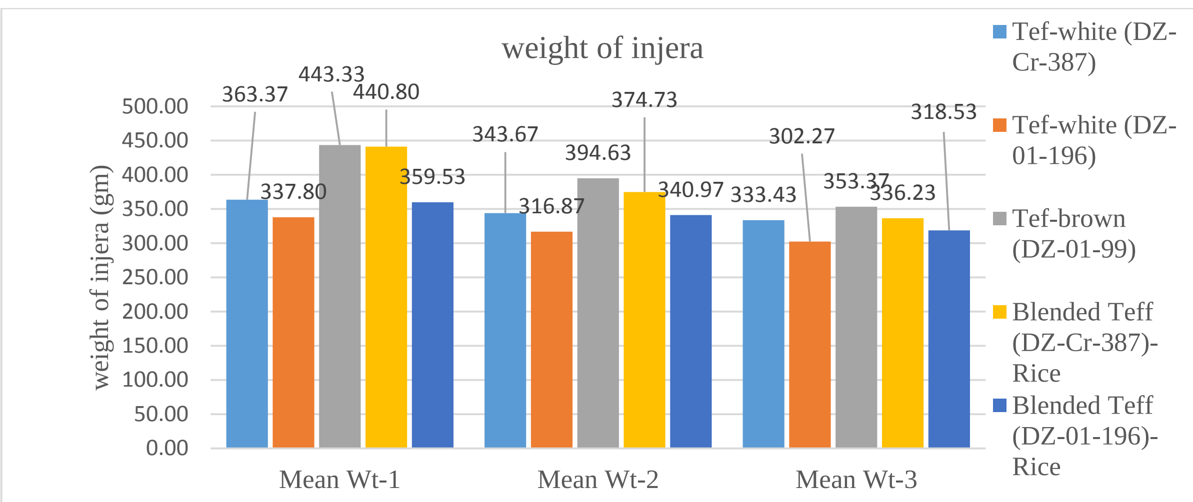


Figure: 4.4.3: The weight of injera for the teff varieties and blended teff flour at variable viscosities

Note: Mean Wt-1= the weight of injera from the batter that uses 750ml water
Mean Wt-2= the weight of injera from the batter that uses 1000ml water
Mean Wt-3= the weight of injera from the batter that uses 1250ml water

4.4.4 Weight per milliliter of batter

The relative density of all the teff and blended batters were measured at the time of baking (Appendix C). The Teff-white (DZ-01-196) shows the lowest values in all category whereas blended Teff (DZ-Cr-387)-Rice the highest values comparatively. The relative density of a viscous product indicates the concentration that the materials or substances dissolved (Nzoureddini, H., et al. 1992). Therefore it could be one of good indicator of the flour to water ratio which might help to control for the consistency of the product. The relative density is widely used for descriptive properties of different liquid products and it is widely used in oil, sugar and liquid flavor industries (Noureddini et al., 1992). Once the relative density is obtained it will be easy to find out the weight of batter. Therefore the batter will be filled in predetermined volume of container for one injera baking. These will be continuously checked to control the viscosity of batter while baking. The weight per ml of batter decreases as the amount of water used varies from 750ml to 1250ml. On the other hand the flours batter showed variable weight per ml even in the batter that uses 750ml of, 100ml and 1250ml water respectively.

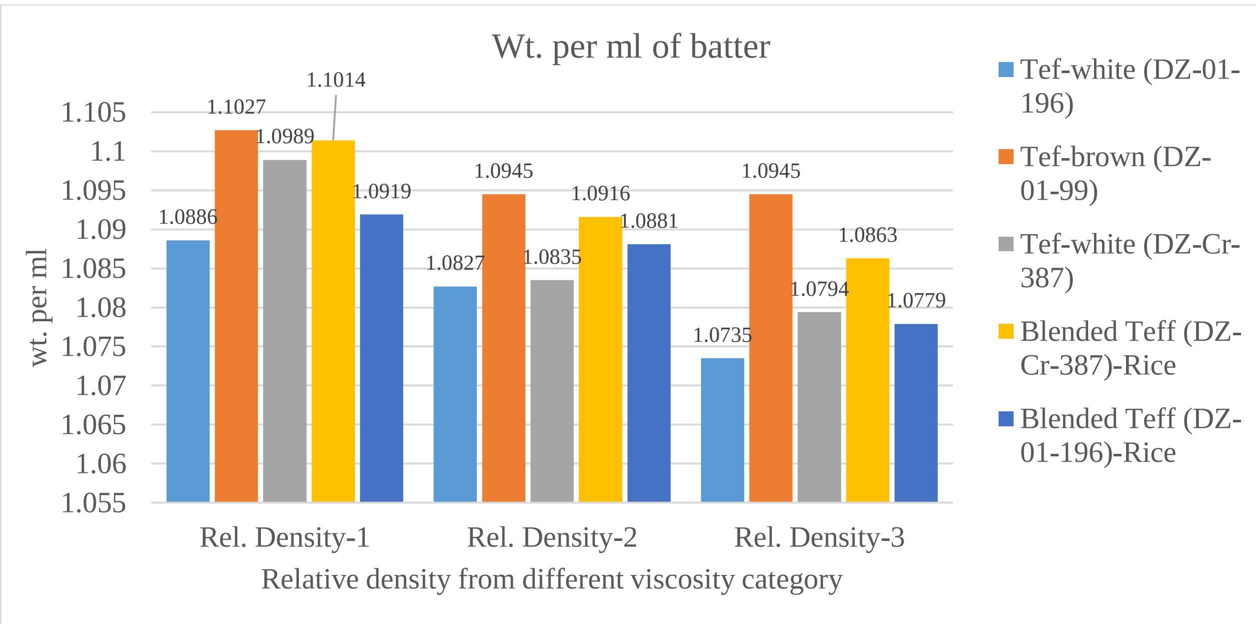


Figure 4.4.4: The weight per ml of flour batter for different teff variety and blended teff.

Note: Rel. Density-1 = the relative density of batter that uses 750ml of water
Rel. Density-2 = the relative density of batter that uses 1000ml of water
Rel. Density-3 = the relative density of batter that uses 1250ml of water

4.4.5 Moisture Content of Injera and Batter

The moisture content for both the teff and blended flour batters and injera were determined by instant moisture analyzer (AND model ML-50, made in Japan). The moisture content of injera for each varieties of teff and blended flour increased accordingly as the measured content of water for each batters increased and varies 63.2% to 73.2%. On the other hand the moisture content for injera from the batter with the minimum amount of water used ranges 63.2 to 67.43%. In some literatures the moisture content are reported to be 65.23% for injera baked at 72hr on the other literature it was found in the range 62-65% (Ashagrie and Abate, 2012; Attuquayefio, 2014). On the contrary, the moisture content for the batter observed were higher relatively the moisture content of the injera and ranges from 73.30% to 82.03%. In the specification for Ethiopian injera the moisture content that the injera should have indicated as 58% to 63% (ESA, 2013). All in all, the moisture content of injera was found lower than that of the moisture of batter.

Therefore the more water content in the batter making used will result the more moisture content in the final product. The moisture content in the product might affect the water activity level which is responsible for the microbial growth and affects the shelf life of the product (Ashagrie and Abate, 2012).

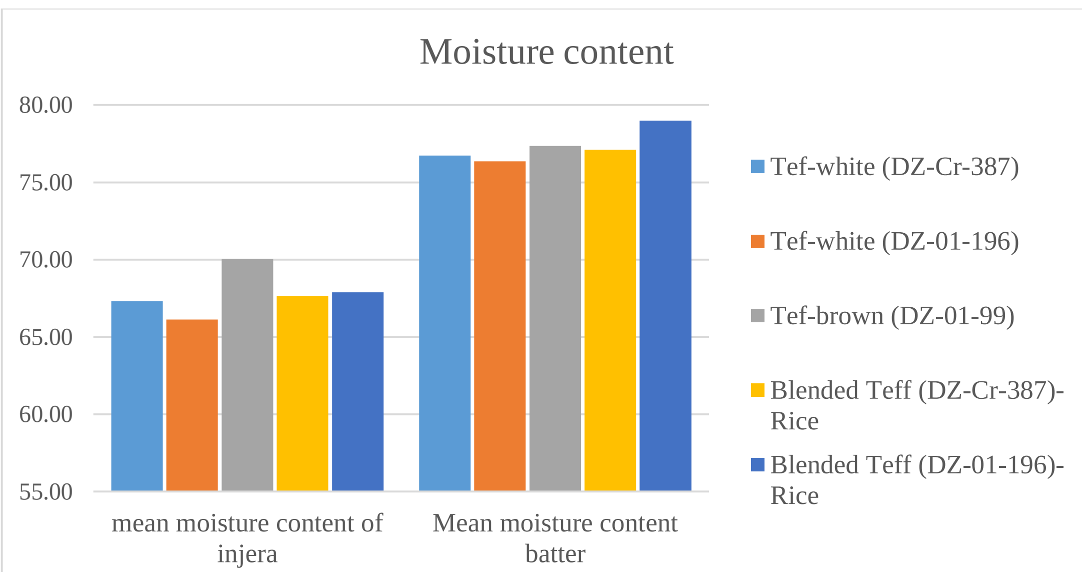


Figure 4.4.5: The moisture content for the batter and injera.

4.4.6 Number of eyes on Injera

Table 4.4.6 The No. of eyes per unit area of injera backed with different viscosity of batter

Sample	Sample at Viscosity-1	Sample at Viscosity-2	Sample at Viscosity-3
Teff-white (DZ-Cr-387)	12.94^{a}	13.36^{a}	14.22^{a}
Teff-white (DZ-01-196)	11.75^{a}	12.83^{ab}	13.81^{b}
Teff-brown (DZ-01-99)	6.03^{a}	8.33^{b}	12.22^{c}
Blended Teff (DZ-Cr-387)-Rice	14.67^{a}	15.39^{a}	20.36^{b}
Blended Teff (DZ-01-196)-Rice	12.00^{a}	15.78^{b}	22.53^{c}

The mean Values of the above number of eyes on injera with different letters are significantly different at 0.05level as the viscosity of their batter varies.

Note: Sample at viscosity-1 injera from the batter that uses 750ml
Sample at viscosity-2 injera from the batter that uses 100ml
Sample at viscosity-3 injera from the batter that uses 1250ml

The number of eyes on injera were determined and reported in this work per unit area by counting the eyes on 3cm x 3cm piece of injera. Four portion from different parts of injera were taken for the determination of the number of eyes. There were some variation on the size of the eye nuclei observed for injera obtained from variable viscosity. The Teff-brown (DZ-01-99) injera showed the smallest number of eyes compared to the other teff varieties and blended teff injera (Table 4.4.6). Therefore the result in Table 4.4.6 indicated that the viscosity of the batter at the time of baking have impacted on the number and other characteristics of eyes. On the other hand it was clearly seen that the number of eyes on injera had slightly close each other in the same category of viscosity (Table 4.4.6). The number of eyes for Teff-brown (DZ-01-99) was found minimum number of eyes on injera as compared to the others. The viscosity of this variety of teff was seen maximum of all the others varieties as a result the viscosity has impacted the number of eyes on injera of Teff-brown (DZ-01-99). Teff-brown (DZ-01-99) showed minimum number of eyes on injera which is due to high viscosity of its respective batter. In 750ml of water used batter the viscosity Teff-brown (DZ-01-99) was 24859cP with the minimum number of eyes on injera 6.03eyes per cm^2 as compared to the other teff varieties. On the other hand as the maximum water (1250ml) used the viscosity of Teff-brown (DZ-01-99) was16600cP and the number of eyes 12.22eyes per cm^2. So it was clrearly seen that the viscosity have impact on the number of eys.

There are different ways of determination of the number of eyes on injera reported by different authors. Like in the Thesis work of Attuquayefio, (2014) the number of eyes determined by image analysis of injera using flatbed scanner for batters at different fermentation hrs. There is a lack of defined specification for the definite total number of eyes that the injera should have. In addition to the texture, the eyes of the injera are one of the major quality attributes. In some literature the eyes of injera explained not to be too few or to many on the surface of injera.

4.4.7 Diameter of Injera (Size of Injera)

The diameter of injera totally depends on the diameter of baking clay stove *mitad*. Injera was backed by covering the whole part of the electric mitad in a circular thin form which helps injera to have the diameter. The size of teff injera is taken into account because the standard agency has set the minimum size to be 51cm in diameter. Therefore during the whole course of the work the size was checked using a measuring tape. So the diameter of injera was found 51cm on average (ESA, 2013).

4.5 Correlating viscosity with the weight of injera and other variables

Pearson correlations between numerous variables in Teff injera processing and their corresponding characteristics of the batter were deduced (Table 4.5.1). The P-values for each variables correlation significance level also analyzed as shown in Table 4.5.2. The Pearson correlation of viscosity variable with the othe variables were found both negatively and positively and their significance level also varied (Table 4.5.1).

Using Pearson correlation analysis, a range of correlation coefficients (r) (from -0.675 to 0.958) was obtained for the relationships between viscosity and the other variables; weight of injera, pH of injera, pH of batter, moisture content of injera, weight per ml, number of eyes, Moisture content of batter.

From the Table 4.5.1 the variable viscosity was found strongly correlated to the weight of injera ($r = 0.947$, $P \neq 0.00$) with significant values. The other strong correlation of viscosity observed with the weight per ml of the batter $r = 0.958$, $P \neq 0.0$. However, the pH of injera ($r = -0.459$, $P = 0.085$)

and the moisture content (r = -0.399, P = 0.140) negatively correlated with viscosity but not to significant extents. Whereas the other negatively correlated variables with viscosity were the pH of Batter (r = -0.522, P= 0.046), moisture content of batter (r= -0.675, p = 0.006) and the number of eyes on injera (r = -0.596, P = 0.019) to the significant extent.

The Pearson correlation of the weight of injera with the other variables were found most of them negatively correlated except the weight per ml variable (r = 0.898, P < 0.0001) which is positively correlated with significant extents. The strong negatively correlated variables the pH of injera (r = -0.622, P = 0.013) and the pH of Batter (r = -0.639, P = 0.010) were found with the weight of injera to the significant extents. However the other variables the moisture content of injera (r = -0.205, P = 0.463), the moisture content of batter (r = -0.493, P = 0.062) and the number of eyes (r = -0.459, P = 0.085) were also negatively correlated but not to significant extents.

The variable the pH of injera were positively correlated only with the pH of batter (r = 0.636, p = 0.011) to significant extents. The other variables the moisture content of injera (r = -0.194, P = 0.488), the moisture content of batter (r = -0.006, P = 0.982), the weight per ml (r = -0.450, P = 0.092) and the number of eyes (r = -0.071, P = 0.801) were negatively correlated with the pH of injera but not to significant extents. From these negatively correlated variables the weight per ml showed better correlation in comparison.

The Pearson correlation for the variable of the pH of the batter were explained from the Table 4.5.1 and 4.5.2. Accordingly, the pH of batter were negatively correlated with the variables of the moisture content of injera (r = -0.172, P = 0.540) and of batter (r = -0.058, P = 0.837), weight per nl (r = -0.595, P = 0.019) and the number of eyes (r = -0.071, P = 0.837) but not significant extent except the weight per ml which was to significant extents.

The moisture content of injera showed strong positive correlation with the moisture content of batter (r = 0.861, P < 0.0001) but with weak positive correlation to the number of eyes (r = 0.197, p = 0.482). The correlation of the moisture content of injera with the moisture content of batter was to the significant extents whereas with the number of eyes not to the significant extents. However, the moisture content of injera was negatively correlated with the weight per ml (r = -0.427, P = 0.113) but not to the significant extents.

The moisture content of the batter showed strong negative correlation with the weight per ml (r = -0.667, P = 0.007) but strong positive correlation with the number of eyes (r = 0.568, P = 0.027). Therefore, the weight per ml and the number of eyes correlation with the moisture content of batter was to significant extents. Finally the weight per ml of the batter were negatively correlated with the number of eyes (r = -0.512, P = 0.051) but not to significant extents.

Table 4.5.1: The overall Correlation matrix (Pearson) of variables

Variables	Viscosity	Wt of Injera	pH Injera	pH batter	Moist Injera	Moist Batter	Wt per ml	No Eyes
Viscosity	**1**	**0.947**	-0.459	**-0.522**	-0.399	**-0.675**	**0.958**	**-0.596**
Wt of Injera	**0.947**	**1**	**-0.622**	**-0.639**	-0.205	-0.493	**0.898**	-0.459
PH Injera	-0.459	**-0.622**	**1**	**0.636**	-0.194	-0.006	-0.450	-0.071
PH batter	**-0.522**	**-0.639**	**0.636**	**1**	-0.172	-0.058	**-0.595**	-0.071
Moist Injera	-0.399	-0.205	-0.194	-0.172	**1**	**0.861**	-0.427	0.197
Moist Batter	**-0.675**	-0.493	-0.006	-0.058	**0.861**	**1**	**-0.667**	**0.568**
Wt per ml	**0.958**	**0.898**	-0.450	**-0.595**	-0.427	**-0.667**	**1**	-0.512
No of Eyes	**-0.596**	-0.459	-0.071	-0.071	0.197	**0.568**	-0.512	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 4.5.2: P -values of the variables correlation

Variables	Viscosity	Wt of Inje	pH Injer	pH batter	Moist Ine	Moist batter	Wt per ml	No Eyes
Viscosity	**0**	**0.000**	0.085	**0.046**	0.140	**0.006**	**0.000**	**0.019**
Wt of Injera	**< 0.0001**	**0**	**0.013**	**0.010**	0.463	0.062	**< 0.0001**	0.085
PH Injera	0.085	**0.013**	**0**	**0.011**	0.488	0.982	0.092	0.801

PH batter	**0.046**	**0.010**	**0.011**	**0**	0.540	0.837	**0.019**	0.837
Moist Injera	0.140	0.463	0.488	0.540	**0**	**< 0.0001**	0.113	0.482
Moit Batter	**0.006**	0.062	0.982	0.837	**< 0.0001**	**0**	**0.007**	**0.027**
Wt per ml	**< 0.0001**	**< 0.0001**	0.092	**0.019**	0.113	**0.007**	**0**	0.051
No Eyes	**0.019**	0.085	0.801	0.802	0.482	**0.027**	0.051	**0**

Values in bold are different from 0 with a significance level alpha=0.05

4.6 Principal Component Analysis of the Variables

Variables	F1	F2
Viscosity	0.985	-0.011
Wt of Injera	0.936	-0.252
PH Injera	-0.496	0.701
PH batter	-0.544	0.716
Moist Injera	-0.456	-0.712
Moist Batter	-0.724	-0.639
Wt per ml	0.973	-0.036
No Eyes	-0.572	-0.404

Tables 4.6: Correlations between variables and factors

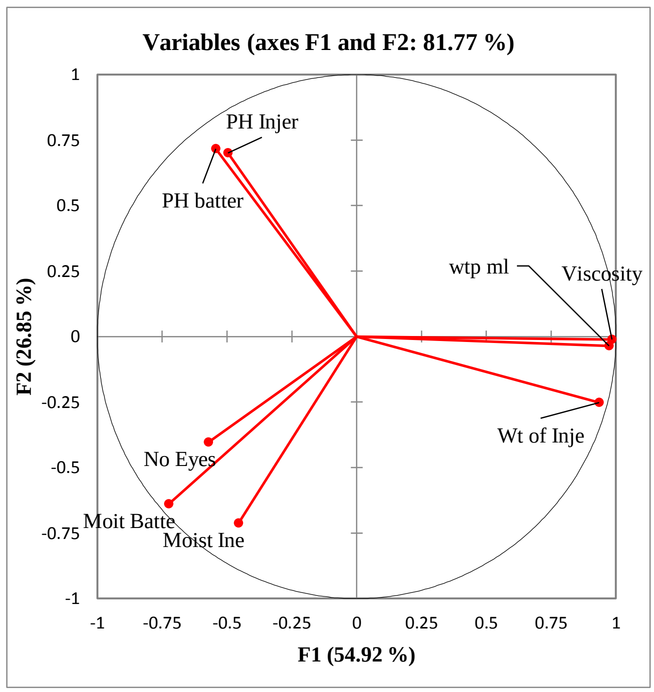


Figure 4.6 PCA plot: correlation circle for the variables

The Principal Component Analysis (PCA) was run with all samples and the inter correlation between the variables were observed. The purpose of running the PCA is simply to reduce a set of *n* variables to *m* components. The XLSTAT 2014.5.03 software was used for the analyzing the PCA and the other parameters of the data. The PCA used for the variables inter correlation was helped to decompose into three subgroup components based on their eigenvalue and eigenvector along the component F1 and F2 (Hrušková, M., et al. 2013, Campo, E., et al. 2016).

Therefore data variance was explained from 81.77% by the first two loaded factors, from 54.92%, 26.25% by F1 and F2 respectively (Table 4.6). The viscosity of batters, weight of injera and weight per ml of the batter were associated together—along the F1 axis (figure 4.6). This association of these variables indicated that the strength of the high correlation between them. So the effects and the changes of one variable has an influence on the other too.

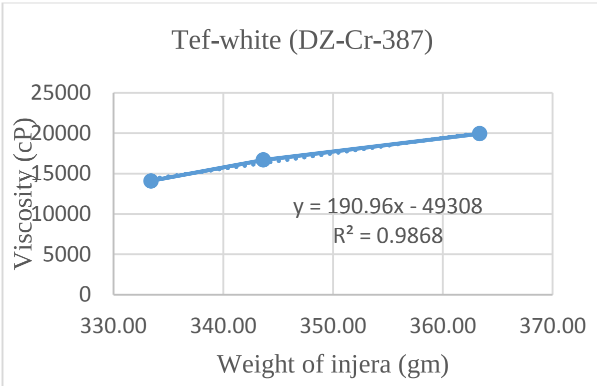
The second component of the variables includes the pH of injera and the pH of batter which were associated together—along the F2 axis (figure 4.6). The component which relate the two variables indicate that the pH of batter and injera have strong positive correlation (Table 4.6). On the other hand the other dimensional reduction includes the moisture content of batter, the moisture content of injera and number of eyes (Figure 4.6). Therefore, the component which includes these variables associated them together—along the F1 axis (Figure 4.6).

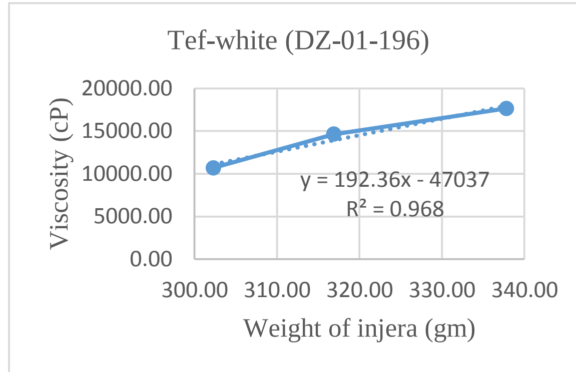
Therefore the dimensional reduction of the variable helps the variables to be arranged into the components according to the correlation with the factor.

4.7. Regression curves of the variables for the varieties of teff and blended flour

The models obtained (figure 4.7.1) A up to D might be a good tool for determining the appropriate viscosity of the batter for the desired weight of injera. The two teff varieties Teff-white (DZ-Cr-387) and Teff-white (DZ-01-196) showed no significance difference in their equation ($y = 190.96x - 49308$, $R^2 = 0.9868$ and $y = 192.36x - 47037$, $R^2 = 0.968$) obtained from the regression curve (figure 4.7.1 A and B). The two teff varieties was reported in the above that they showed no significance difference in their pasting profile, WHC and other characteristics so do the same in their regression curves.

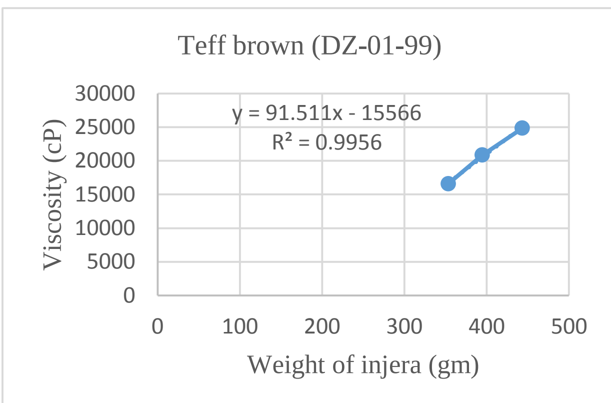
The other Blended Teff white (DZ-Cr-387)-Rice was found significantly different in its model ($y = 107.7x - 21862$ $R^2 = 0.9854$) as it compared to the other blended teff and teff varieties (figure 4.7.1 D). On the other hand the Teff-brown (DZ-01-99) and blended Teff (DZ-01-196)-Rice had $y = 91.511x - 15566$, $R^2 = 0.9956$ and $y = 139.78x - 31796$, $R^2 = 0.9829$ respectively (figure 4.7.1 C and E).

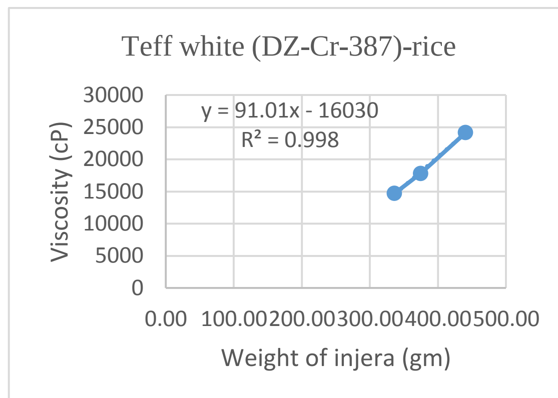




A

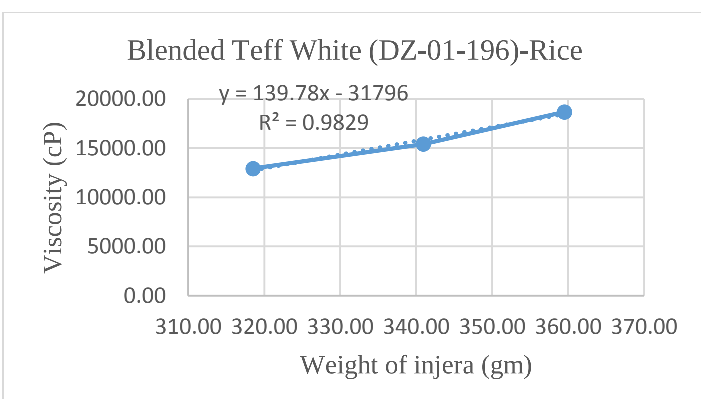
B





C

D



E

Figure 4.7.1: The regression curve for the variables of viscosity and weight of injera for different teff varieties and blended teff.

The regression curves for each teff varieties and blende flours analyzed between the weights of injera VS viscosity might help to hypothesize the model equation. Based on the relationship between these two variables there are different regression equation obtained. Measurement of the viscosity of the batter ready to bake is crucial step in the baking of injera. The viscosity of batter determines the weight of injera under a controlled baking system. These model equations could be used as the postulate idea for the preparation of the appropriate viscosity in order to get consistent weight of injera. Keeping in mind that, the effect of factors during baking on the weight of injera, the regression equation might help to find the viscosity of batter for baking with the desired weight of injera. For example to bake injera with a weight 310gm, one can put the 310 figure in the above equations to obtain the viscosity values for the batter. From the overall regression between viscosity and weight of injera regardless of the varieties base it was see that there was good correlation between the variables with Y= 90.829x - 15131, R^2 0.9149. However, there are factors that influences the weight of injera like baking time, baking temperature, the personal skills and other. Regardless of these factors the above regression equation might be used for predicting the actual viscosity of the batter to get a set weight injera.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The general objective of this work was to study the correlation between the viscosity ready to bake and the weight of injera. Some variables which were supposed to have impact on viscosity variation was analyzed. On the other hand factors which could affect the weight of injera like baking time, temperature of hot clay pan (*mitad*) and water to flour ratio were controlled and blocked. The Pearson correlation between the variables in this work were plotted and both positive and negative direction with different significance level obtained. The PCA analysis was performed using XLSTAT 2014.5.03 software for the dimensional reduction of the variables.

The viscosity values of teff and blended teff batters were found variable even as the same measured amount of water added. This clearly showed that the viscosity of batters were not depended on the amount of water added rather other factors influence the viscosity value like amylose content and starch content. Maximum viscosity of the batter was observed for Teff-brown (DZ-01-99) (24859mPa.s) and Teff-white (DZ-Cr-387)-Rice (24179mPa.s) compared to the others flours batter in the same viscosity category. The Teff-white (DZ-01-196) has the lowest viscosity values in all the viscosity categories in comparison the others flours.

The weight of injera varies for each varieties of teff flour and blended teff flour as their respective viscosities of the batter varies. Viscosity has an impact on the weight of injera, the number of eyes on injera.

The correlation between the viscosity and the weight of injera was significant ($r = 0.947$, $P \neq 0.00$) and positively correlated as considering without variety base with a regression equation $Y= 90.829x - 15131$, R^2 0.9149. Therefore, the weight of injera increased linearly as the viscosity of the batter increased. From the regression curves for each teff varieties and blended teff flour different linear equation obtained which might helped to calculate the actual viscosity for obtaining the desired weight of injera. Therefore controlling the viscosity of batter will help to influence on the quality attributes of injera and economic benefits for the injera bakeries. From the PCA the variables which are in the same component shows significant strong correlation and helps to have a clue even for further study.

5.2. Recommendations

Recommendations for further work to enhance more concerned researches on the following:

- It needs further work considering the effects of different milling grades (particle size) on the viscosity of batter.
- A more in depth analysis on the role of viscosity the batter for different varieties of teff
- The more intensive work needed on more factors for the determination of the most prominent one which influence the quality of injera.
- Sensory analysis, size or eye distribution on injera should be conducted with respect to different viscosity batter mixture.

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DECLARATION

I, the undersigned, declare that the thesis is my original work, has not been presented for degrees in any other university and all sources of material used for the thesis have been duly acknowledged

Name: Teshome Assefa Gebeyehu

Signature: ___________________

Place: College of Natural Sciences, Addis Ababa University

Date: ______________________

This thesis has been submitted for examination with my approval as a university advisor.

____

Name of your thesis advisor

Appendices

List of tables and raw data

Appendix A: Viscosity values for blended teff and teff varities batter

	Viscosity-1	Viscosity-2	Viscosity-3
Tef-white (DZ-01-196)	17646	14632	10683
Tef-brown (DZ-01-99)	24859	20863	16600
Tef-white (DZ-Cr-387)	19950	16701	14113
Blended Teff (DZ-Cr-387)-Rice	24179	17826	14728
Blended Teff (DZ-01-196)-Rice	18697	15427	12925

Appendix B: The weight of injera for the teff varieties and blended teff flour at variable viscosities

	Mean wt-1	Mean wt-2	Mean wt-3
Tef-white (DZ-Cr-387)	363.37	343.67	333.43
Tef-white (DZ-01-196)	337.80	316.87	302.27
Tef-brown (DZ-01-99)	443.33	394.63	353.37
Blended Teff (DZ-Cr-387)-Rice	440.80	374.73	336.23
Blended Teff (DZ-01-196)-Rice	359.53	340.97	318.53

Appendix C: The weight per ml of flour batter for different teff variety and blended teff.

	Rel. Density-1	Rel. Density-2	Rel. Density-3
Tef-white (DZ-01-196)	1.0886	1.0827	1.0735
Tef-brown (DZ-01-99)	1.1027	1.0945	1.0945
Tef-white (DZ-Cr-387)	1.0989	1.0835	1.0794
Blended Teff (DZ-Cr-387)-Rice	1.1014	1.0916	1.0863
Blended Teff (DZ-01-196)-Rice	1.0919	1.0881	1.0779

Appendix D: The moisture content of injera and batter

Sample Name	Treatment	Mean MC Injera	Mean MC Batter
Tef-white (DZ-Cr-387)	Q-01	63.23±0.45	73.97±0.15
	Q-02	65.57±0.71	75.87±0.25
	Q-03	73.10±0.72	80.33±0.15
Tef-white (DZ-01-196)	M-01	63.20±0.30	73.30±0.10
	M-02	65.40±0.36	76.10±0.70
	M-03	69.77±0.70	79.67±0.65
Tef-brown (DZ-01-99)	A-01	67.43±0.31	75.67±0.32
	A-02	70.60±0.30	77.53±0.15
	A-03	72.10±0.20	78.87±0.21
Blended Teff (DZ-Cr-387)-Rice	RQ-01	65.17±0.55	74.50±0.26
	RQ-02	67.87±0.47	77.30±0.20
	RQ-03	69.87±0.31	79.50±0.36
Blended Teff (DZ-01-196)-Rice	RM-01	65.83±0.40	76.23±0.15
	RM-02	67.77±0.65	78.70±1.04
	RM-03	70.03±0.21	82.03±0.21

Appendix E: Quality control glucose standard

Sample Name	Weight of sample (mg)			Weight mean (mg)	Moisture %	Dry weight (mg)	Absorbance @ 510 nm			Absorbance mean @ 510nm	Total Starch %
	Rep_1	Rep_2	Rep_3				Run 1	Run 2	Run 3		
Starch maize	100.40	102.80	99.90	101.03	8.10	92.85	1.037	1.012	0.999	1.016	92.645
Starch maize	100.60	100.00	100.50	100.37	8.10	92.24	0.995	0.977	1.013	0.995	91.333
Starch maize	100.00	100.10	100.20	100.10	8.10	91.99	0.987	0.996	0.985	0.989	91.055
Starch maize	101.10	101.20	99.10	100.47	8.10	92.33	0.995	0.977	0.991	0.988	90.570
											91.401

Information from Glucose standard

Total starch= 93 %

Moisture value= 8.3%

Standard Glucose mean absorbance of 100µg D-glucose = 1.063

Appendix F: Total Starch for the teff flour

Sample Name	Weight of sample (mg)			Wt mean (mg)	Moisture %	Dry Wt (mg)	Absorbance @ 510 nm			Absorbance mean @ 510nm	Total Starch %
	Rep_1	Rep_2	Rep_3				Run 1	Run 2	Run 3		
Kuncho	99.60	101.50	100.10	100.40	8.87	91.50	0.787	0.773	0.747	0.77	71.158
Asgori	100.50	100.50	100.60	100.53	9.25	91.24	0.770	0.808	0.781	0.79	72.970
Magna	101.00	99.90	100.30	100.40	7.41	92.96	0.796	0.798	0.789	0.79	72.350

Standard Glucose mean = 1.063

Appendix G: Amylose Content determination of Teff flour

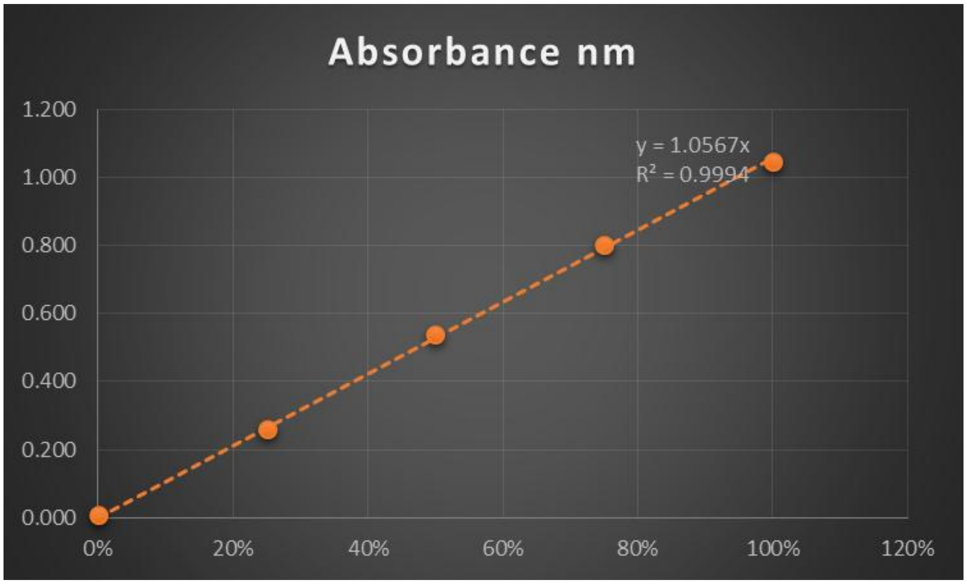
Cultivars	Sample Weight (mg)			Absorbance (nm)					Moisture (%)	Total starch	Dry starch Wt (mg)	Amylose (%)
	Run 1	Run 2	Mean	Run 1	Run 1A	Run 2	Run 2A	mean (nm)				
Kuncho	31.60	30.90	31.25	0.126	0.124	0.130	0.129	0.127	8.87	71.158	20.265	22.531
Asgori	30.10	30.70	30.40	0.116	0.114	0.117	0.123	0.118	10.50	72.970	20.131	20.853
Magna	31.80	31.50	31.65	0.120	0.124	0.121	0.119	0.121	7.41	72.350	21.201	19.871

The standard curve for the amylose

$Y=0.0043X+0.0287$

$R^2 = 0.9923$

Appendix H: GOPOD Standardization



Appendix I: The relation beteween the spindle number at fixed RPM with the viscosity value and minimum viscosity value criteria table adopted from the instrument manual.

A.5 R Standard Spindel Auswahl
R standard spindle selection

Maximum guideline values in cP (mPa·s)

Spindel-Nr. Spindle no.	R1	R2	R3	R4	R5	R6	R7
Drehzahl min^{-1} RPM *	Viskosität/Viscosity mPa·s						
0,01	1M	4M	10M	20M	40M	100M	400M
0,3	33,3K	133,3K	333,3K	666,6K	1,3M	3,33M	13,3M
0,5	20K	80K	200K	400K	800K	2M	8M
0,6	16,6K	66,6K	166,6K	333,3K	666,6K	1,6M	6,6M
1	10K	40K	100K	200K	400K	1M	4M
1,5	6,6K	26,6K	66,6K	133,3K	66,6K	666,6K	2,6M
2	5K	20K	50K	100K	200K	500K	2M
2,5	4K	16K	40K	80K	160K	400K	1,6M
3	3,3K	13,3K	33,3K	66,6K	133,3K	333,3K	1,3M
4	2,5K	10K	25K	50K	100K	250K	1M
5	2K	8K	20K	40K	80K	200K	800K
6	1,6K	6,6K	16,6K	33,3K	66,6K	166,6K	666,6K
10	1K	4K	10K	20K	40K	100K	400K
12	833	3,3K	8,3K	16,6K	33,3K	83,3K	333,3K
20	500	2K	5K	10K	20K	50K	200K
30	333	1,3K	3,3K	6,6K	13,3K	33,3K	133,3K
50	200	800	2K	4K	8K	20K	80K
60	160	660	1,6K	3,3K	6,6K	16,6K	66,6K
100	100	400	1K	2K	4K	10K	40K
200	50	200	500	1K	2K	5K	20K

* Auswahl an verschiedenen Drehzahlen / Selection of rotational speed
K Indicates miles. Example: 7,8K = 7.800
M Indicates Millions Example: 1,56M = 1.560.000

☞ It is not recommended to work with viscosity values of less than 15% of the lower part of the selected scale.

Thermo Scientific 5 HAAKE Viscotester E