ADDIS ABABA UNIVERSTIY

COLLEGE NATURAL AND COMPUTATIONAL SCIENCE

CENTER FOR FOOD SCIENCE AND NUTRITION

Influence of Nitrogen Fertilizer Rates and Varieties on Grain yield, Grain Nutrition and Injera Sensory Quality of Tef [Eragrostis tef (Zucc.)Trotter] varieties

A thesis Submitted to the College of Natural and Computational Science of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Food Science and Nutrition

BY

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Under the supervision of

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June, 2018

Addis Ababa

Declaration

I, the undersigned, declare that, this is original work and has never been presented in any other university as well as research institutes and all the source material used for this proposal have been fully acknowledged.

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Date of submission June 15/ 2018

The thesis has been submitted for examination with my approval as university advisors.

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Signature________________	**________________**
Date: __________________	**__________________**

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DEDICATION

This thesis is dedicated to my lovely mother, Ms. Rakib Sisay whom I lost since 2006. My dissertation is also dedicated to Mr. Getachew Beyene Abrha for his senior advisor on my life and all things he have been done from the first of my journey again becomes the base line for this success of my way.

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Acronyms

ANOVA	Analysis of variance
SPSS	Statistical Package for Social Science
TSP	Triple supper phosphate
DZARC	Debre Zeit Agricultural Research Center
SNNP	South Nations, Nationalities and Peoples
RCBD	Randomized completed block design
AOAC	Association of official analytical chemists
AACC	American association of cereal chemists
Uv-vis	Ultra -violate spectrophotometer
SD	Standard deviation
Asl	Above sea level
MARC	Melkasa Agricultural Research Center
CIE	Commission Internationale d'Eclairage
L*	Lightness color
a*	Redness color
b*	Yellowness color
QAAFI	Queensland Alliance for Agricultural and Food Innovation
HI	Harvest index

Abstracts

Tef [Eragrostis tef (Zucc.) Trotter] is one of major staple crops grown in Ethiopia. Studies have showed that tef has good nutritional composition. Excess applications of N fertilizer can affect the sensory properties of foods. Therefore, afield experiment was conducted to assess the effects of N fertilizer rates on grain nutrition and sensory quality of injera of three tef varieties at Debre Zeit Agricultural Research Center in 2017 main cropping season. Three tef varieties (Kora, Boset and Asgori) and five N rates (0, 30, 60, 90 and 120 kg N ha^{-1}) were used in Randomize Completed Block Design with three replications, while Triple Super Phosphate was applied at the same dose for all treatments. Phenological and yield component parameters were determined and significant $P<0.05$ by N rates and varieties. Grain nutrition, mineral content (Fe, Ca and P) and ant-nutritional factors were determined using standard methods. Sensory quality of injera and color were determined using panelists and injera eye software, respectively. N rates had almost negligible effects on grain nutrition except protein which was increased with N rate, while carbohydrate deceased significantly at $P<0.05$. Varieties with N rate did not show increasing or decreasing trends in mineral content. From means of varieties, Boset (30.14) and Asgori (30.18) had higher Fe content, but Kora (68.22) and Boset (65.93) had maximum Ca content in mg 100 g^{-1}. Results using panelists did not show much significant on sensory quality of injera. Kora at the control plot (K0) had better color, flavor, texture and taste values of injera, but slightly decreased with N rates, while Boset and Asgori did not show significant differences. Grand means of varieties and N rates did not have significant difference on color, flavor, texture and taste of injera and rated from neither like nor dislike–like very much, but Asgori had different color and taste. Injera eye software indicated that, interactions of varieties with N rate did not show increasing or decreasing trends on L values of injera. But the color of injera was significantly affected by varieties differences. From grand means of varieties, Kora had higher (55.74) L* value followed by Boset (54.71), but Asgori (51.26) had lower L*value, had lower injera quality. Injera from Asgori variety had maximum red color but the same effect for Kora and Boset. Kora and Boset had higher yellow color at control plot, but for Asgori it increased with N rate.*

Key words: Tef varieties, fertilizer, Injera, sensory quality and color –CIEL*ab value

1. Introduction

1.1. Back ground

Tef (*Eragrostis tef* (Zucc) Trotter) is Ethiopia's Miracle crop. It is an annual grass species and a member of the grass family poaceae and genus *Eragrostis* [1].Tef is a panicle bearing C4 self-pollinated cereal crop originating from Ethiopia [2]. Tef has the largest share of area (million hectares) or 29% of, under cereal cultivation and third (after maize and wheat) in terms of grain production (18.57% or 50.2 million quintals) in Ethiopia [3]. Depending on the varieties, the color of tef grains can be ivory, light tan to deep brown or dark reddish brown purple [4]. Based on people's preference for their consumption, white tef becomes the most expensive, while in terms of nutrient red tef is more nutritious and gains acceptance by the health consumers in Ethiopia [5].

Bultosa and Taylor, [6] reported that tef contains the predominantly starchy (73%) endosperm and the starch content of tef is higher than most cereals. The grain protein content of 13 tef varieties were ranged from 8.7 – 11.15% with mean values of 10.4%, and the crude fat content of tef is in the range of 2.0- 3.05 with mean values of 2.3% [7]. Tef is high in proteins including all eight essential amino acids while it is superior in lysine to wheat or barley along with its high carbohydrates and fiber contents [8].

Tef grain is ground into flour, fermented and made into *injera*, sour-dough type flat bread, which forms the traditional food in Ethiopia [9, 10]. In addition to tef, grains such as sorghum, maize, barley, wheat and finger millet are sometimes used for the purpose of food preparations in Ethiopia [7]. Tef grain may also be eaten as porridge or used as an ingredient of home-brewed alcoholic drinks. The principal use of tef grain for human food is the Ethiopian bread *injera* (staples for the majority of Ethiopians), sweet unleavened bread, local spirit, porridge and soups) with a sour taste [4, 9, 11, 12] . *Injera* is a national food in Ethiopia which is prepared through fermentation processes. The fermentation preparation consists of two stages of natural fermentation, which last for about 24 to 72 hours, depending on ambient temperatures[4].

Tef has many advantages and needs large scale production, but its productivity has been below the potential. Due to the reason of yield limiting factor of poor soil fertility and other factors, currently the average national productivity of tef is1.664 t/ha [13] which is very low as compared to other cereal grains which grown in Ethiopia [14]. Mwangi, [14] reported that the use of inorganic fertilizer is critical to increase yield..

Tef with stands low moisture conditions and has the ability to tolerate and grow on Vertisols having a drainage problem, which make it a preferred by farmers. Balesh [15] reported that due to the lack of adequate synthetic fertilizer input , limited return of organic residue and manure, high biomass removal, erosion and leaching of high rate nutrient depletion in soil. Soil degradation and depletion of soil nutrients are among the major factors intimidating sustainable cereal production in the Ethiopian highlands. Among the major plant nutrients, N is the most limiting factor calling for external inputs in the form of fertilizer for commercial cereal crop production in most agro ecological zones. As cited by Giday [16], who reported that nitrogen fertilizers have easily solubilizing properties, thus the fertilizer applied to the soil can be lost from the soil plant system and this makes the nutrient inaccessible for the plants through leaching, NH_3 volatilization, denitrification, immobilization and the recovery of N by the crops from the soluble N fertilizer such as urea is often as low as 30-40% [17].

The response of crops to the fertilizer application of N depends up on different factors such as location and season [18]. Sharma [19] , reported that addition of N fertilizer increased plant height, which resulted an increase in leaf number per plant. The major form of nitrogen fertilizer used is urea. It is efficient, very soluble and moves freely up and down with soil moisture [20].

Application of N fertilizer is considered essential to improve yield productions of cereal crops such as tef [21]. But a study using three rates of N fertilizer with twelve rice cultivars [22], revealed that application of higher N fertilizer often reduced grain yield because of excessive vegetative growth and increased lodging and pest damage. Lodging, which can be defined as the permanent displacement and is a process by which the shoots of small grained cereals are displaced from their vertical standpoint [23]. It is a complicated phenomenon that is influenced by many factors including wind, rain, geographical position or the landscape, soil type, crop history, agricultural system and disease. It is frequently associated with conditions that promote plant growth such as an abundant supply of nutrients.

Lodging can reduce yield by up to 80% and causes several knock-on effects including reduced grain quality, greater drying costs and slower harvest [23]. In areas with high rainfall and high accumulation of organic matter, lodging is a serious challenge and is aggravated by the high rate of N fertilizer application. Assefa *et al*, [24], reported that the greatest cause for yield loss in tef is lodging and the genetic control of lodging undertaken by molecular breeding techniques and biotechnology.

1.2. Statement of the problem

The most important constraint in tef production is its intrinsic low productivity. This has, among others, been due to inability of farmers to use the required quantities of mineral nutrition and use of unbalanced chemical fertilizer applications [25]. Application of optimum fertilizer rates for specific soil type greatly contributes to yield enhancement. Systematic studies should be conducted under varying conditions and in various regions to determine the fertilizer requirements of tef for optimizing yield. Moreover, to realize optimum yields of the crop, appropriate fertilizer rates have to be used since this may vary according to soil type and weather conditions of the area. One of the alternative ways for the increments of cereal yield productions is the use of appropriate fertilizers which should be a source of all essential nutrients. Therefore, plant nutrition depends on the availability and uptake of macro and micro nutrients contained in the soil [26]. N is responsible for the development of leaf area and is a major mineral element used in agricultural fertilization. But studies show that applications of different fertilizer levels on different crop types at the same time affects the yield of plants [27]. Schuphan [28, 29], reported that excess N application diminishes taste and flavor, lower resistance to disease, insect damage and reduce the biological values of plant protein.

Gu [22], conducted using three levels of N fertilizer as main treatments with twelve rice japonica cultivars and concluded that as N fertilizer dressing system is increased, it significantly decreased overall deliciousness regardless of cultivars. High N fertilizer application may increase the carbon absorption, concentration of photosynthetic enzymes in leaves, and the larger yields dilute micronutrient contents. Therefore, high N fertilizer lowers the contents of micronutrient. As the amount of N increases the protein content becomes raised, and the palatability was significantly and negatively correlated with protein content. This shows that higher N application, results in more deterioration of grain quality and the tastiness were significantly and negatively correlated with high protein content. In contrast protein content at high rate of N, the lower concentrations of amylose improve the cooking and eating qualities [22]. Studies only reported that applications of organic or inorganic fertilizer increased the yield and grain nutritional values of cereal crops but not focused on the sensory quality of food products, especially *injera*. A study reported by Araya [30], shows that applications of recommended verm-compost have positive effects on the increments of nutrients, but not included the sensory quality of injera from the variety as influenced with the recommended fertilizer. In addition to this during the study, the experimental soil physico-chemical characteristics was not assessed before planting and this becomes difficult to conclude that the applications of organic fertilizer improves yield and nutrient values, but the soil may be source of grain nutrient.

Nitrogen availability directly affects the major quality characteristics including visual quality and taste of horticultural crops [31]. In addition to this, N has capacity to increase plant vegetative growth, and it can cause shading and that delays the fruit development of tomato fruits.

Therefore, this study mainly focused on the interaction of fertilizer with yield production including nutrition compositions and sensorial quality of tef varieties. There is some variation in quality of injera from the last decade. The reason behind this still is controversial. This may be due to the increments of fertilizer application for the purpose of yield production increasing. But there is no reported information from published literature regarding this situation on tef; therefore, this study was focused on the assessment of different levels of N fertilizer application on the nutritional quality tef grain and sensory acceptability of *injera* from tef varieties.

1.3 Research questions

- Is there a significance difference on the phenotypic and yield productions of tef varieties as N fertilizer rates increases?
- Is there a significance difference on grain nutritional quality of tef varieties as influenced by N fertilizer rates?
- Is there a significance difference on the sensory quality of tef injera due to N fertilizer rates application increases?

1.4. Objectives of the study

1.4.1. General objective

- To assess the influence of N fertilizer rates and varieties on gain yield, grain nutritional composition and injera sensory quality of tef [Eragrostis tef (Zucc.)Trotter] varieties

1.4.2. Specific objective

- To assess the phenotypic and yield production of tef varieties as influenced by N fertilizer rates
- To assess the influence of N fertilizer rates on grain nutritional quality of tef varieties
- To evaluate the sensory acceptability of tef injera as N fertilizer rates increases

1.5. Significance of the study

This thesis work generally results in

- ✓ A warring of farmers that application of excess nitrogen fertilizer may be affect the grain quality of tef
- ✓ Optimizing the rates of nitrogen fertilizer application on the nutritional composition and sensory acceptability of injera of tef productions
- ✓ Introducing base line information correlations of quality characteristics of tef food products and fertilizer rates
- ✓ Introducing basic information that whether varieties and nitrogen fertilizer affects the color of tef injera
- ✓ Announcing the use of injera eye software for determination of eyes and color of injera

2. Literature review

2.1. Origin and distribution of tef

Tef (*Eragrostis tef (Zucc) Trotter)* is an interesting grain, ancient, minute in size and it is full of nutrition. Tef was introduced to Ethiopian before the Semitic invasion of 1000 to 4000 BC [32]. Because of highly diversified agro-ecological systems, Ethiopia is the origin and genetic diversity for many crops that are economically importance such as tef [33, 34]. Tef belongs to the Poacea or Grass family and believed to be the first domesticated by pre–Semitic inhabitants in Ethiopia between 4000 and 1000 B.C. The crop species is an allotetraploid believed to have originated from Eragrostis pilosa , and it is an allotetraploid plant with a chromosome number of 2n =40 and the basic chromosome number of the genus Eragrostis is X =10 [35, 36].

Within the genus Eragrostis 43% of the species seem to have originated in Africa, 18% in South America, 12% in Asia, 10% in Australia, 9% in Central America, 6% in North America and 2% in Europe [37]. Tef has been introduced to different parts of the world through various institutions and individuals. The Royal Botanic Gardens, Kew, imported seed from Ethiopia in 1866 and distributed it to India, Australia, the USA and South Africa. According to Ebba, [38], Burt Davy in 1916 introduced tef to California (USA), Malawi, Zaire, India, Sri Lanka, Australia, New Zealand and Argentina; Skyes in 1911 introduced it to Zimbabwe, Mozambique, Kenya, Uganda, Tanzania; Horuitz in 1940 to Palestine. Tef is highly diverse and variable in terms of morphological and agronomic parameters [39]. Tef is endemic to Ethiopia and its major diversity is found only in that country. As with several other crops, the exact date and location for the domestication of tef is unknown. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ [40].

2.2. Production of tef in Ethiopia

Tef is the most important cereal crop of Ethiopia accounting for about 28.5% of the total acreage and 18.6% of the gross grain production of all cereals [41]. It is grown by over 6.3 million farming household and constitutes the major staple food grain for over 50 million Ethiopian people. This implies that tef is very important in the overall national food security of the country. Tef, maize, wheat and sorghum were the major cereals based on area coverage. From the cereals, tef had the largest area coverage and even larger than the total area devoted to pulses. The percentage coverage of farmer's varieties of tef showed increasing trend from 98.9% in 2005/06 to 99.32% in 2007/08 then 99.34% in 2009/10 [42]. Ketema [40], stated that more than half of the area under cereals in Ethiopia is for tef production.

Tef is grown in almost all regions of the country for home consumption since it is a preferred grain, and for local market since it fetches the highest grain price compared with other cereals and is used as a cash crop by farmers. Within Ethiopia the administrative regions of Shewa, Gojam, Gonder Wello and Welega are the major tef-production areas. It is widely grown in both high-potential and marginal production areas. These areas include most parts of the Vertisols that suffer from waterlogging and other non-Vertisol parts of the country that suffer from low moisture stress [40].

According to Demeke and Di Marcantonio [43] , in Ethiopia, tef is grown mainly in Amhara and Oromia regions. The highest production was observed in East and West Gojam of Amhara and East and West Shoa of Oromia and a smaller quantity of tef is also produced in Tigray and SNNP regions. In different areas of our country tef is produced mostly in these regions which are described in the table (1) below.

Table 1: Tef cultivation area and production by different region in Ethiopia

Region	Area (ha)	Share of total area (%)	Production (Qt)	Share of total product (%)
Tigray	165,804	6.01	2,095,066	6.02
Amhara	1,014,268	36.77	12,791,077	36.75
Oromia	1,289,405	46.74	16,718,025	48.04
SNNPR	265,377	9.62	2,967,594	8.53
Benishangul	23,648	0.86	231,073	0.66
Total	2,758,502	100.00	34,802,836	100.00

Qt= quntal which is 100 kg ,, Source: Demeke and Di Marcantonio, 2013, [43],

2.3. Agronomy and physiology of tef

In Ethiopia tef is cultivated in much the same way as wheat and barley. Depending on the location and maturity period of the cultivar it is grown during the main growing season between July and November, and also during the small rainy season between March and June. It is mainly cultivated as a monocrop, but occasionally under a multiple cropping system [40]. Tef is adapted to a wide range of environments and is presently cultivated under diverse agro climatic conditions. It can be grown from sea level up to 2800 m asl, under various rainfall, temperature and soil regimes. However, according to experiences gained so far from national yield trials, conducted at different locations across the country, tef performs excellently at an altitude of 1800-2100 m, annual rainfall of 750-850 mm, growing season rainfall of 450-550 mm and a temperature range of 10°C-27°C. A very good result can also be obtained at an altitude range of 1700-2200 m and growing-season rainfall of 300 mm [40].

Tef is unique in its ability to grow and yield on poorly drained Vertisols which most cereals cannot tolerate. Unlike other cereals, the seeds of tef can be easily stored under local storage conditions without losing viability since the grains are resistant to attack by storage pests [40]. Tef is a unique durable crop grown over a wide range of environmental conditions in Ethiopia and has been utilized as food and supplements for majority of the human diet in Ethiopia [44]. Ketema , [40] reported that tef plant can be grown from sea level up to 2800 meters above sea level under various rainfall conditions, temperature and soil regimes. The history of tef cultivation in Ethiopia goes back 6000 years [32].

The main principle in agronomy and physiology is aimed at ensuring appropriate supply of crop with sufficient water and nutrients to keep its health for maximum light interception and carbon dioxide fixation. Hence, the understanding of critical water stress sensitive developmental stages is vital for management of this scarce resource. Mengsitu, [45] stated that on the influence of various soil moisture regimes on physiological processes of tef, it was found that severe water stress (75% of water withhold) has caused 92.8% and 60% reduction in net assimilation and respiration, respectively.

2.4. Tef varieties and agronomic based classifications

Eragrostis species are classified based on characteristics of culms, spike lets, lateral veins, pedicels, panicle, flowering scales, and flower scale colors. Recently, the taxonomy of tef has been clarified by numerical taxonomy techniques, cytology and biochemistry, including leaf flavanoids and seed protein electrophoretic patterns [35]. Based on diverse agro-ecologies for tef cultivation, improved tef varieties released by DZARC collaborated which are classified in to three group varieties for high land (water lodging areas), varieties for low land rain fall (terminal drought-prone) areas and varieties for optimum rain fall area which are improved released from 1970 -2014 as described in the table 2, 3, and 4 respectively below.

Table 2: Released and improved of tef varieties for optimum rain fall areas

Varieties name	Common name	Releasing center	Year of Release	Days to mature	Seed color	Yield (t/ha)	
						Research field	On farm
DZ-01-99	Asgori	DZARC	1970	80-130	Brown	2.4-3.0	1.7-2.2
Dz-01-196	Magna	DZARC	1970	80-113	Very white	1.8-2.2	1.4-1.6
DZ-01-354	Enatite	DZARC	1970	85-130	Pale white	2.4-3.2	1.7-2.2
Dz-01-787	Wellenkomi	DZARC	1978	90-130	Ale white	2.4-3.0	1.7-2.2
DZ-Cr-44	Mengesha	DZARC	1982	125-140	White	2.4-3.0	1.7-2.2
Dz-Cr-82	Melko	DZARC	1982	112-119	White	2.4-2.8	1.8-2.2
DZ-Cr -255	Gibe	DZARC	1993	114-126	White	2.0-3.0	1.6-2.2
DZ-01-974	Dukem	DZARC	1995	76-138	White	2.4-3.4	2.0-2.5
DZ-Cr- 358	Ziquala	DZARC	1995	75-137	White	2.1-3.6	1.8-2.4
DZ-01-2053	Holetta key	Holetta	1998/99	124-140	Brown	3.4	2.5
DZ-01-1278	Ambo Toke	Holetta	1999/00	125-140	White	3.6	2.7
DZ- 01-1285	Koye	DZARC	2002	104-118	White	2.4-3.6	1.8-2.5
DZ-01-2054	Gola	DZARC	2003	68-100	White	1.0-2.2	1.6
PGRC/E 205396	Ajora	DZARC	2004	85-110	White	1.31	1.14
DZ- 01-146	Genete	DZARC	2005	78-85	Pale White	2.17	1.55
DZ-01-1821	Zobel	DZARC	2005	78-85	White	2.07	1.51
DZ- 01-1868	Yilimana	DZARC	2005	108	White	2.32	1.63

Source: Personal communication and data recording documents from DZARC (1970-2014)

Table 3: Released tef varieties for low rain fall (terminal drought –prone) areas

Varieties name	Common name	Releasing center	Year of Release	Days to mature	Seed color	Yield (t/ha)	
						Research field	On farm
DZ- Cr -37	Tsedey	DZARC	1984	82-90	White	1.8-2.8	1.4-1.9
DZ-01-1281	Gerado	DZARC	2002	73-95	White	2.2	1.0-1.7
DZ-Cr- 1681	Key Tena	DZARC	2002	84-93	Brown	2.5	1.6-1.9
HO- Cr- 136	Amarach	DZARC	2006	63-87	White	1.3	1.2
Acc-. 205953	Mechare	Sirinka	2007	79	Pale White	2.06	1.79
DZ- Cr- 387 RIL 127	Gemechis	Melkassa	2007	62-83	White	1.3-2.0	1.4
DZ- Cr- 385 RIL 295	Sidama	DZARC	2009	88	White	1.6	1.4
DZ- Cr – 387 RIL 273	Lakech	DZARC	2009	90	Very White	2.24	1.3-1.8
DZ- CRr - 409 Sel 50D	Boset	DZARC	2012	75-86	Very White	1.8-2.0	1.4-1.8
Acc. 214746A	Were-kiyu	DZARC	2014	94	White	2.2	- - -

Source: Personal communication and data recording documents from DZARC (1970-2014)

Table 4: Released and improved of tef varieties for high land (water lodging) areas

Varieties name	Common name	Releasing center	Year of Release	Days to maturity	Color	Yield (t/ha)	
						Research field	On farm
DZ- 01-899	Gimbichu	DZARC	2005	118-137	White	1.8	1.6
DZ- 01-2673	Dega Tef	DZARC	2005	112-123	White	1.8-2.8	1.6-2.0
DZ-01-2423	Dima	Adet	2005	105	Brown	2.46	1.68
DZ-Cr-387 RIL355	Quncho	DZARC	2006	80-113	Very white	2.4-2.8	2.0-2.2
DZ-0 1-1880	Gunduru	Bako	2006	132	White	1.5-2.3	1.4-2.0
DZ-Tafi adi -72	Kena	Bako	2008	110-134	Very white	1.7-2.7	1.3-2.3
DZ-01- 3186	Estub	Adet	2008	92-127	White	1.9-2.7	1.6-2.2
DZ-Cr-438 RIL133 B	Kora	DZARC	2014	110-117	Very white	2.5-2.8	2.0-2.2
DZ-Cr- 438 RIL 91A	Dagim	DZARC	2016	112-115	Very white	2.6-2.8	2.0-2.2
DZ-cr-438 RIL 7	Abola	Adet	2016	--	Very white	2.1-2.8	1.5-1.7
DZ-Cr-438 RIL 125	Negussie	DZARC	2017	--	Very white	-	-
DZ-Cr-442 RIL 77C	Felagot	DZARC	2017		Brown	--	--
DZ-Cr-457 RIL 181	Tesfa	DZARC	2017		White	--	--
DZ-Cr-417 RIL (DZ-Cr-974 XPI 222988)	Heber-1	Adet	2017		Very white	--	--
Areka 01	New	Areka	2017		White	--	--

Source: Personal communication and data recording documents from DZARC (1970-2014).

2.5. Nutritional quality of tef

Tef *(Eragrostis tef [Zucc] Trotter)* grain is cultivated as a major cereal crop in Ethiopia and is a staple food for the majority of Ethiopians [46]. In a country of over 80 million people, tef accounts for about 15% of all calories consumed in Ethiopia [47]. According to Assefa [48], the crop has both its origin and diversity in Ethiopia, and plays a vital role in the country's overall food security. Tef is a resilient crop that can withstand varying environmental and cultural conditions, including reasonable tolerance to both drought and waterlogging [48]. The major advantageous of tef grain is as raw material for product development, this is due to highly protein and amino acid compositions and its gluten free [4].

The main components of tef grain are protein, ash, fat, fiber, moisture and carbohydrates**.** In addition to its nutritional qualities, the tef grain is gluten-free. The demand for gluten-free foods is growing as more people are diagnosed with celiac disease and other types of gluten sensitivity [6, 49, 50]. Despite of its advantage for celiac patients' disease prevention, its micro nutrients of tef, Iron can also use for the prevention of anemia, (Iron deficiencies). An iron deficiency is one of the frequent micronutrient deficiencies which can be prevented by food fortification and nutritional supplement [51]. Hence, tef grain products can serve as a good option in combating this problem [52, 53].

Tef flour can also use as a raw material for industrial food productions. It used for biscuits and cake making [54] and pasta formulations [55]. On the other hand tef flour can be used for productions of traditional local alcohol beverages such as opaque beer called tella, sprit called katikala/ arake and shameta which are prepared at house level [56]. Gebremariam [56, 57], reported that tef shown good malting properties to be a promising row material for gluten free brewing.

Cereal grains are the major sources of carbohydrate and protein contents**.** They contribute 70% of calorie and 50% of protein consumption in human nutrition and cereals are a source of dietary fiber, contributing to about 50% of the fiber intake in western countries [58] . Carbohydrate is composition of 80% of tef grain and it has a starch content of 73%. Comparing of tef to other cereal grains such as sorghum, 13 tef varieties have amylose content ranged from 20 to 26 percent [7].

The protein content of tef grain is found between the ranges of 8 to 11 percent which is similar to other cereals such as wheat. The major fractional protein storages of tef grain is glutelins (45%) and albumins (37%), while the minor constituent is prolamins (12 %) [59, 60].

Different tef varieties have different mineral concentrations. Red tef has a higher content of iron and calcium than mixed or white tef varieties [61]. In the contrast of this, white tef have a higher copper content than the red and mixed tef varieties [5, 61].

Bultosa [7] reported that the crude fat content in 13 Ethiopian tef varieties ranged 3.0-2.0% with mean of 2.3% and among these cultivars the highest crude fat was for DZ-Cr-82 and the lowest was among DZ-01-354, DZ-01-99, DZ-Cr-37, DZ-01-974 and DZ-01-1681. Tef grains are rich in unsaturated fatty acids (oleic acid, 32.4% and linoleic acid 23.8%), but the common cereal grains such as rice, wheat and maize contains negligible amount of linoleic acid and only trace of α-linolenic acid [62] . Due to the reason that tef is a minute sized with higher proportion of bran versus endosperm and germ [7], the crude fiber, total and soluble dietary fiber content of tef is much higher than wheat, sorghum, rice and maize. Tef is the major source of essential fatty acid, fiber, minerals (especially calcium and iron), phytochemicals such as polyphenols and phytates [5].

On the physiological compositions of tef, Assefa and Bultosa [7, 39] stated that thousand kernel weight of the improved tef varieties ranged between 0.19 and 0.42g while the hectoliter weight of the popular tef variety called Quncho (DZ-Cr-387) was 86.42 kg/hL, and this may show perhaps tef grain is the smallest among carbohydrate-rich kernels [7, 63]. Based on different studies, the major nutritional compositions of tef can be described using the table (5) below.

Table 5: Grain nutrition, amino acid and microelement contents of tef grain compared with sorghum, brown rice and wheat

Component	Tef	Sorghum	Brawn rice	Wheat
Starch (%)	73	62.9	64.3	71
Crude protein (%)	11.0	8.3	7.3	11.7
Amino acid (g/16g N)				
Lysine	3.7	0.3	3.7	2.1
Isoleucine	4.1	0.7	4.5	3.7
Leucine	8.5	2.1	8.2	7.0
Valine	5.5	0.8	6.0	4.1
Phenylalanine	5.7	0.9	5.5	4.9

Tyrosine	3.8	0.7	5.2	2.3
Tryptophan	1.3	0.2	1.2	1.1
Threonine	4.3	0.5	3.7	2.7
Histidine	3.2	0.4	2.3	2.1
Arginine	5.2	0.6	8.5	3.5
Methionine	4.1	0.3	2.7	1.5
Cystine	2.5	0.3	1.8	2.4
Asparagine + Aspartic acid	6.4	5.1		9.0
Serine	4.1	0.8	5.0	5.0
Glutamine + Glutamic Acid	21.8	29.5		17.0
Proline	8.2	1.3	5.0	10.2
Glycine	3.1	0.5	4.5	4.0
Alanine	10.1	1.6	5.5	3.6
Crude fat (%)	2.5	3.9	14.0	3.2
Crude fiber (%)	3.0	0.6	0.6-1.0	2.0
Ash (%)	2.8	1.6	1.4	1.6
Minerals (mg/100g)				
Calcium	165.2	50	6.9	39.5
Copper	2.6	0.4	0.2	0.2
Iron	15.7	6.0	0.57	3.5
Magnesium	181.0	180.0	16.9	103.5
Manganese	3.8		0.4	1.0

Sources: [6, 7, 40, 57, 64-68]

2.6. Fertilizers

A fertilizer is any material, organic or inorganic, natural or synthetic, that supplies plants with the necessary nutrients for plant growth and optimum yield [69]. Fertilizers are the most effective agents which are used for increasing yield production and quality improvements of food items. Nitrogen, Phosphorus and Potassium (NPK) are the major groups of fertilizer which serves as the main plant nutrients [70]. Agricultural fertilizer can be inorganic or organic fertilizers. Organic fertilizers are environmentally friendly and improve soil health, water-holding capacity, high cation exchange capacity and low bulk density and they a foster diverse population of beneficial soil microorganisms [71]. In contrast to organic fertilizer, the nutrients in chemical fertilizers are already in inorganic form and can be immediately used by the plants. Mineral fertilizers are subject to leaching, which occurs when the fertilizers are washed by rain or irrigation water down below the level of the plant roots. Nitrogen is particularly susceptible to leaching. Before the plants use organic fertilizer it must be broken down by soil microorganisms into simpler, inorganic molecules and ions [71]. The use of chemical fertilizers of urea, DAP (Di-ammonium phosphate), and Potash are considered to be the rich plant nutrient in the form of manure for better growth and high yield.

2.7. Soil fertility and nitrogen availability

There is a complex interaction between different components of the organic farm and the quantity and quality of the end products depend on the functioning of the whole system. As such, it is very difficult to isolate soil fertility from production and environmental aspects of the system [72]. Low soil fertility is exacerbated by soil fertility depletion through nutrient removal with harvest, tillage, weeding, and losses in runoff and soil erosion [73]. Many farmers are unable to compensate for such losses, which resulted in negative nutrient balances [74].

N in the soil can be exists in different forms and in large amount, and it may exist beyond the demand of some crops. Even though all forms N is not available to plants, it is found in the form of organic matter more than 90% [75]. The availability of nitrogen is increase through decomposition by soil microorganisms. The decomposition and formation of organic matter is therefore the vital loss and gain of nitrogen for plants. Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops. Swift & Palm [76] (2000) however stated that it is more helpful to view soil fertility as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production.

2.8. Importance of phosphorus fertilizer for tef

Phosphorus (P) is an essential plant nutrient which involves in all physiological activities of the crop production. Many research findings indicated that application of P fertilizer increases growth and yield of the crops. Adequate P nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, root growth particularly development of lateral roots and fibrous rootlets [77]. As a result of continued land degradation and rapid population growth, addressing poor soil fertility in the farming land in the tropics including Ethiopia has become a major issue to achieve food security at household level [78].

Increasing tef yield requires improving soil P supply and identifying P efficient varieties[79]. In Ethiopia, N is deficient in almost all soils [80] and P is deficient in about 70% of soils [81]. P deficiency is a common mineral nutritional problem in both calcareous soils and acidic soils due to formation of poorly soluble P complexes with calcium in alkaline and aluminum and iron in acidic soils. It is estimated that P availability to plant roots is limited in nearly 67% of the cultivated soils, causing an important constraint to crop production [82]. The development of P efficient genotypes with a great ability to grow and yield in soils with limited P supply improves the sustainability of crop production [83].

Vertisols are heavy textural and the presence of expending type clay minerals result in a very narrow range moisture stress and water excess. In vertisols, base saturation is high with calcium and magnesium dominant in the sorptive complex. P availability is generally low in vertisols. Plants having P scarcity shows stunted growth and in contrast to shortage of N, are often dark green in color. Next to nitrogen, P application is of secondary importance and is recommended at minimum levels of application, except on highly weathered red soil that fix considerable quantity of the applied P [84].

Expect at highly weathered soils that fix considerable amount of applied P and tef was not responded to P in Vertisol of Debre Zeit [21], thy suggested that P application at the 10 kg ha^{-1} was recommended for maintenance of soil fertility.

2.9. Role of nitrogen fertilizer in plant yield and yield components of tef

N is often the most limiting factor in crop production. Hence, application of fertilizer N results in higher biomass yields and protein yield and concentration in plant tissue is commonly increased. N often affects amino acid composition of protein and in turn its nutritional quality. In cereals, abundant supply of N decreases the relative proportion of lysine and threonine, thus, reducing the biological value of the protein. Increasing N supply generally improves kernel integrity and strength, resulting in better milling properties of the grain. In oil seed crops, protein levels are increased up on N fertilization, whereas oil concentration is decreased [85]. N promotes leaf area and leaf area index which may be due to a higher number and size of leaves [86].Managements of N fertilizers offer the opportunity of increasing grain protein and quality. Haftom [87] reported that N fertilizer rate caused significant effect in yield characteristics. Applying higher amount of N rate (92 kg ha-1) were increased the panicle length (38 cm) and plant height (92 cm) of tef. Using N fertilizer can improves various yield related parameters such as thousand seed weight; increase the productive tillers and number of spikes peer unit area, number of grain and biological yield with higher yield productions [88, 89].

2.10. Lodging of tef plants

Lodging is the permanent displacement of stems from the vertical position. Lodging can be limit yield productions directly by reducing photosynthetic capacity due to changes in sunshade architecture [90]. It can be occurred either due to stem lodging, resulting from the bending or breaking of the lower culm internodes, or root lodging results from a failure in root soil integrity [91]. The problems of lodging can be reduced by decreasing plant height or the application of growth regulators like ethephon or chlormequatchloride (CCC), [92]. Rain increases lodging risk by decreasing soil strength and increasing the load which the plant must bear. Wind then acts as the force which pushes the plant over or buckles the stem.

Lodging risk is strongly influenced by a number of husbandry decisions including variety choice, sowing date, seed rate, drilling depth, soil fertility and the application of plant growth regulating chemicals [93]. As studies have shown that yield is reduced when plants are shortened too much with dwarfing genes or plant growth regulators [94, 95]. Because a reduction in plant height to improve lodging resistance may reduce the photosynthetic capacity of a canopy, another target is needed for further improvement in lodging resistance.

Lodging in cereals is most likely during the 2 or 3 months preceding harvest and occurs through interactions between plant, wind, rain and soil [96]. Yield losses of up to 45% have been observed due to the lodging problem [90, 97]. In Ethiopia, lodging of tef is also a common phenomenon and one of the causes for the current low grain yields: the Ethiopian national average grain yield of teff is in the order of 800 kg ha-1[98]. This low national average is partly associated with constraints such as waterlogging, drought and nutrient limitation[98].

2.11. Response of tef to nitrogen fertilizer

Tef performs well on various soils. However its yield is limited by nutrient deficiencies, mainly N and P. The response of crop to N depends on soil fertility, moisture ,location and season [18]. Sharma [19], reported that addition of N fertilizer increased plant height, which results an increase in leaf number per plant. K.Habtegebrial et al reported that [99], both total dry matter and grain yields were increased as N-fertilizer increases. There was a linear increase in dry matter production when N was increased from zero nitrogen (0 kg ha-1) to higher N (90 kg ha-1). The grain yield showed a similar increasing trend up to medium nitrogen level but decreased from medium to higher nitrogen. N fertilization significantly affected the soil total N and carbon to N ratio at lower depth (15--30 cm).Average total N at the lower depth increased by 35.2 kg ha^{-1} yr^{-1} when N application rate was increased from medium N to higher N, suggesting that higher N levels are to be avoided to reduce excessive leaching to lower depths.

2.12. Effects of nitrogen in plant and grain nutrition

N is the most abundant mineral nutrient in plants. It constitutes 2 - 4 percent of plant dry matter. Apart from the process of N fixation that occurs in legumes, plants absorb N either as the nitrate ion (NO_3^-) or the ammonium ion (NH_4^+). N is a part of the chlorophyll (the green pigment in leaves) and is an essential constituent of all proteins. It is responsible for the dark green color of stem and leaves, vigorous growth, branching / tillering, leaf production, size enlargement, and yield formation. Absorbed N is transported through the xylem (in stem) to the leaf canopy as nitrate ions, or it may be reduced in the root region and transported in an organic form, such as amino acids or amides. N is mobile in the phloem (the plant tissue through which the sap containing dissolved food materials passes downwards to the stem, roots, etc.); as such, it can be re-translocated from older to younger leaves under N deficiency and translocated from leaves to the developing seed or fruit. The principal organic forms of N in phloem sap are amides, amino acids and ureides [100].

Nutrient elements, especially N affects the capacity of photosynthesis. The concentration of N is the main factor for photosynthesis rate of C3 and C4 plants. The amount of N present in the leaves delays the aging of the leaf. In cereals, leaves remain green for long, especially in the greens for a long time in period of ear emergence increases photosynthetic activity [101]. Leaves are the organ contributing to the formation of yield in plants. Approximately 70 - 90% of the final grain yield is derived from photosynthetic produced by the plant during the grain filling. The flag leaf and head usually contribute most, but certainly not all, of the photosynthate to the grain [102].

Nitrogen is a major mineral element used in agricultural fertilization. The nutrition of the plants depends on the availability and uptake of macro and micro nutrients contained in the soil. N is a constituent of essential cellular components such as amino acids, proteins and nucleic acids. And N is also the controller of P, K and other nutrients, and it improves the tastiness of many crops [103]. Since N is the most limiting factor in crop production and application of fertilizer nitrogen results in higher biomass and protein yield and increased the concentration of plant tissue. N is often affects amino acid composition of protein and in turns its nutritional quality. In cereals, abundant supply of nitrogen decreases the relative proportion of lysine and threonine, thus, reducing the biological value of the protein. Increasing nitrogen supply generally improves kernel integrity and strength, resulting in better milling properties of the grain [104].

2.13. Effects of fertilizers on the sensory quality of cereal crops

In addition to increase production of yields, using different agricultural amendments, mineral or organic fertilizer plays a key role in physicochemical differences and sensory acceptability of cereal crops. From these mineral fertilizer, N is one of the most important and necessary element used for plant as available nutrients. Appropriate supply of N fertilizer is important for getting yields on commercial scale indispensable for sufficient food supply and it is essential for the improving of market quality and biological values of the products [28]. Applications of fertilizers such as N, P and potassium can be used for the increments of minerals such manganese, copper, calcium and sulfur [105]**.** But fertilization and cultural practice affects cereal grains, such as rice's amylose, protein, and mineral contents of that cultivars, this may influence the sensory properties of the cooked rice. Perez [106], reported that the proteins of grains derived from translocation of accumulated plant N at flowering. Due to the lower N content in organic fertilizers the protein content of conventionally, N treatment grown rice is usually higher than that organically grown rice. Elaine [107], reported that five rice cultivars grown with 100% N rate was observed with higher mean protein contents than the cultivars grown organically or 50%N rates. The difference in protein content makes a difference in pasting and cooking of the cultivars, this is due to these cultivars grown with different types of fertilizer. Because of using 50% of the recommended nitrogen rate yielded the same protein content and same pasting and cooked textural properties as that grown organically, it is clear that organic management did not influence these properties. In addition, no differences in flavor were observed due to management method. These results demonstrate that rice grown on land that is being transitioned into organic production is not expected to have significant differences in cooking or processing quality [107]. Based on this study, higher nitrogen fertilizer dressing system may cause a problem on the sensorial acceptance of the food products.

2.14. Physical characteristics and quality attributes of injera

A typical *injera* is normally round in shape and measures about 60 cm in diameter. A normal *Injera* have a thickness of about 6 mm. The front side of good quality of injera has uniformly spaced honeycomb-like "eyes", each measuring about 4-5 mm in depth and 4 mm in diameter. Due to inadequate fermentation or much absit in dough are the major factors that have great contribution for the productions of less quality of *injera*. The studies reported that injera having good quality becomes soft and pliable in texture that enables for the consumer to warp and pick up wot and *injera* with fingers to eat [108].

2.15. Number of holes, filtered eyes and color (CIE-L*ab) (Lightness, redness and yellowness) values of injera

The first quality parameters which used for the evaluations and acceptance of food products by the consumers are appearance and the color of food item. The color we observed on the surface of food item is the first sensation that the consumer perceives and uses as a tool to accept or reject the food. The color of food item determined by visual (human) inspection or by using a color measuring instruments. Determinations of color of food item using human senses are subjective and extremely variable from observer to observer. Therefore, to minimize such like ambiguity and to carry out a more objective color analysis, it may be better to measure the color using color measuring instrument using color standards as reference material.

The color of foods has been measured in L*ab. The L*ab, or CIELab, color space is an international standard for color measurements, adopted by the Commission International d"Eclairage (CIE) in 1976. L* measures the lightness component of food item, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from -120 to 120 [109]. The L*ab space is perceptually uniform, that the Euclidean distance between two different colors corresponds approximately to the color difference perceived by the human eye (Hunt, 1991). In order to carry out a detailed characterization of the image of a food item and thus more precisely evaluated its quality, it is necessary to know the color value of each pixel of its surface. However, at present available commercial colorimeters measure L*ab only over a very few square centimeters, and thus their measurements are not very representative in heterogeneous materials such as most food items [110] .

3. MATERIAL AND METHODS

3.1. Description of the study site

The field study was carried out at Debre Zeit Agricultural Research Center (DZARC) from August - November during the main cropping season of 2017. Debre Zeit is located at 47 km to the southeast of Addis Ababa. The experimental field at this site is characterized by heavy black soil which is the dominant soil of the study area with high water retention capacity by its nature. The place is located at 8° 44' N latitude and 38° 58' E longitude at an altitude of 1860 meters above sea level. The study area receives an annual average rainfall of about 832, and the average minimum and maximum mean temperatures are about 8.9 and 24.3 °c respectively. Sample preparation, quality parameter analysis and sensory evaluation were conducted at MARC, EIAR and Addis Ababa University Center for Food Science and Nutrition Laboratory

3.2. Selections of experimental tef varieties

The field experimental materials were three different tef varieties having different color and yield production capacity through different ecological zones. These tef varieties were released and breed by DZARC in different years with different agronomical parameters as described on Table 6. The basic criteria for the selections of these three tef varieties were that Kora was recently genetically developed tef, while Boset tef is due to its early maturity and Asgori tef varieties is because of its brown seeded color.

Table 6: Description of experimental tef varieties

No.	Tef varieties	Local name	Seed color	Year of release	Days to maturity	Yield (t/ha)	
						On station	On farm
1	DZ-Cr-438 RIL133 B	Kora	Very white	2014	110 – 117	2.5-2.8	2.0-2.2
2	DZ-Cr-409 RIL50d	Boset	Very White	2012	75-86	1.8-2.0	1.4-1.8
3	DZ-01-99	Asgori	Brown	1970	80-130	2.2-2.8	1.8-2.2

3.3. Experimental designs of treatments of fertilizer rates and tef varieties

The experiment was comprised with the entire factorial combinations of three tef varieties (two white seeded ones Kora and Boset and one brown seeded Asgori) and five nitrogen fertilizer levels (0, 30, 60, 90 and 120 kg N ha^{-1}). The factorial combination was laid in RCBD with three replications.

3.4. Experimental land preparation

The field experiment was conducted at DZARC experimental research site in main cropping season. Land was prepared according to the recommended practice. It was ploughed two times using tractor before sowing and the last ploughing was used for sowing seeds. The total area of the experimental field was 47 m x 37 m which is equal to 1739 m^2. Based on this total area, the plot size was 5 m x 5 m = 25 m^2. The distance between plots was 1 m, and the distance between blocks was1.5 m.

3.5. Soil sampling and physico-chemical analysis of the experimental site

Composite soil sample was collected by using randomized zigzag method before sowing within 0-15 cm soil depth. A total of 45 soil samples were collected from the entire experimental field. The sample were packed using polyethylene bags and transported to the laboratory. Then the soil sample was dried in a shaded area from direct sun light. The dried soil samples were ground using soil grinder machine which increases the surface area of the soil and this was passed through 0.5 mm mesh sieve for the required parameter analysis. Soil pH was determined using a glass electrode attached to a digital pH meter (potentiometer). Electrical conductivity measured using conductivity meter. Organic carbon and total nitrogen were determined using the method of Walkely and Black [111] and Kjeldhal methods, respectively [112]. Available phosphorus was determined using Olsen method [113].

3.6. Experimental treatment application

After the seed beds were leveled, the seeds of tef were sown in rows using 20 cm row spacing, and the treatments were applied as per the design. TSP was applied uniformly on all plots used as a source of P (46% P_2O_5) at the rate of 100 kg ha^{-1}, which is based on the blanket recommendations of DZARC for low levels of P content in vertisols. Urea was used as the source of N, and all rates of N were applied in split form with half of the total nitrogen fertilizer applied at the time of sowing and remaining half applied after twenty three days after emergence

(Table 1). All fertilizers were applied as row-side bands. The seeds amounting to 37.5 g per plot based on the recommended seeding rate of 15 kg ha^{-1} were sown by hand drilling in the rows.

(A) (B)

(C)

Figure 1: (A) = Tef germinations after first treatment applications, (B) = second round treatment applications and (C) = tef at stages of maturity

3.7. Effects of N fertilizer rates on phenological parameters of tef varieties

3.7.1 Heading days

This refers to the number of days from sowing date to the time when 50% of the plants started to emerge panicles through visual observation.

3.7.2 Maturity date

Physiological maturity was assessed based on visual observation as indicated by the senescence of the leaves and free threshing of grains from the glumes when pressed between the forefinger and thumb.

3.7.3 Plant height (cm)

Plant height was measured at physiological maturity from the ground to the tips of panicle using ten randomly pre-tagged plants in each plot.

3.7.4 Panicle length

Panicle length was measured from 10 randomly pre-tagged plants of each plot and measured from the nods (the first panicle branch stared) to the tip of the panicle.

3.7.5 Total tiller number per plant

The numbers of the total tillers per plant was determined by counting all the tillers from the 10 randomly selected pre-tagged plants.

3.7.6 Number of productive tiller per plant

The numbers of productive tillers per plant were measured by counting the fertile tillers from ten randomly selected and pre-tagged plants from the middle parts of each plot.

3.8. Effects of N Fertilizer level and varieties on yield and yield component parameters

3.8.1. Lodging index

Lodging index was computed as the average of the product sum of each degree of lodging (0-5 scale) and their respective percentage of the total divided by five. It was recorded by using Caldicott and Nuttall [114] method. The equation that was used for determination of lodging index was as follows (1).

Lodging index =

$$\frac{\text{Sum (lodging scores or degree } \times \text{ the respective percentage area lodged)}}{5} \ldots\ldots\ldots (1)$$

3.8.2. Above ground dry biomass yield (kg ha^{-1})

Above ground biomass yield was determined at maturity by weighing the whole plants (leaves, stems, chaff and kernels) harvested from the net plot area after sun drying using balance.

3.8.3. Grain Yield (kg ha^{-1})

The grain yields were measured by harvesting the grains crop harvested from the net plot area of 5 m x 5 m (25 m^2) excluding the border effects using balance.

3.8.4. Straw yield (kg ha^{-1})

After threshing and measuring the grain yield; the straw yield was determined by subtracting the grain yield from the total above ground biomass yield.

3.8.5. Harvest index

The harvest index was calculated by dividing the grain yield by the total above ground air dry biomass yield and multiplying by 100 to get it as percentage described in the equation below (2).

$$\text{Harvest Index (\%)} = \frac{\textbf{grain yield per plot}}{\textbf{Above ground dry biomas per plot}} \times \mathbf{100} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \mathbf{(2)}$$

3.8.6. Thousand Seed weight (g)

The mass thousand seed was determined for each plot by carefully counting the grains individually and weighing them using a sensitive balance.

3.9. Preparation of flour from three tef varieties

For the preparation of tef flour, first the grain was cleaned by sifting or winnowing before milling to remove husks, dust, stalks, and other extraneous materials then the tef seeds were cleaned using a sieve with size of 1 mm. Then the cleaned tef seed was ground into flour using milling machine of model number of 3010-019EN55014/EN5501, cyclone sample mill, USA-AID with 0.5 mm of sieve size.

3.10. Effects of N fertilizer rates on nutritional composition of tef grain

3.10.1 Moisture content

Moisture content of tef flour sample were determined according AOAC, 2000, using the official method number 925.09 of oven drying method having model number of DHG-9123A [115]. A crucible was cleaned and dried in an oven dry method at 105 ^{o}C for 1 hour and placed in desiccators and moisture was removed. Weight of crucible (W1) was determined. 2 g samples of tef flour was weighed in the dry crucible (W2) and dried at 135 ^{O}C for 1 hour and after cooling the sample in desiccators to room temperature was weighed again (W3). Finally the moisture content of tef flour was calculated using the equation below (3).

$$\%MO = \frac{W2-W3}{W2-W1} \times 100 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

Where:

%MO = percentages of moisture content

W_1= weight of the empty crucible

W_2= weight of the crucible plus weight of fresh sample

W_3= weight of the crucible plus weight of the sample after oven dried

3.10.2. Ash content

The ash content was determined by (AOAC) [115] using the official method 923.03. Porcelain dishes were placed in a muffle furnace for 30 min at 550 ^oC. The dishes were cooled in desiccators (with granular silica gel) for some minutes at room temperature and weighed (W1). 3 g of tef flour of fresh sample was weighed (W2). Finally the crucibles with the weighed sample were placed on a hot plate under a fume-hood and the temperature was slowly increased the samples become thoroughly charred. Then dishes with sample (charred) were placed inside the muffle furnace at 550 ^oC for 5 hours. After the time finished the crucible was cooled in desiccators for 1 hour and reweighed (W3). The final ash content was determined using the equation below (4).

$$\%Ash = \frac{W3-W1}{W2-W1} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

Where:

%Ash = percentages ash content

W_1= weight of the empty dishes

W_2= weight of the dishes plus weight of fresh sample

W_3= weight of the crucible plus weight of the sample after oven dried

3.10.3. Crude protein content

Tef crude protein content was determined through Kjeldhal method according to official method of AOAC, number 979.09, using FOSS kjeltec 8400 [116]. Air dried sample of 1 g was taken in a tecator tube and 15 ml of concentrated sulfuric acid was added and mixed. Then 2 tablets of 1000 kjeltabs Cu/3, 5 mixture of catalyst was added into each tube, and allowed to digest using FOSS digester at 420 ^{o}c for 1 hour. After the temperature of the digester reached 420 ºc, the tubes was lowered into the digester. The digestion was allowed and a clear solution was obtained at about 1 hours. The distillation and titration process was carried out using FOSS kjeltec 8400 digital machine having receiver solution, 40% of sodium hydroxide and 0.1N of hydrochloric acid as titrant solutions and deionized water. During this analysis ammonium iron (II) sulphate hexa hydrate (0.15 g) with theoretical nitrogen values of ammonium sulphate (21.09%) was used to check the recovery. The percentages of protein were calculated by the FOSS Kjetec 8400 digitally using the conversion factors of 6.25 in triplicate form. The general formula used for calculations of crude protein was described below (5):

$$\%N = \frac{(\text{VHCl sample} - \text{VHCl blank}) \times \text{N HCl} \times 14.0}{\text{Wight of sample (g)}} \times 100 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

After the crude protein was determined using equation (5) in the above, the percentage protein content of tef was determined (6).

$$\%\text{Protein} = \%N \times 6.25 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (6)$$

Where:

%N= Percent of nitrogen

V HCl = Volume consumed by the sample in liter to the end point of titration,

V HCl blank = Volume consumed by the blank (without sample)

N = normality of HCL (0.1N),

Wt. = Weight of sample in gram and 14.0 = Molecular weight of nitrogen

3.10.4. Crude fat content

The crude fat content of tef flour sample was determined using soxtec^{TM} 8000, FOSS extraction using official method of (AOAC, 2000) 920.39. 3 g of tef flour was weighed using thimble and covered with purified cotton. Then 50 ml of petroleum ether was added as a solvent. The sample with the solvent was placed in the soxtec extractor for 1 hour. After 1 hour the extra or residual solvent was evaporated using oven dry method at 103 ^{o}c and the pure extracted fat was cooled in a desiccator and weighed. Then crude fat was determined using equation (7):

$$\%\text{crude fat} = \frac{\text{Weight of deried fat}}{\text{Fresh sample (g)}} \times 100 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (7)$$

3.10.5 Crude fiber content

Crude fiber was determined by the method of (AOAC). After the tef flour is subjected acid digestion and alkaline distillation, the combustible and insoluble organic residue was obtained. Using analytical balance 2 gram of tef flour sample was measured in the dried crucible (W1). 200 ml of 1.25 % H_2SO_4 solution was added to each sample containing beakers and was allowed to boil for 37 minutes. Then the acid was later drain using vacuum pump; sample was cooled for five minutes and then washed three times using de-ionized water. Using column, 1.25 % NaOH solutions was added as the same procedure in the above for sulfuric acid. Crucibles having residue was dried at 130 ^{0}C for three hours using oven and after drying cooled in desiccators and weighted (W2). The crucibles were transferred to muffle furnace and kept for 3 hours at 525 ^{0}C. Crucible containing ash was later cooled in desiccators and weighted (W3) and the crude fiber content was determined using equation (8).

$$\%\text{Crude fiber} = \frac{W2-W3}{W1} \times 100 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (8)$$

Where:

W1= weight of fresh sample

W2= mass of the crucible

W3= mass of the crucible and the sand

3.10.6 Carbohydrate (CHO) content

The amount of carbohydrate content of tef flour samples was determined by difference, which will be done by subtracting the sum percentage of moisture content, ash, crude protein, crude fat, and crude fiber from 100, as described below (9).

$$\%\text{ CH} = 100 - (\%\text{mositure} + \%\text{fat} + \%\text{protien} + \%\text{ash} + \text{crude fiber}) \cdots\cdots\cdots\cdots\cdots\cdots (9)$$

Where: % CHO = percentage of carbohydrate

3.11. Effects of N fertilizer rates on mineral contents of tef grain

3.11.1. Iron (Fe) and Calcium (Ca) determinations

Iron (Fe) and calcium (Ca) mineral contents were determined by Atomic absorbtion spectrophotometer method using method number of AACC [117] using Agilent technologies,200 series AA. 0.5 g flour sample was ashed using for Calcium and Iron concentration analysis. The sample was ashed using maffle furnace at 550 for five hour. The ash was moistening using distilled water and dissolved in HCl and filtered in to 100 ml as final volume. The crucible was rinsed using and filtered using filter paper and finally the solution was marked with deionized water and the metal concentrations were determined after the standard solutions were prepared..

Standard solution of Fe and Ca: First 100 ppm of individual metal standard solution was prepared from their respective stock solutions (1000 mg/L). Then five series of standard working metal solution 4, 8, 12, 16, 20 for Fe and 1.2,24, 3.6, 4.8, 6.0 for Ca were prepared in 50 ml using deionized water. Using Agilent technology (200 series AA) the concentrations of standard and sample solution was determined. Final concentrations of metals were determined using the equation below (10).

$$\text{Metal concentrations (ppm)} = \frac{(\mathrm{R} \times \mathrm{TV})}{(\mathrm{Wt.})} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (10)$$

Where

R =Element concentrations the sample solution read from the instrument (ppm)

TV = Total volume of the sample extract

Wt. = weight of sample

3.11.2. Phosphorus (P) content of tef grain

Total P from tef flour sample was determined based on the dry-ashing procedure by measuring the absorbance of phosphomolybdate blue method AACC [117]. 3 gram of tef flour was measured. A sample portion was added to 30 -50 ml crucibles. Crucibles were placed in a cool muffle furnace with increase in temperature gradually to 550 °C and ashing continued for 4 to16 hours. After cooling the ashed sample, the crucibles was carefully taken and dissolved by using 5 ml of 12N hydrochloric acid (HCl) after moist the ashed sample with deionized water and mixed with a glass rod and added drop wise of 12N HCl until effervescence becomes completed. Then the solution was evaporated to dryness, occasionally stirring with a glass rod. Then 15 ml of 6 M hydrochloric acid was added to the residue followed by about 120 ml of deionized water. The solution was stirred with the glass rod, which should be left in the beaker, and covered the beaker with a watch-glass. Then the solution was gently boiled and maintained at boiling point until no more ash can be seen to dissolve and filtered on ash-free filter paper and collected the filtrate in a 250 ml volumetric flask. Wash the beaker and filter with 5 ml of hot 6N hydrochloric acid and twice with boiling water and mark up with deionized water. From the filtrate solution 5 ml of the aliquot of the dissolved ash was taken into a 100 ml volumetric flask, 10 ml ammonium vanadomolybdate reagent was added and diluted with deionized water. 50ppm P stock solution was prepared by weighing 0.219 g of potassium dihydrogen phosphate (KH_2PO_4) in 1L volume with deionized water. Standard solutions containing 0.5, 1.0, 1.5, 2.0 and 2.5 ppm P was prepared from the stock solution. Also a blank solution was made with 10 ml ammonium-vanadomolybdate reagent, absorbance for the blank, standards and samples was recorded after 30 minutes at 460 nm wavelengths by using Spectrophotometer (uv-vis spectrophotometer) Cary-60, Malaysia. By plotting calibration curve using standards, the concentration of P in the sample was determined using the formula below (11).

$$P\ (ppm) = \frac{C \times V1 \times V2 \times mcf}{Wt \times A} \cdots\cdots\cdots (11)$$

Where:

C = P concentration in sample digest read from the curve, ppm

V_1= Volume of the digest (250 ml)

V_2 = volume of the dilution (100 ml color developed)

A = Aliquot (5 ml)

Mcf = moisture correction factor and Wt. = weight of sample in gram

3.12. Determinations of anti-nutritional factors in tef grain

3.12.1. Determinations of phytic acid content

The amount of phytic acid concentration was determined by using modified of Vaintraub and Lapteva [118]. About 0.1g of dried flour sample was extracted with 100 ml 2.4% HCl for 1 hour at an ambient temperature and centrifuged (3000 rpm/30min). The supernatant solution was used for phytate estimation. About 2 ml of Wade reagent was added to 3 ml of the sample solution and centrifuged. Then the absorbance of phytic acid was determined at 500 nm using UV-VIS spectrophotometer.

A series of standard solutions of 5, 9, 18, 27 and 36 ppm were prepared from 90 ppm which was prepared from 300 ppm using phytic acid (analytical grade sodium phytate salt) using 0.2N HCl. Then 3 ml of each working solution was added into 15 ml of centrifuge tubes and 2 ml of wade reagent was added and mixed using vortex mixer. Blank solution was prepared by measuring 3 ml distilled water then added 2 ml Wade reagent in 15 ml plastic tubes. The absorbance for standard, blank solutions and then the sample solution was measured at 500 nm. Using the absorbance versus concentration standard curve was figure out and the final concentration was determined using the formula given below (12).

$$\text{Phytic acid content in } (\mu g / g) = \frac{[\text{CAb}-\text{As})-\text{intercp}]}{\text{Slpoe} \times \text{W} \times 3} \times 10 \cdots\cdots\cdots\cdots\cdots\cdots (12)$$

Where: CAb= Concentration blank absorbance, As = sample absorbance, W = weight of sample

3.12.2. Determinations of tannin contents

Condensed tannin was analyzed by vanillin-HCl method of Price et al. [119]. The Vanillin-HCl reagent was prepared by mixing equal volume of 8% concentrated HCl in methanol and 1% Vanillin in methanol. The solution of the reagent was mixed just before use. 1.0 g sample was placed in small conical flask. Then 10 ml of 1% concentrated HCl in methanol was added in to 15 ml plastic tubes. The samples were shakes for 24 hours mechanical shaker (IKA^R AS 130.1, USA) at room temperature. Then the sample was centrifuged at 1000 rpm for 5 minutes. About 1 ml of the supernatant solution was pipetted into another test tube and mixed with 5 ml of vanillin - HCl reagent and waited for 20 minute. Working standard solution was prepared from D-catechin that 40 mg of catechin was dissolved in 100 ml of methanol (stock). Then 0.15, 0.2, 0.4, 0.6 , 0.8 and 1 ml of stock solution was measured in a test tube and adjusted each test tube to 1 ml with 1% HCl in methanol. Five ml of vanillin - HCl reagent was added to each test tube. After 20 munits the reaction becomes completed and the absorbance was determined using Spectrophotometer (uv-vis) of Cary-60, Malaysia at 500 nm. Then tannin content was expressed as catechin equivalent using the equation below (13). A blank solution was also analyzed and standard curve was also prepared from catechin.

$$\text{Tannin (mg/g)} = \frac{[(As - Ab) - Intercept\,] \times 10}{Slope \times d \times W} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (13)$$

Where,

A_s = Sample absorbance
A_b = Blank absorbance
W = Weight of sample in gram, d = density of solution (0.791 g/ml)

3.13. Preparation of injera from the tef varieties

For the preparation of injera, the only required ingredients were the tef flour and water. The injera was prepared according to Bemihiretu [120] and Senayit [108] injera preparation process with some modifications as described below (Figure 2).

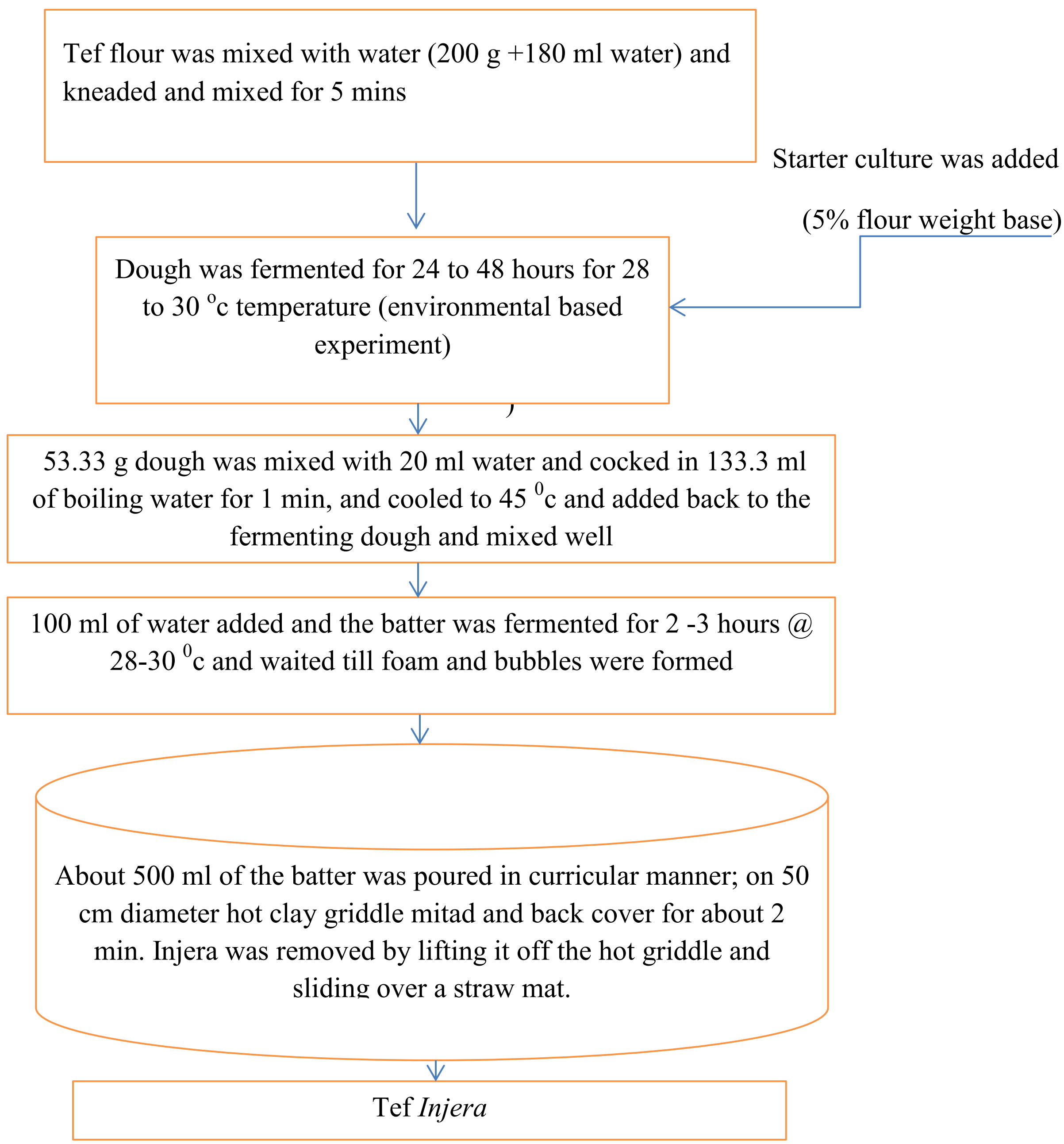

Figure 2: Flow diagram of *injera* making procedure, Source [108, 120]

N.B: To avoid contaminations, the ersho or starter cultures were prepared from each sample for individual dough making process.

Using the above flow diagram, a total of fifteen *injera* were prepared from these three tef varieties with five different rates of N fertilizer after composite from each three replications as described in Table 8. Then the *injera* were used for sensory evaluations.

Figure 3: Preparations of dough and baking of injera (from left to right)

3.14. Sensory Evaluation of tef injera

In order to determine consumer acceptability of injera prepared using *Eragrostis tef* a sensory evaluation of the final product was conducted. Obtained trained panel becoming difficult, therefore, the staff of food science and nutrition of Melkasa Agricultural Research Center (MARC) consisting of 15 panelists who regularly consume injera as their staple food was selected for sensory evaluations of *injera.* These panelists have little experiences about conducting sensory evaluations food products.

It was believed that these panelists were provided a technical judgment of acceptability useful to predict potential consumer preference. The panelists were provided with the randomly sequenced 15 samples injera for testing. They were asked to evaluate the products for color, flavor, texture (mouthfeel), appearance (eye size, honey comb structure of the top and bottom surface of the injera) and overall acceptability of the injera products. All the samples were presented to panelists in a flat tray at some condition for some hours after baking. Since the panelists were not fully-trained, and to make the evaluation process consistent, a simple nine-point hedonic scale was used, 1(Dislike extremely),2(Dislike very much), 3(Dislike moderately),4(dislike slightly), 5(neither like nor dislike), 6(like slightly),7(like moderately), 8(like very much), 9(like extremely). During the analysis of the sensory evaluation using the panelist's, water was used to rinse their mouths after tasting each sample of *injera* productions. Therefore, panelists using for the evaluation of *injera* were figure out below (Figure 4).

Figure 4: Sensory evaluation of injera using panelists

3.15. Determinations of number of holes, filtered eyes and color (CIE-L*ab) (Lightness, redness and yellowness) values of injera

The color of camera for scored values for all these parameters were determined after 24 hours the *injera* were baked. Two parallel fluorescent lamps were used to illuminate the sample. The lamps were situated at 10 cm above the sample at the angle of 45^{o} of the sample plane to give a uniform light intensity. To avoid light reflection from the room interior walls of the room was switched off before acquiring the images of *injera.* Finally the images of *injera* were captured using camera with model of Samsung galaxy J5 prime Camera 13 pixel with resolution of 720 x 1280 pixel was located vertically at a distance of 45 cm from the injera sample. The images of samples were captured on the camera setting and no flash. A total of two images for each formula of *injera* were taken. The photo images taken using a camera were transferred to a computer hard disc and opened with *injera* eye software. CIE L *ab were measured on the digital image of the sample visualized on the monitor using *injera* eye software pointing the cursor on the surface area of the sample and by clicking on it. Two surface points from each *injera* sample were taken by cutting using cutter having closely related maximum size and standard deviations of injera samples.

Therefore, the number of holes, filtered eyes and color of injera were determined using new developed software, injera eye software. Melkasa agricultural research center (MARC), Ethiopia, initially was gained training of this injera eye software by Dr. Glen Fox, cereal grain science food security, Queensland alliance for Agricultural and food innovation (QAAFI). Therefore, this software is now available at MARC and used by the researchers to analyze the eyes of injera prepared from sorghum grain. Based on this information the software also used for the determinations of the eyes of injera of tef varieties. This software was used by modifying the total areas of injera used for representative sample to count the number of holes of eyes, filtered eye and the color of injera holes on the surface of injera (Figure 5).

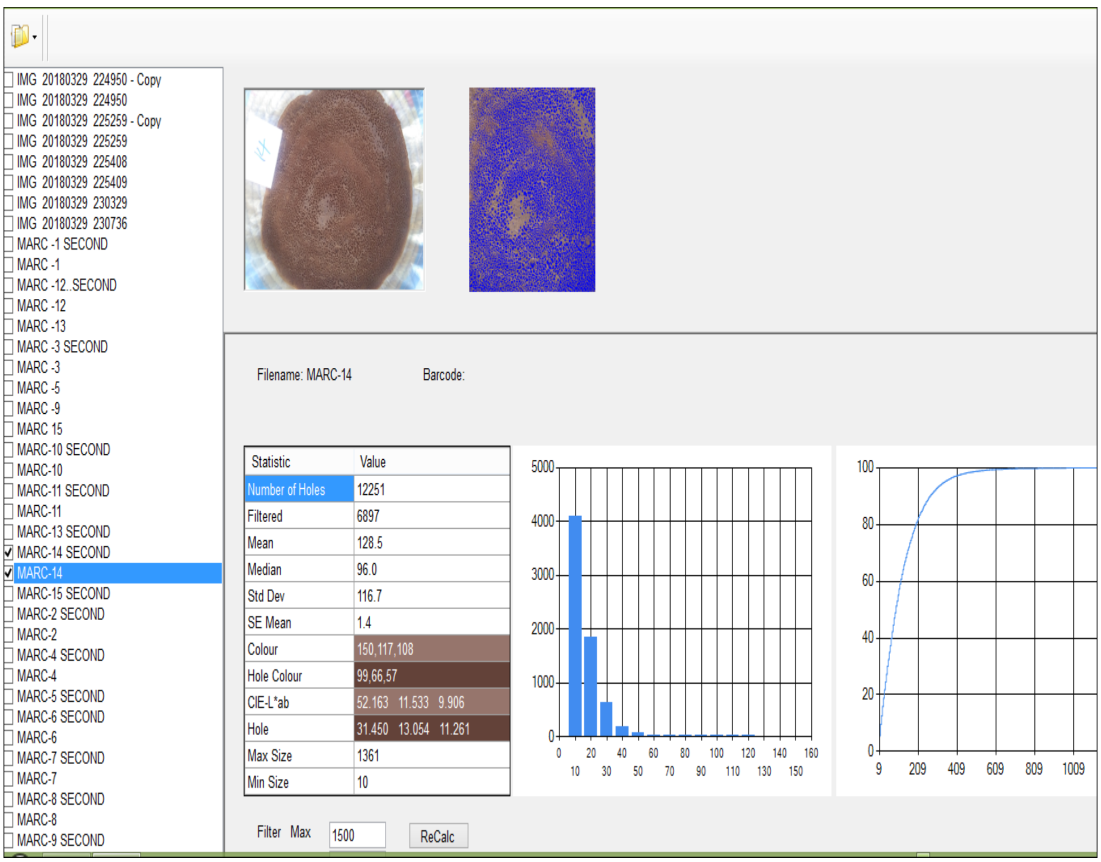

Figure 5: Analysis of number of holes, filtered eyes and color (CIE L*ab) values of injera

From (Figure 5), the first graph, X-axis indicates pixels (eye pixels), while Y-axis is for number of injera holes. As X (pixels) approaches to zero, the numbers of eyes become maximum, thus pixel and eye size have inverse relationship. Maximum size measures the representative area which cuts from the images of the injera that has sample maximum value, while minimum size is simply the dot which formed by the cutter on the surface of injera gives the minimum sample area value of 10.

3.16. Statistical Analysis

All agronomical measurements, the proximate composition, mineral and ant-nutritional factors were measured in triplicate and the results were recorded as mean ± standard error (SE). The variation between the mean levels in all treatments was measured using GenStat 17th edition www.vsni.co.uk software. Multiple comparisons between factor levels were done. GenStat 17th edition is widely used statistical software to check the presence of significance difference at 95% confidence level between mean levels of in each treatment.

In the second step the relationship between treatments and factors in *injera* sensory evaluation was analyzed by SPSS 20.0 Window evaluation version program using Duncan's multiple range post-hoc test. The sensory evaluation was analyzed using SPSS software, which provides an estimation of all parameters. On the other hand, the number of eyes of *injera*, filtered number of eyes and color of *injera* were determined using *injera* eyes software, which was adopted from MARC, Ethiopia, initially the software application was delivered to MARC by Dr. Glen Fox, cereal grain science food security, Queensland alliance for agriculture and food innovation (QAAFI) and that is comparable with imaging techniques.

4.0. Results and Discussion

4.1. Soil physico-chemical characteristics of the experimental site

The results of pre-planting initial soil analysis of soil physico-chemical properties are presented on Table 7. The electrical conductivity (EC) is a measure of salinity and $_{P}H$ of the composite soil sample were analyzed using 1:1 soil water ratio of paste saturation method. Soil reaction (expressed as $_{P}H$ value) indicated the degree of soil acidity or alkalinity. It affects nutrient availability and toxicity, microbial activity and root growth. An activity such as decompositions of organic matter, applications of commercial fertilizers as well as farming practices affects the degree of soil reactions.

As reported by Tilahun [121] from the study of Forth and Ellis, (1997), which is in line with our result, that the average P^H value of 6.50 (Table 7) indicated that the experimental soil type is classified as slightly acidic soil. Next to N, P is the most commonly plant growth-limiting nutrient in the tropical soils [122]. The result analysis of available P was recorded in low ranges which was below the threshold levels (10 ppm) of P in the tropical soils [123]. As cited by Mirutse [124] for soil N and organic carbon, respectively, the total percentages of N is 0.124% and the response of tef to different source of applied N indicated that the available form of the total soil N could be inadequate and it is likely to be stored in organic matter and clay minerals. The total mean percentage of organic carbon (1.41) content of the experimental site was comparable to soils in the semiarid regions. Due to the lower amount of organic materials applied to the soil and complete removal of the biomass from the field, most cultivated soils of Ethiopia are poor in organic matter [125].

Table 7: Soil physico-chemical properties of the experimental field based on pre-planting soil sample (0-15 cm depth) analysis

S.S (0-15cm) depth	EC(ds/cm) 1:1	$P^H(H_2O)$ 1:1	%OC	%OM	%TN	Ava. P (ppm)
Block -1	0.181	6.83	1.51	2.61	0.130	7.212
Block -2	0.226	6.37	1.39	2.40	0.120	7.205
Block-3	0.215	6.31	1.41	2.43	0.122	6.928
Mean ± SE	0.207±0.170	6.50 ± 0.093	1.44 ± 0.037	2.48 ± 0.066	0.124 ± 0.003	7.12 ± 0.094

EC = electrical conductivity, $_{P}H$= power of hydrogen ion, OC-= organic carbon, Om = organic matter, TN = total nitrogen, Ava. P=Available phosphorus, S.S=soil sample and SE=standard errors of means

4.2. Effects of N fertilizer levels on phenological parameters of tef varieties

4.2.1. Days to heading

Days to heading was significantly ($P < 0.05$) affected by tef varieties and N fertilizer rate as well as by the interaction of the two factors. Generally, as the rates of N application increased, the number of days to heading was shortened. Hence, the longest days (50.6, 50.33, 50.67 and 50.00) for Kora tef variety was recorded at 0, 30, 90 and 120 kg N ha^{-1} respectively. But a slightly lower day was recorded at 60 kg N ha^{-1}. Based on this result, for Kora tef variety the optimum N fertilizer rate could be 60 kg N ha^{-1}, for better flowering day. Boset tef variety showed the same effect for all N fertilizer rates and this was the same for Asgori tef variety, except at 0 N rates (control plot) which have maximum days of heading, 49.00 (Table 8). This may be due to the reason that nitrogen fixation may exist and its availability may be deficient in the soil. This report was in agreement with the findings of Assefa [126], that as the rate of NP increased, the number of days to heading was shortened. From the three tef varieties, Boset and Asgori were early to flowering as compared to Kora. On the other hand, the present results were contradicted with the findings of Mebratu [127] showing ;- that days to flowering of tef was delayed with the applications of inorganic fertilizer and farmyard manure and also with that of Gebretsadik [128], who reported that panicle emergence tef was delayed with the applications of N fertilizer rates.

4.2.2. Days to maturity

Days to maturity of tef plant was highly significantly ($P < 0.01$) affected by tef varieties; and significant ($P<0.05$) by N fertilizer application rates, but it was not significantly affected by the interaction of two factors (Table 8). The less of response to the N rate applications may be attributed to the variability of fertility levels or soil N content, and highly genetically difference between the three tef varieties. Studied reported that Asgori (DZ-01-99) tef variety was early released, and its days to maturity was 80-130 and this report was in agreement with our present findings (105.4) [129]. The early flowering tef varieties Boset and Asgori have respectively taken 101.4 and 103.79 days to mature, but as compared with the report of Mebratu [127], for Boset tef variety with supplied inorganic fertilizer was lowered by five days. This contradicted with our present findings, while it was comparable with late maturing variety Kora (108.9 days). Maturing groups of tef variety were due to genetic character and not much altered by growing environment. From the average means of all N rates (over all tef varieties), the days to maturity were almost similar effects except with 0, 90 and 120 kg N ha^{-1} rates that showed the maximum days to maturity.

4.2.3. Plant height

The analysis of variance showed that plant height was highly significant ($P<0.01$) affected by both varieties and N fertilizer application, but it was not significantly affected by the interactions of these two factors. The tef plants grown on the plots that received N fertilizer were significantly taller than as compared with these plants which grown on the control plot, without N fertilizer applications (Table 8). In addition to this from the rating means of tef varieties (overall N rates), Kora (135.9) variety had the highest plant height and then the second one is Boset (115.1), while the shortest plant height was for Asgori (111.7). From the grand means of N rates (overall of tef varieties), plant height increased consistently with increasing the levels of N such that the maximum plant height (128.4 cm) was obtained from the applications of the highest N level (120 kg/ha), while the lowest plant height (112.8 cm) was obtained from the control plot. Similarly, Tesfaye [130], reported that plant height increased with the applications of different N rates. Generally plant height of tef increased with N rate applications rates and this was in line with the report of Mirutse [124],showing that plant height of tef was linearly increased with N rate. On the other hand, as reported by Assefa [129], Asgori tef variety which was described with plant height (53-100 cm) had mean height of 111.1 cm not in line with the present study.

Table 8: Phenological parameters as influenced by varieties and N rates

Treatments		Parameters					
Varieties	N rate (kg/ha)	Days to heading	Days to maturity	Plant height (cm)	Panicle length (cm)	Total tiler number	Productive tiller number
Kora	0	50.67[a]	109.00[a]	127.93[a]	49.93[a]	7.0[a]	5.7[a]
	30	50.33[ab]	107.67[a]	133.87[a]	50.20[a]	7.0[a]	5.7[a]
	60	48.33[bc]	108.33[a]	136.8[a]	50.87[a]	7.9[a]	6.0[a]
	90	50.67[a]	109.33[a]	139.67[a]	50.43[a]	8.3[a]	6.7[a]
	120	50.00[ab]	110.33[a]	141.43[a]	51.70[a]	8.0[a]	6.0[a]
Boset	0	46.33[d]	105.00[a]	107.37[a]	42.53[a]	8.7[a]	7.7[a]
	30	45.00[d]	102.00[a]	108.37[a]	42.10[a]	8.7[a]	7.0[a]
	60	45.00[d]	100.67[a]	115.37[a]	43.23[a]	8.7[a]	6.7[a]
	90	45.00[d]	105.67[a]	119.4[a]	42.20[a]	8.7[a]	7.0[a]
	120	45.00[d]	108.00[a]	125.13[a]	42.37[a]	8.3[a]	7.3[a]
Asgori	0	49.00[bc]	104.00[a]	103.07[a]	45.20[a]	99.0[a]	7.0[a]
	30	45.00[d]	104.33[a]	107.90[a]	46.03[a]	10.3[a]	9.0[a]
	60	45.00[d]	104.00[a]	112.60[a]	46.7[a]	10.7[a]	8.7[a]
	90	45.00[d]	107.00[a]	116.23[a]	46.17[a]	10.3[a]	8.3[a]
	120	45.00[d]	107.00[a]	118.53[a]	46.40[a]	10.3[a]	8.7[a]
S. E ±		0.560	1.686	1.703	0.3362	0.750	0.930
Means of varieties (over all N rates)							
Kora		50.00[a]	108.9[a]	135.9[a]	50.63[a]	7.53[c]	6.00[c]
Boset		45.27[b]	104.3[b]	115.1[b]	42.49[c]	8.60[b]	7.13[b]
Asgori		45.8[b]	105.4[b]	111.7[c]	45.9[b]	10.13[a]	8.33[a]
S. E ±		0.251	0.754	0.762	0.941	0.340	0.320
Means of N rate (over all tef varieties)							
0		48.67[a]	106.0[abc]	112.8[e]	45.89[b]	8.2[a]	6.8[a]
30		46.78[b]	104.7[ab]	116.6[d]	46.11[b]	8.7[a]	7.2[a]
60		46.11[b]	104.3[c]	121.6[c]	46.72[a]	8.9[a]	7.1[a]
90		46.89[b]	107.3[ab]	125.1[b]	46.27[ab]	9.1[a]	7.3[a]
120		46.67[b]	108.7[a]	128.4[a]	46.82[a]	8.9[a]	7.3[a]
S. E ±		0.323	0.973	0.98	0.1504	0.440	0.410
Over all mean		47.02	106.20	120.90	46.36	8.8	7.20
CV (%)		2.1	2.7	2.4	1.3	14.9	17.3

CV = coefficient of variation and S.E = standards errors of means. Means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at $p \leq 0.05$. Values are the means of triplicate experiments.

4.2.4. Panicle length

The analysis of variance showed that, panicle length was highly significantly ($P < 0.01$) affected by varieties and different fertilizer rates, but it was not significantly affected by the interaction of the two factors. Of three tef varieties, the highest (56.07 cm) and lowest panicle length (42.49

cm) of tef was observed for Kora and Boset, respectively (Table 8**).** From the observations of the average means of tef varieties (over all N rates), the panicle length of tef varieties were different and this mainly due to genetic difference among varieties.

On the other hand regardless of tef varieties, the highest panicle length was recorded from the N rates of 60, 90 and 120 kg N ha^{-1} and the lowest panicle length of tef was recorded with the control plot and 30 kg N ha^{-1}, respectively (Table 8). The present findings did not agree with the reports of Fishaye [124] showing; that panicle length of tef increased with higher rates of N applications. Thus the present findings contradict with the concepts that high N fertilizer promotes plant vegetative growth eventually leading to increased panicle length of plants. In contrast to the present results panicle length of tef increased with supplied inorganic and farmyard manures [127]. In line with the other parameters, there were not significant differences in panicle length due to the application of 30 kg N ha^{-1} and control plots. The panicle length of these tef varieties were no significantly different among 60, 90 and 120 kg N ha-^{1} fertilizers and this may be due to the variability of soil fertility of the experimental site. Depending on this and from the economic points of view the optimum N source for tef varieties could be 60 kg N ha^{-1}.

4.2.5 Total and productive tiller number of tef varieties

Total tiller number and number of productive tillers were not significantly affected by either the main effects N fertilizer rates or the interaction effects, but both of them were highly significantly affected by tef varieties ($P< 0.01$). The highest means of total (10.13) and productive (8.3) tiller numbers were recorded from Asgori tef variety. But the lowest means of total (7.5) tiller and productive (6.00) tiller number were observed for Kora tef variety (Table 8).

Generally, there were no differences in number of productive tiller among the levels of N fertilizers (overall tef varieties). This result is in agreement with the findings of Tesfaye [130] who reported no significant differences in productive tillers between the higher N rate and the control plots. In contrast with the result of this study, Assefa [131] reported that the number of the productive tillers of tef was significantly increased with increasing rates of NPK. Giday [16] also reported positive and significant increase in number of productive tillers with increasing rates of N fertilizer on tef

4.3. Effects of N Fertilizer levels on yield and yield component parameters of tef varieties

4.3.1. Lodging index

Lodging index was significantly ($P < 0.05$) affected by N rate and the interaction of varieties, but not significantly affected by tef varieties (Table 9). For kora tef varieties, the lodging index was linearly increased with the N rate, but Boset and Asgori the lodging index was fluctuated at 60 and 120 kg N ha^{-1}. Generally, the lodging index was increased with N fertilizer rates.

Thus, this was in line with the report of Assefa [126] showing, that lodging index increased with the applications of NP fertilizer rates. Likewise, lodging index was reported to highly significantly affected by the applications of more nutrients in the soil [132]. Gebretsadik [128] reported that lodging index was increased with applications of N fertilizer and this was in line with our present studies.

4.3.2. Above -ground dry biomass yield

Total above - ground dry biomass was highly significantly ($P< 0.01$) affected by varieties, N rates as well as interactions of tef varieties and N rates. The highest (8693, 9120 and 8387) and the lowest (6893, 4520 and 4853 kg ha^{-1}) of means of above ground dry biomass yield were obtained from Kora, Boset and Asgori tef varieties respectively (Table 9). For Boset and Asgori tef varieties their maximum biomasses yield were recorded at 120 kg ha^{-1}. On the other hand the mean values of N rates (overall tef varieties) indicated that above - ground biomass yield increased linearly with N rate except at 90 kg ha^{-1}, which had little more grain yield. This makes a case to have lower biomass yield. Generally, our present findings are in line with the results of Giday [16], showing that, total above - ground biomass yield increased with N rate.

4.3.3. Grain yield

Applications of different N fertilizer rates were highly significantly ($p< 0.01$) increased grain yield of tef varieties (Table 9). For Kora, Boset and Asgori tef varieties, the highest grain yield were recorded at 60 to 90 kg N ha^{-1} of N fertilizer rates. Based on this trend and the economic point of view, it would be more profitable to use 60 kg N ha^{-1} N rates instead of, 90 and 120 kg N ha^{-1}. On the other hand low mean grain yield of (1709, 1402 and 1413 kg ha^{-1} for Kora, Boset and Asgori respectively) were obtained from the control plots, without the applications of N fertilizer. This may be the indicative of low availability of soil N at the experimental site. This was also positively correlated with the means of N rates (overall tef varieties) showed that grain yield increase with N rate applications. Among these three tef varieties Boset was the first yielder (Table 9). Thus our present findings was in agreement with the report of Fano [133].

4.3.4. Straw yield

The analysis of variance showed that the two main factors (tef varieties and N rates) and their interactions were highly significant (P<0.01) affected for straw yields. The lowest mean straw yield of (5184, 3118 and 3441 kg ha^{-1}) was obtained from the control plot of Kora, Boset and Asgori respectively (Table 9). The highest mean yields of 6857, 7119 and 7119 kg ha^{-1}) for Kora, Boset and Asgori tef varieties respectively were obtained from the application of 60 and 120 kg N ha^{-1}. Boset and Asgori tef varieties showed lowest grain yield with N rate of 120 kg N ha^{-1}. That is why their maximum straw yields become higher at this rate. But for kora tef variety its straw yield was optimum at 60 kg N ha^{-1}, whereas its grain was almost equal with the rate of 90 kg ha^{-1}. Generally, from the means of individual N rate (overall tef varieties) total straw yield increased with increasing N fertilizer rates (Table 9). In line with the present findings, Giday [16] also reported that straw yield increased with N rate on tef. Likewise, the current results also confirmed the findings of Gebretsadik [128]; that grain yield increased with the applications of N fertilizer rates.

4.3.5. Harvest index (HI)

The effect applications of different nitrogen fertilizer rates on tef harvest index (HI) was highly significantly (p<0.01) affected. HI of tef for all control plots was higher than from all plots having different nitrogen rates. This was due to higher shoot biomass coupled with lower grain yield obtained from the control plots (Table 9). This result contradicted with the findings of Giday [16] showing; that HI was higher at all nitrogen rate applications except the control plots. For these three tef varieties, Kora, Boset and Asgori at which their HI was lowest at 120 kg ha-1 this was due to higher above ground dry biomass of tef varieties. Averaged over all the three tef varieties, the means of N rates revealed HI did not increased with N fertilizer rates (Table 9). This was not confirmed with the findings of Habtamu [134] showing; that higher HI values were obtained with maximum N rates.

Table 9: Yield and yield parameters of tef as influenced by varieties and nitrogen fertilizer rates

Treatments		Parameters					
Varieties	N rate (kg/ha)	Lodging Index (%)	Above ground dry biomass (kg/ha)	Grain yield (kg/ha)	Straw yield(kg/ha)	Harvest index (%)	1000 seed weight (g)
Kora	0	55.67^{def}	6893^{f}	1709^{e}	5184^{fg}	0.2483^{def}	0.290^{a}
	30	58.05^{cde}	7120^{ef}	1775de	5345^{f}	0.2496^{def}	0.293^{a}
	60	58.05^{cde}	8693^{ab}	1836^{cd}	6857^{ab}	0.2113^{h}	0.307^{a}
	90	65.53^{ab}	8080^{cd}	1926^{bc}	6154^{cd}	0.2384^{fg}	0.310^{a}
	120	67.87^{a}	8213^{bc}	1754de	6459^{bc}	0.2143^{h}	0.283^{a}
Boset	0	54.33^{ef}	4520^{g}	1402^{f}	6000^{a}	0.3108^{a}	0.310^{a}
	30	57.00^{de}	6613^{f}	1859^{cd}	3118^{h}	0.2817^{bc}	0.263^{a}
	60	65.22^{abc}	8013^{cd}	2115^{a}	4754^{g}	0.2637^{cde}	0.287^{a}
	90	60.40^{bcde}	7613de	2035^{ab}	5899de	0.2680^{cd}	0.293^{a}
	120	62.63^{abcd}	9120^{a}	2001^{b}	5578ef	0.2193^{gh}	0.290^{a}
Asgori	0	48.33^{f}	4853^{g}	1413^{f}	7119^{a}	0.2913^{ab}	0.317^{a}
	30	62.00^{abc}	6893^{f}	1491^{f}	3441^{h}	0.2170^{h}	0.323^{a}
	60	68.00^{a}	7947^{cd}	1762de	5402^{ef}	0.2220^{ef}	0.360^{a}
	90	61.81^{abcd}	7587de	1865^{cd}	6184^{cd}	0.2460^{ef}	0.347^{a}
	120	62.04^{abcd}	8387^{bc}	1268^{g}	5722^{def}	0.1517^{i}	0.347^{a}
S. E ±		2.532	190.7	39.00	187.11	0.0073	0.019
Means of varieties (over all N rates)							
Kora		61.03^{a}	7800^{a}	1800^{a}	6000^{a}	0.2324^{b}	0.297^{b}
Boset		59.93^{a}	7176^{b}	1883^{a}	5293^{c}	0.2687^{a}	0.289^{b}
Asgori		60.44^{a}	7133^{b}	1560^{c}	5574^{b}	0.2256^{b}	0.339^{a}
S. E ±		1.132	85.3	17.4	83.68	0.0033	0.009
Means of N rate (over all tef varieties)							
0		52.78^{c}	5422^{e}	1508^{c}	3914^{e}	0.2834^{a}	0.306^{a}
30		59.02^{b}	6876^{d}	1708^{b}	5167^{d}	0.2494^{b}	0.293^{a}
60		63.76^{a}	8218^{b}	1904^{a}	6313^{b}	0.2323^{c}	0.318^{a}
90		62.61^{ab}	7760^{c}	1942^{a}	5818^{c}	0.2508^{b}	0.317^{a}
120		64.18^{a}	8573^{a}	1674^{b}	6899^{d}	0.1951^{d}	0.307^{a}
S. E ±		1.462	190.7	39.00	108.03	0.0042	0.011
Over all mean		60.47	7369.67	1747.67	5622.00	0.22422	0.308
CV (%)		7.3	4.5	3.9	5.8	5.2	10.8

CV (%) = Coefficient of variation, S.E = standards of errors of means, means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at $p \leq 0.05$.Values are means of triplicate experiments.

4.3.6. Thousand Seed weight

Thousand kernel was highly significantly ($P<0.01$) affected by varieties, but not significant affected by N fertilizer application rates as well as the interactions of varieties and N rates (Table 9). The highest mean thousand kernel weight (0.3387) was noted for brown-seeded variety Asgori as compared to other varieties which showed comparable means (Table 9). The present finings with respect to N fertilizer rates are not in line with the results of Giday [16], who found that thousand seed weight increased with applications of N rates. On the other hand, Alemu [126], that thousand seed weight increased with NP rate.

4.4. Effects of N fertilizer rates on nutritional composition of tef grain

4.4.1 Moisture content

The moisture content of tef varieties were significantly ($P<0.05$) affected by applications of different N fertilizer rates. But moisture content did not show increasing or decreasing trends with fertilizer rates (Table 10). Our present findings are in line with reports of Johnson [135], that higher water contents of soil provided water for plants and reduced drought stress and the physiological maturity of plants can be maintained. The moisture content tef grain recorded from the various fertilizer treatments was in the ranges reported by Bultosa [7] as, 9-11%. Hence, the moisture contents for brown seeded tef variety Asgori (DZ-01-99) and the white seeded tef variety (DZ-01-196) ranged from 12.14 to 13.00% and 11.99-12.23%, respectively [136]. Averaged overall N rates, the mean values of moisture content of tef varieties were equally 9.91%. Overall the three varieties, the average means of moisture content were slightly higher with N rates of 30 and 60 kg N ha^{-1}.While the lowest value was recorded from the rates of 90 and 120 kg N ha^{-1} (Table 10).

4.4.2 Ash contents of grain

Ash in tef grain is an indication of inorganic elements that are present in food as minerals. The ash content of tef grain did not show any significant effects of both varieties and N fertilizer rates as well as the interaction of these two factors. Generally, the ash content ranged between 1.99 to 3.16%, and this is in line with values reported for tef by Bultosa [7]. The ash content of Kora, Boset and Asgori was 2.46, 2.36 and 2.42%, respectively. On the other hand, Bultosa [7] obtained the maximum ash content of 3.16% for the brown seeded variety of Asgori, whereas the present result showed ash content of 2.42% for this same variety. This suggested that the applications of N fertilizer could not alter the contents of inorganic elements.

4.4.3 Protein contents of grain

Protein content was highly significantly ($P<0.01$) affected by applications of different N fertilizer rates, while it was not affected by varieties and the interaction of varieties and N fertilizer rates (Table 10). The N fertilizer rates showed slightly variable protein content that ranged from 9.51% -11.14% based on dry weight base. The lowest (9.51%) protein content was obtained from the control plot, without applied N fertilizer rates. While the highest (11.14 %) protein content was recorded at the maximum N rate of 120 kg N ha^{-1}, and this value is also comparable with protein contents recorded at 60 and 90 kg N ha^{-1}(Table 10). The average crude protein content of the three tef varieties were almost the same, but that of brown seeded variety Asgori (DZ-01-99) was not the line with the results of Bultosa [7] showing that its protein content was higher as compared with other varieties. Our present result showed that protein content of tef flour was increased with N fertilizer rate, but it did not deviate much from the protein contents of tef grain reported by Bultosa [7] as ranging from 8.7% to 11% with mean values of 10.4%. The percentages of protein values were calculated based on nitrogen conversion factors (6.25). The increase in protein content with N rate is not unexpected since N forms a major constituent of proteins.

Table 10: Nutritional composition of tef grain as influenced by varieties and N fertilizer rates

Treatments		Parameters						
Varieties	N rate (kg/ha)	%Moisture	%Ash	%Protein	%Crude fat	%Crude fiber	%Carbo hydrate	Energy (Kcal)
Kora	0	988[a]	2.48[a]	9.97[a]	2.08[a]	2.86[a]	75.59[a]	361.00[a]
	30	9.83[a]	2.50[a]	9.50[a]	2.16[a]	3.46[a]	76.00[a]	361.47[a]
	60	10.13[a]	2.38[a]	10.61[a]	2.13[a]	2.60[a]	74.75[a]	360.60[a]
	90	9.97[a]	2.41[a]	10.39[a]	2.24[a]	3.07[a]	74.99[a]	361.65[a]
	120	9.73[a]	2.53[a]	11.7[a]	2.20[a]	3.03[a]	73.77[a]	361.98[a]
Boset	0	9.87[a]	2.58[a]	9.57[a]	2.55[a]	3.40[a]	75.42[a]	362.94[a]
	30	10.28[a]	2.29[a]	10.35[a]	2.15[a]	2.50[a]	74.93[a]	360.46[a]
	60	9.91[a]	2.32[a]	10.57[a]	2.09[a]	2.48[a]	75.10[a]	361.56[a]
	90	9.70[a]	2.40[a]	11.51[a]	2.14[a]	2.74[a]	74.25[a]	362.27[a]
	120	9.81[a]	2.23[a]	11.21[a]	2.10[a]	2.70[a]	74.59[a]	362.66[a]
Asgori	0	9.99[a]	2.30[a]	8.99[a]	2.24[a]	3.73[a]	76.47[a]	362.00[a]
	30	10.00[a]	2.39[a]	10.58[a]	2.21[a]	2.92[a]	74.82[a]	361.46[a]
	60	10.07[a]	2.45[a]	10.79[a]	2.17[a]	3.35[a]	74.51[a]	360.71[a]
	90	9.60[a]	2.41[a]	10.98[a]	2.16[a]	2.84[a]	74.85[a]	362.74[a]
	120	9.86[a]	2.52[a]	10.42[a]	2.18[a]	2.72[a]	75.02[a]	361.39[a]
S. E ±		0.124	0.118	0.409	0.101	0.333	0.508	0.733
Means of varieties (over all N rates)								
Kora		9.91[a]	2.46[a]	10.45[a]	2.16[a]	3.00[a]	75.02[a]	361.34[a]
Boset		9.92[a]	2.36[a]	10.64[a]	2.22[a]	2.76[a]	74.86[a]	361.98[a]
Asgori		9.91[a]	2.42[a]	10.35[a]	2.19[a]	3.11[a]	75.13[a]	361.66[a]
S. E ±		0.056	0.053	0.183	0.045	0.149	0.227	0.328
Means of N rate (over all tef varieties)								
0		9.92[ab]	0.245[a]	9.51[c]	2.29[a]	3.33[a]	75.83[a]	361.98[a]
30		10.04[a]	2.40[a]	10.14[bc]	2.17[a]	2.96[a]	75.25[ab]	361.13[a]
60		10.04[a]	2.39[a]	10.66[ab]	2.13[a]	2.81[a]	7479[b]	360.95[a]
90		9.76[b]	2.41[a]	10.96[a]	2.18[a]	2.88[a]	74.70[b]	362.22[a]
120		9.80[b]	2.43[a]	11.14[a]	2.18[a]	2.81[a]	74.46[b]	362.01[a]
S. E ±		0.072	0.068	0.236	0.058	0.192	0.293	0.423
Over all mean		9.91	2.41	10.48	2.19	2.96	75.00	361.66
CV (%)		2.24	8.5	6.8	8.0	19.5	1.2	0.4

%CV = coefficients of variation, S.E= standards errors of means and; Means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at $p \leq 0.05$. Values are means of triplicate experiments.

4.4.4 Crude fat content

The analysis of variance showed that; crude fat content of grain was not significantly affected by varieties, N fertilizer rates as well as the interaction of the two factors. The crude fat content for the three tef varieties as affected by different N fertilizer rates ranged between 2.16 to 2.22 % for Kora, Boset and Asgori tef varieties (Table 10). The intermediate value (2.19%) was recorded for Asgori tef variety. The ranges of crude fat contents obtained were in line with the values of 2.0 to 3.0% mean of 2.3 ±0.5% reported by Bultosa [7]. The fat accumulations of tef varieties were uniform and have not shown significant differences and of a constant ratio the endosperm and embryo growth by giving optimal conditions to physiological process as described by Simion for corn as affected by organic [137].

4.4.5 Crude fiber

The crude fiber content of the grains was not significantly affected by varieties, N fertilizer levels as well as the interaction of the two factors (Table 10). Regardless of N fertilizer rates, the brown seeded Asgori tef variety had the maximum crude fiber content followed by Kora tef variety. But the differences were not statistically significant. Averaged over all varieties, the means of N rates indicated no significances, but that the control plot had greater value of crude fiber. From the three tef varieties the range of crude fiber content was between 2.76 to 3.11%, and this is in line with the report of Baye [5].

4.4.6 Total Carbohydrate (CHO) and energy (Kcal) content

The carbohydrate content of tef grain was not significantly ($P<0.05$) affected by the tef varieties, while it was significantly affected by the N rates (Table 10). As the N applications rates increased the carbohydrates content decreased and this was inversely related with the protein contents. But neither the different rates of N fertilizer nor the three tef varieties exerted significantly effects on the energy content of tef grains (Table 10).

4.5. Effects of N fertilizer rates and varieties on the anti-nutritional factor of grain

4.5.1 Phytic acid content

The interaction N rates and tef varieties were highly significant at ($P<0.001$) on phytic acid content of tef grain. Phytic acid concentrations from control plots, without application of nitrogen fertilizer were comparable with those receiving different rates of N fertilizer (Table 11). This is because phytate is a primary P storage in the plant, and; a higher phytic acid is expected with fertilization. According to Baye [5], the phytate content for tef varieties ranged from 682 to 1374 mg 100 g^{-1} on dry weight basis, and this not in line with present findings showing a range of 98.2 to114.3 mg 100 $g^{-1.}$ This difference may due to the reason whether a methodology difference and phosphorus may be form a complex with soil and this can be reduce the phytate contents, phosphorus storage form.

Table 11: Mean phytic acid and tannin content of tef grain as influenced by different N fertilizer rates and varieties

Treatments		Parameters (mg 100 g $^{-1}$)	
Varieties	N rates (kg N ha^{-1})	Phytic acid	Tannin
Kora	0	103.7^{b}	31.46^{a}
	30	114.3^{ab}	29.25^{a}
	60	101.1^{b}	28.49^{a}
	90	98.2^{b}	27.88^{a}
	120	108.8^{ab}	28.12^{a}
Boset	0	104.3^{b}	16.86^{a}
	30	98.4^{b}	20.17^{a}
	60	123.3^{a}	24.22^{a}
	90	108.0^{ab}	21.63^{a}
	120	109.1^{ab}	18.05^{a}
Asgori	0	114.0^{ab}	22.10^{a}
	30	100.7^{b}	13.87^{a}
	60	114.6^{ab}	16.29^{a}
	90	103.1^{b}	15.83^{a}
	120	108.6^{ab}	16.34^{a}
S. E ±		3.365	2.335
Means of varieties (over all N rates)			
Kora		105.22^{a}	29.04^{a}
Boset		108.61^{a}	20.19^{b}
Asgori		108.19^{a}	16.89^{c}
S. E ±		1.505	1.044
Means of N rate (over all tef varieties)			
0		107.3^{bc}	23.47^{a}
30		104.4^{bc}	21.10^{a}
60		113.0^{a}	23.00^{a}
90		103.1^{c}	21.78^{a}
120		108.9^{ab}	20.83^{a}
S. E ±		1.943	1.348
Over all mean		107.34	22.04
CV (%)		5.4	18.3

CV = Coefficient of Variation and S. EM = standard of errors of means; PHA= phytic acid (mg 100 g-1), Means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at $p \leq 0.05$. Values are means of triplicate experiments.

4.5.2 Tannin contents of tef grain

The tannin anti-nutritional factor content of tef flour was highly significantly (P<0.001) affected by varieties, but it was not significantly affected not by n fertilizer rates as well as the interaction of varieties and N fertilizer rates (Table 11). From the means of tef varieties (over all N rates), higher tannin contents of (29.04) and (20.19) mg 100 g^{-1} was recorded form the white-seeded tef varieties Kora and Boset, respectively (Table 11). But the lowest tannin content of 16.89 mg CE 100 g^{-1} was noted for the brown seeded. This impels that both white –seeded tef varieties of Kora and Boset had higher tannin content due probably to genetic differences. As reported by Baye [5] the condensed tannin content of different tef varieties were about 16 mg 100 g^{-1} and this was almost similar with the result in the present study for the brown- seeded tef variety Asgori. In addition to this , Gerbaba (unpublished) [138] reported that; the condensed tannin content of brown seeded tef variety was 16.52 mg CE 100 g $^{-1}$, and this was also in line with the present findings (16.89 mg CE g^{-1}) particularly for Asgori tef variety, but not with the results of Kora and Boset varieties

4.6. Effects of nitrogen fertilizer rates on mineral contents of tef grain

4.6.1 Iron (Fe)

The analysis of variance indicated that the mineral content of Iron (Fe) was significantly ($P<0.05$) affected by varieties and the interaction with N fertilizer rates (Table 12). The maximum (29.12, 34.58 and 37.39 Fe content of kora, Boset and Asgori tef varieties were recorded at 90, 90 and 120 kg N ha^{-1}, while the minimum (25.85, 26.96 and 23.33) were obtained at 60, 120 and 60 kg N ha^{-1}, respectively. Averaged over all N rates, the means of tef varieties indicated a significant differences, that both Boset and Asgori varieties had maximum (30.14 and 30.38) mg 100 g^{-1} Fe contents than Kora (22.60) varieties. While averaged over all tef varieties, the means of N rates that, 90 kg N ha^{-1} had maximum (33.39) Fe content followed by 120 kg N ha^{-1} (30.79). Therefore, the ranges of Fe contents for both white (Kora and Boset) tef varieties of our present study were found between 25 .85 to 34.58 mg 100 g^{-1}, respectively, but for Asgori was found between 23.33 to37.39 mg 100 g^{-1}. This result was in line with the report of Baye [5] , that the ranges of Fe content of white tef varieties were found between 9.5-37.7, while for red tef variety was exists between 11.6->150 mg 100 g^{-1}. Compared individual average means of tef varieties of Boset and Asgori , the Fe content of both tef varieties were the same in magnitude; this was not in line with findings of Abebe [139], showing red tef variety had a higher Fe content than white tef varieties. These high contents of Iron of tef varieties may also bring from soil contamination [139]. In addition to this, as compared with other cereal crops, tef has higher iron contents; this may due to the surface areas of tef.

Table 12: Mineral contents of tef grain as influenced by the interaction of tef varieties with different N fertilizers rates

Treatments		Parameters		
Varieties	N rate (kg/ha)	P(ppm)	Fe (mg 100 g^{-1})	Ca (mg 100 g^{-1})
Kora	0	216.7^{cde}	27.63^{defg}	57.67^{de}
	30	216.9^{bcde}	27.41^{defg}	72.83^{bc}
	60	217.5^{ab}	25.85^{efg}	68.14^{abcd}
	90	216.9^{bcde}	29.12^{cde}	73.89^{ab}
	120	216.6^{de}	28.02^{def}	68.60^{abcd}
Boset	0	216.6^{e}	28.49^{cd}	74.85^{a}
	30	217.4^{ab}	28.11^{def}	61.67^{de}
	60	217.8^{a}	32.57^{bc}	63.38^{bcde}
	90	216.4^{e}	34.58^{ab}	65.13^{abcde}
	120	216.7^{cde}	26.96^{defg}	64.63^{abcde}
Asgori	0	217.2^{abc}	23.33^{g}	62.85^{cde}
	30	217.1^{bcd}	30.25^{cd}	62.46^{cde}
	60	217.2^{abcd}	24.22^{fg}	57.09^{e}
	90	216.7^{cde}	36.49^{ab}	58.84^{de}
	120	217.3^{abc}	37.39^{a}	58.49^{de}
S. E ±		0.226	1.426	3.79
Means of varieties (over all N rates)				
Kora		216.91^{a}	22.60^{b}	68.22^{a}
Boset		216.92^{a}	30.14^{a}	65.93^{a}
Asgori		217.10^{a}	30.38^{a}	59.95^{b}
S. E ±		0.101	0.638	1.70
Means of N rate (over all tef varieties)				
0		216.7^{bc}	26.56^{c}	65.12^{a}
30		217.1^{ab}	28.59^{bc}	65.65^{a}
60		217.5^{a}	27.04^{c}	62.87^{a}
90		216.7^{b}	33.39^{a}	65.96^{a}
120		216.8^{b}	30.79^{b}	63.91^{a}
S. EM ±		0.1301	0.823	2.69
Over all mean		216.98	29.37	64.70
CV (%)		0.2	1.8	2.5

CV = Coefficient of Variation and S.EM = standards of errors of means, P =Phosphorus, Fe= Iron and Ca= Calcium and; Means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at $p \leq 0.05$. Values are means of triplicate experiments.

4.6.2 Calcium (Ca)

Calcium (Ca) content was significantly ($P<0.05$) affected by varieties and the interaction with N fertilizer rates, but not by N rates (Table 12). From the interaction effects, it did not show increasing or decreasing in Ca content for the three tef varieties of Kora, Boset and Asgori. The maximum (73.89, 74.85 and 62.85) mg 100 g^{-1} Ca content were observed at plot number with 90

(Kora), 0 (Boset and Asgori) kg N ha^{-1}, while the minimum (57.67, 61.67 and 5.07) mg 100 g^{-1} were recorded at 0, 30 and 60 kg N ha^{-1} of Kora, Boset and Asgori, respectively. The ranges of Ca content for both white tef varieties of Kora and Boset were found between 57. 67 to 74.85; while for Asgori was found between 57.09 to 62.85 mg 100 g^{-1}, respectively. This result also in agreements with Baye [5] who reported that Ca content for white tef varieties exists between 17-124, while for red tef variety is 18 to178 mg 100 g^{-1}, respectively. Regardless to N fertilizer rates, the maximum Ca content was observed from Kora (68.22) tef variety followed by Boset (65.93), but the minimum (59.95) mg 100 g $^{-1}$ was recorded from Asgori. This was not in line again with the findings of Abebe [139] , that red tef has higher Ca content than white tef varieties.

4.6.3 Phosphorus (ppm) content of tef grain

The analysis of variance indicated that P mineral content of tef grain was significantly ($P<0.05$) affected by N rates, and the interaction, but not by varieties. Applications of TSP with different N fertilizer rates had significant effects on the P mineral content of tef grain. From the averaged over all N rates, the means of varieties indicated no significant differences and had almost the same P content of varieties of Kora (216.91), Boset (216.92) and Asgori (217.10) ppm, respectively. As reported by Kebede, [140] showing that, red tef grain have higher P content, but this is not in line with our result, that P contents of the two white-seeded and one brown seeded Asgori varieties had almost the same P mineral content (Table 12). Regardless of tef varieties, the maximum P content was recorded at 60 kg N ha^{-1} followed by 30 kg N ha^{-1}. This implies that P and N fertilizer interactions have significant effect on the concentrations P of tef flour.

4.7. Effects of N fertilizer rates and varieties on sensory quality of *injera*

The sensory evaluation responses and acceptability of tef injera made from the flours of three tef varieties as influenced by different N fertilizer rates were presented in Table 13. The sensory evaluation scored values for all sensory attributes were determined after 24 hours the injera of baking. In this study, a panelist of 15 judges were used to described the degree of consumers acceptance satisfactions on to the injera prepared from different tef varieties as affected by different N rates.

4.7.1 Color

The analysis of variance for sensory evaluations of injera form the three tef varieties as influenced with different N fertilizer rates are presented in the (Table 13). The color of *injera* for the three tef varieties were significantly ($P < 0.05$) affected by both N fertilizer rates and varieties as well as the interaction of two factors. As application of N fertilizer increased, the color of *injera* for the first three N fertilizer rates of the three varieties were slightly decreased. From the response of panelists and the LSD values indicated that, the sensory evaluations of injera were not much significantly different. However, Kora had maximum (8.27) color value of *injera* at K0 and rated as like-very much, while the minimum (5.57) color values was observed at K60 and K90 and rated as neither-like nor dislike. The interaction of variety with N rate on the color value of injera from Boset variety had the same effects and rated as like-slightly, except the maximum (7.33) and minimum (5.93) values were recorded at B120 and B90 and rated as neither like nor dislike and like-moderately respectively. On the other hand Asgori tef variety had maximum color value at all interactions and rated like-slightly, however the minimum (5.53) color value was observed at A30 and rated as neither like nor dislike.

The grand means of variety of Kora (G.MK) (6.63), Boset (G.MB) (6.53) and Asgori (G.MA) (6.04) indicated that the color of baked injera was slightly affected by tef varieties. Both *injera* from white seeded varieties of Kora and Boset were the same in color, but Asgori was different and the rated values are like-slightly.

Grand means of N fertilizer rates indicated that, the color of injera become maximum at the control plot (without N fertilizer) and decreased as N fertilizer rate increased for the first four N rates (0 to 90 kg N ha^{-1}), but the color slightly increased at 120 kg N ha^{-1} and this may be due probably to N fixation and this negatively affects availability of N for plant use. Generally, as LSD value show that except the application of 0 and 90 kg N ha^{-1}, remain N rates had the same effects on the color of injera.

And *injera* appearance is one of the most important quality parameters which tells us the eyes on the surface of injera that is honeycomb like structure of top surface formed when CO_2 gas bubbled [141]. *Injera* with uniformly distributed eyes on its top surface and closely located to one another and had no blind spot on its surface is the indicative of good injera .The color of *injera* affected its preference by the consumers and areas where injera is consumed as staple food such as Ethiopia, people prefer their color of injera to be white [142]. The Figure 6 indicated the comparisons of color of varieties interaction with N rates.

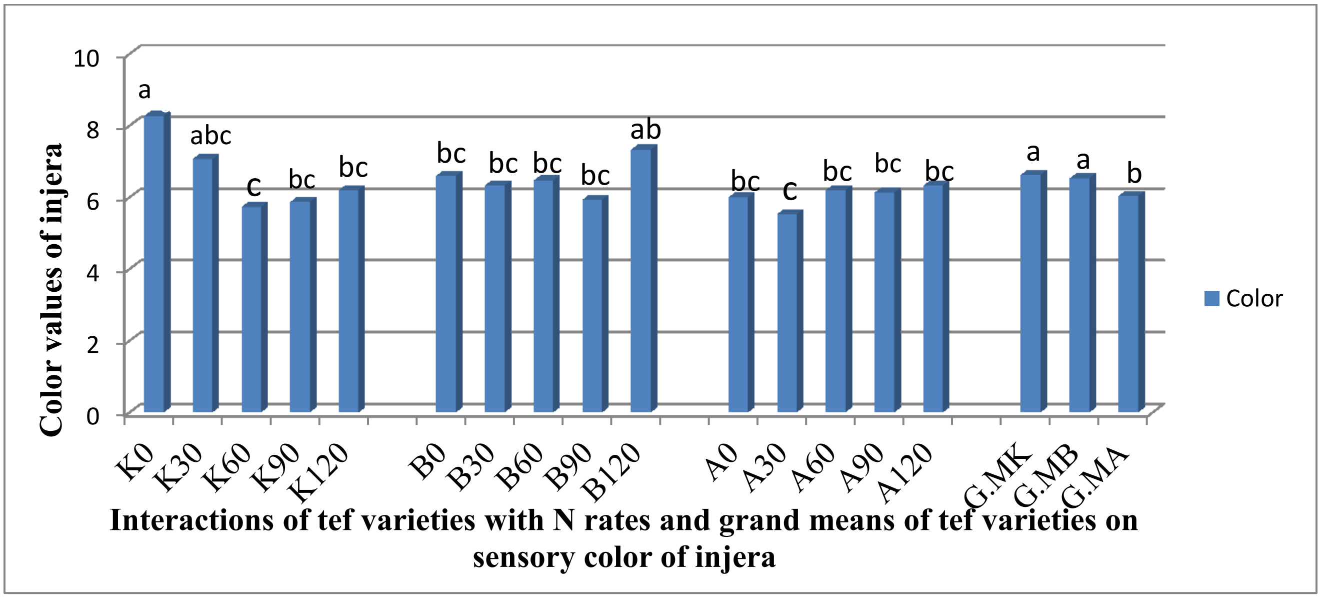

Figure 6: Interaction effects of tef varieties with N rates and the grand means of varieties on the color of injera using panelists, K= Kora, B =Boset and A =Asgori tef varieties, 0 to 120 indicate five N rates, while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties.

4.7.2 Flavor

From the sensory response of panelists, flavor of injera was significantly ($P<0.05$) affected by the interaction of the two factors, but not by N rates and varieties (Table 13). Therefore, many studies reported that the applications of N fertilizer rates have a negative significant effects on the flavor of food products of cereal crops and vegetables such as rice and potatoes, respectively [22, 28]. Our present result is significant but not shown increasing or decreasing trends and this was not in line with of Gu [22], who reported that as N fertilizer dressing systems increase, flavor was significantly affected. Therefore, the concepts of applications different source of N fertilizer in agricultural productions caused the changes of flavor of the food item.

However, it was found that interaction of varieties with five N rates have almost the same effects on the flavor of injera. But in magnitude, Kora variety had maximum (7.1) and minimum (5.5) flavor values at K0 and K90 and rated like-moderately and neither like nor dislike respectively. The flavor of *injera* baked from Boset variety ranged from 5.4 (B90) to 6.5(B60) and rated as neither like nor dis-like and like-slightly respectively. Interaction of Asgori variety with N rates showed that injera flavor had the same effects and rated as like-slightly except injera from A0 (5.73) and A120 (5.93) rated as neither like nor dislike.

However, the interaction effects have the same effects on the flavor of injera results from Asgori (A0) tef variety deviated from the rest of tef varieties, which flavor of injera at the control plot was lowered as compared with Kora and Boset. This may be due to the reason that *injera* from red tef is already discernment by the societies and they may not care for their evaluations.

Averaged over all N rates and tef varieties indicated no significant differences on the flavor of injera (Figure 7). Grand means of Kora (G.MK) 6.13, Boset (G.MB) 6.05 and Asgori (G.MA) 6.04 had rated values of like –slightly and Averaged N rate showed that, application of all N rates except 90 kg N ha^{-1}(neither like nor dislike) had the same effects on the flavor of injera and rated as like-slightly.

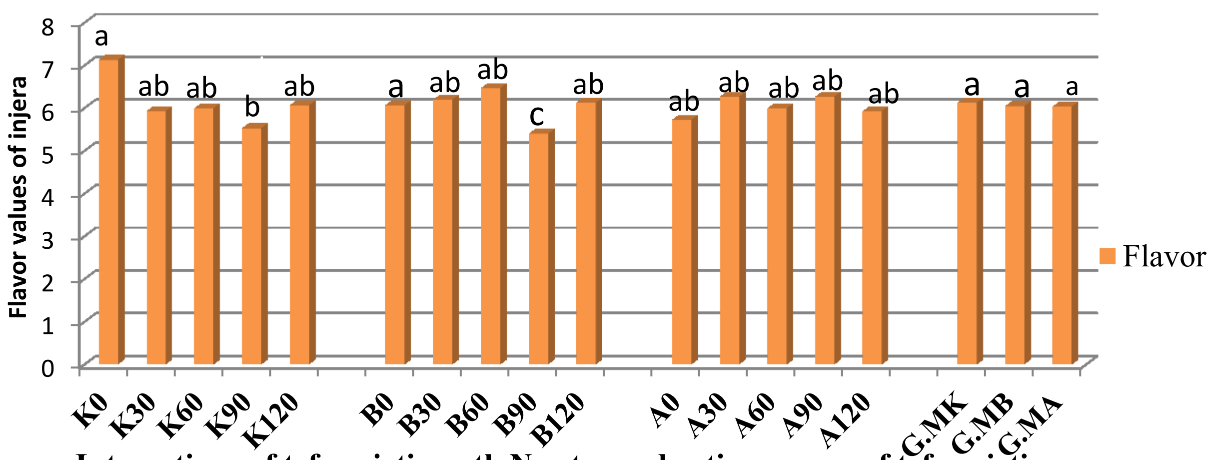

Figure 7: Interaction effects of tef varieties with N rates and grand means of varieties on the flavor of injera using panelists, K= Kora, B =Boset and A =Asgori tef varieties, 0 to 120 indicate five N rates, while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties.

4.7.3 Texture

Texture is another important parameter often used to measure the quality of food products. It is determined by touch and refers to the degree of fluffiness, roughness, smoothness, hardness or softness. *Injera* that becomes soft and easily pliable to wrap and hold the sauce (wot) is most preferable by the consumers [142]. From the response of panelists, texture of *injera* was not significant (P<0.05) affected by N rates and varieties, but affected by the interaction (Table 13). However, the interaction of both white seeded varieties of Kora and Boset had the same effects on the texture of injera and rated as like slightly, but injera at K30, K90 and B60 rated neither like nor dislike (Figure 8). While injera from the interaction of brown seeded of Asgori with N rate had the same effect on flavor of injera and had rated value neither like nor dislike. From the study of Habteab [143], who reported that injera prepared from tef flour only used as control one was not significant differences for the sensory response of texture and this was not in line with our present study. Averaged over all N rates and varieties, the mean values of N rates and varieties indicated no significant differences on texture of injera, respectively (Figure 8).

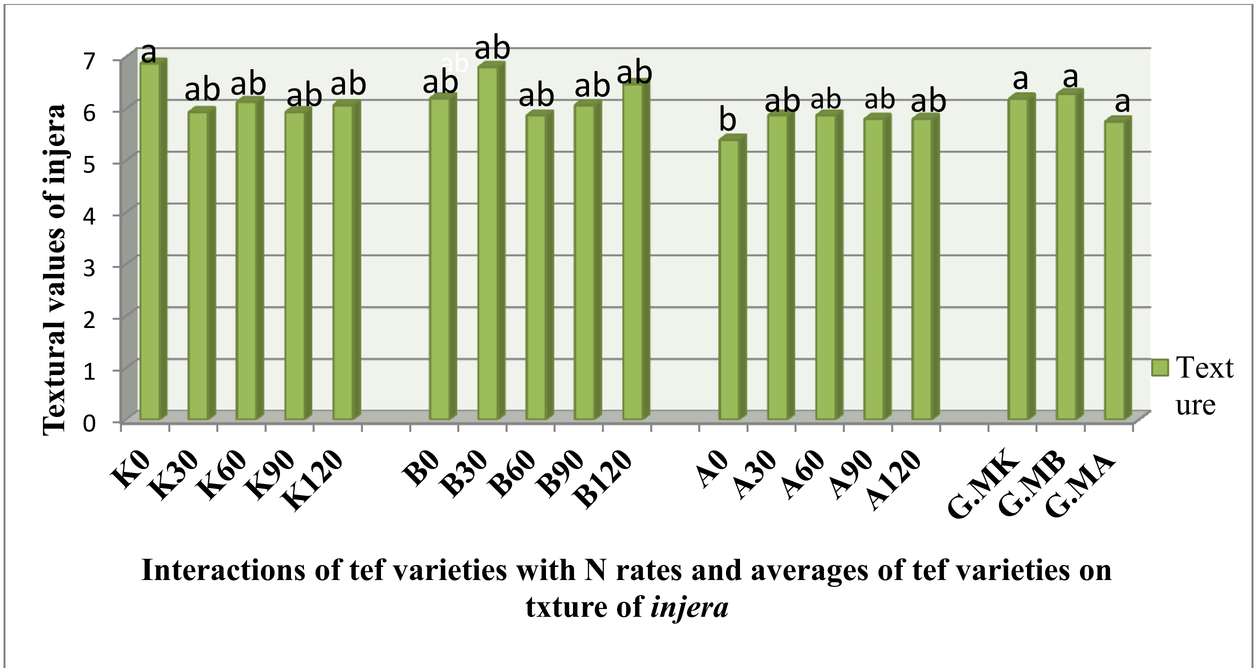

Figure 8: Interaction effects of tef varieties with N rates and grand means of varieties on the texture of injera using panelists, K= Kora, B =Boset and A =Asgori tef varieties, 0 to120 indicate five N rates, while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties.

4.7.4 Taste

Sensory evaluation of taste indicated it is significantly ($P \leq 0.05$) affected by varieties and interaction of the two factors. The sensory evaluations of taste were ranged from 5.87 to7.27. However from the response of the panelists, the interaction of three varieties and five N rates had the same effects on injera taste value and had greater than 6(like-slightly), except injera from

K90 and A90, both had 5.87 taste values and rated as neither like nor dislike. While the maximum taste value was obtained at K0 (7.27) had rated value of like moderately (Table 13).

The whole taste of baked *injera* were rated from neither like nor dislike to like-moderately which was not in line with the findings of yetnberk [141], who reported that, *injera* from tef flour had very soft texture and flavorless after taste and was rated excellent. In addition to this, a study reported by Habteab [143], *injera* prepared form only tef varieties was not significant for the sensory evaluations of taste as compared with *injera* of E.curvula grain and this was not in line with our present study and this implies that applications of N fertilizer have significant effects on taste values of baked *injera.* The grand mean values of varieties (overall N rates) of taste for *injera* was significant (P<0.05) and the minimum (6.04) value was observed from Asgori variety, but both white seeded varieties of Kora (6.55) and Boset (6.61) have the same taste values. This difference may be due to the reason that less attitude in which the societies gave for injera prepared from red tef (Figure 9). Based on the response of the panelists the taste values for the three varieties were rated as like - slightly. Averaged over all varieties, the means of N rates did not significant differences on taste of injera. This implies that, including the control plot (without N fertilizer) all N rates have the same taste response (like-slightly) for the baked *injera* (Figure10).

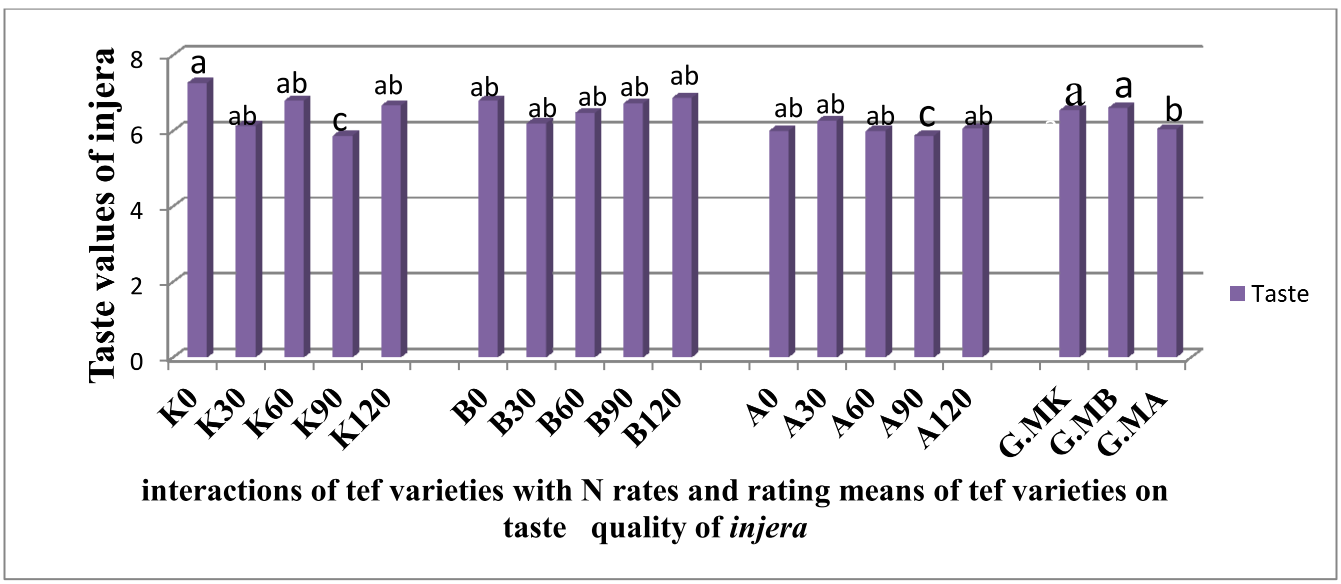

Figure 9: Interaction effects of tef varieties with N rates and grand means varieties on the texture of injera using panelists, K= Kora, B =Boset and A =Asgori tef varieties, 0 -120 indicate five N rates, while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties.

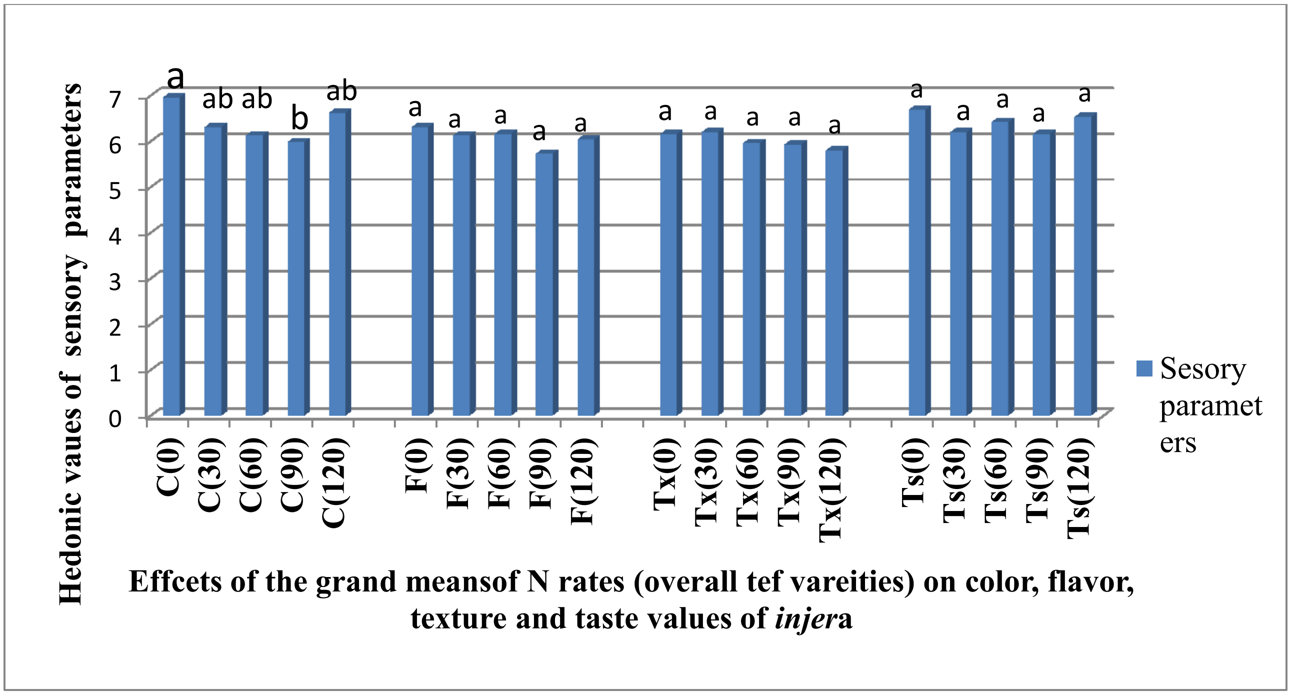

Figure 10: Effects of grand means of N fertilizer rates on color, flavor, texture and taste values of injera using panelists, **C, F, Tx and Ts** represents sensory attributes of color, flavor, texture and taste respectively and 0,30,60,90 and 120 represents N rates (kg N ha^{-1}).

4.7.5 Folding capacity

Folding capacity of injera was not significantly affected by varieties and N rates as well as the interaction of two factors (Table 13). However, the maximum (7.00) values were recorded from K0 (like-moderately) and the minimum (5.80) was observed at K90 and B60 (neither like nor dislike), while all the rest of baked *injera* from the three varieties with the application of N fertilizer rates was rated as like-slightly.

4.7.6 Eye size and distribution of *injera*

Injera, a staple food in Ethiopia, is large pancake-like bread prepared from cereals such as tef, sorghum and millets. It is characterized by having 'eyes' (honeycomb-like holes) on its top surface, which are produced due to the production and escape of carbon dioxide during fermentation and baking process. Therefore, fermentations of the dough contribute on the productions of eye and its distribution on the surface of baked *injera*. Carbon dioxide produced during fermentation is known to play a fundamental role in the formation of cellular structure of leavened breads [144].

From the response of panelists, the eye size of baked *injera* was significantly ($P<0.05$) affected by N fertilizer rates and the interaction, but not by varieties (Table 13). Thus, eye formation and its distribution were mostly depends on the fermentations of the dough. The analysis of variance indicated that, the interaction of varieties with N rates had almost the same effects on the eye size of injera. Generally from the 15 baked *injera* having different N fertilizer rate applications, except K60, B60, B90 and A120 (neither like nor dislike) and K0, K30 and A30 (like-moderately) all baked *injera* with their respective N rate were rated as like-slightly. This indicated that, at the maximum grain yield (plants use the optimum N fertilizer) also have a significant correlation with the changes of sensory attributes such as eye size. This may due probably that optimum N fertilizer have negative significant effects on carbon dioxide bubble formations, have fundamental role on eye size of injera.

On the other hand eye distributions of baked *injera* were significantly ($P<0.05$) affected by varieties and N rates as well as interactions. The sensory evaluation of injera having neither like nor dislike responses on the eye distributions of *injera* were recorded at B0 (5.87), B90 (5.67), A60 (5.87) and A90 (5.73) and like moderately was obtained at K30 (7.33), while the rest of baked injera rated as like-slightly.

The grand mean of varieties indicated that, eye distributions of injera was significant differences between Kora (6.63) and Boset (6.00) varieties, while Asgori (6.15) had almost the same eye distribution with Kora. Regardless of varieties, the maximum (6.80) eye distribution was observed at 30 kg N ha^{-1}, while the minimum (5.87) was recorded at 90 kg N ha^{-1} respectively. Being the performance of eye size and distribution mainly depends on the formation and escapes of carbon dioxide gas [144]. Thus from this point of view it not clear to hypothesize and develop correlation that applications of N fertilizer and productions of carbon dioxide gas significantly affects the eye size and distributions of *injera.*

4.7.7 Top and bottom surfaces of *injera*

The appearances of top and bottom surface of baked injera was not significantly ($p<0.05$) affected by varieties and N rates as well as the interaction. The analysis of variance for the interaction effects of top and bottom surfaces of *injera* were ranged from 6.00 (A60) to 7.40 (B120) (Table 13). From the response of panelists, all baked *injera* was rated as like-slightly except *injera* from B0 and B120 (like-moderately). The study by yetnberk [141] indicated that, *injera* made from tef flour had a white top and bottom surface. Therefore, applications of different N rate fertilizer does not improve or reduced the whiteness of the top and bottom surface of *injera* baked from the three tef varieties and our present report was in line with the report of yetnberk.

Averaged over all N rates and varieties, the mean values of both varieties and N rates indicated that the top and bottom surface of *injera* did not significant differences and rated as like-slightly.

Table 13: Sensory acceptability test result of injera of tef varieties as influenced by five different N fertilizer rates

Treatment	Sensory attributes								
VWR	Color	Flavor	Texture	Taste	FC	ES	ED	TBS	OACC
K0	8.27±0.182^{a}	7.13±0.336^{a}	6.87±0.401^{a}	7.27±0.358^{a}	7.00±0.390^{a}	7.27±0.419^{a}	6.73±0.511^{ab}	6.87±0.506^{a}	7.80±0.355^{a}
K30	7.07±0.300^{abc}	5.93±0.442^{ab}	5.93±0.408^{ab}	6.13±0.559^{ab}	6.07± 0.581^{a}	7.27±0.419^{a}	7.33±0.287^{a}	6.60±0.486^{a}	7.47±0.350^{ab}
K60	5.73±0.530^{c}	6.00±0.447^{ab}	6.13±0.363^{ab}	6.80±0.223^{ab}	6.27± 0.565^{a}	5.87±0.487^{abc}	6.27±0.371^{ab}	6.67±0.333^{a}	6.87±0.335^{abc}
K90	5.87±0.559^{bc}	5.53±0.487^{b}	5.93±0.442^{ab}	5.87±0.363^{c}	5.93 ±0.371^{a}	6.33±0.532^{abc}	6.47±0.363^{ab}	6.87±0.363^{a}	6.87±0.456^{abc}
K120	6.20±0.460^{bc}	6.07±0.483^{ab}	6.07± 0.521^{ab}	6.67±0.398^{ab}	6.33 ± 0.410^{a}	6.67±0.252^{abc}	6.33±0.303^{ab}	6.87±0.256^{a}	7.20±0.312^{abc}
G.MK	**6.63 ± 0.217^{a}**	**6.13 ± 0.202^{a}**	**6.19 ± 0.191^{a}**	**6.55 ± 0.191^{a}**	**6.32 ± 0.210^{a}**	**6.68 ± 0.198^{a}**	**6.63 ± 0.170^{a}**	**6.77 ±0.175^{a}**	**7.24± 0.168^{a}**
B0	6.60±0.375^{bc}	6.07±0.383^{ab}	6.20±0.428^{ab}	6.80±0.500^{ab}	6.80 ±0.327^{a}	6.60±0.335^{abc}	5.87±0.435^{b}	7.07±0.330^{a}	6.87±0.236^{abc}
B30	6.33±0.454^{bc}	6.20 ± 0.428^{ab}	6.80± 0.312^{ab}	6.20 ±0.518^{ab}	6.20 ±0.449^{a}	6.47±0.456^{abc}	6.33±0.398^{ab}	6.47±0.446^{a}	6.93±0.316^{abc}
B60	6.47± 0.487^{bc}	6.47±0.401^{ab}	5.87± 0.456^{ab}	6.47±0.336^{ab}	5.80 ±0.393^{a}	5.60 ±0.349^{c}	6.00±0.458^{ab}	6.73±0.371^{a}	6.60±0.349^{abc}
B90	5.93± 0.521^{bc}	5.40±0.533^{c}	6.07±0.419^{ab}	6.73±0.300^{ab}	6.27 ±0.396 ^{a}	5.87±0.477^{abc}	5.67±0.433^{b}	6.40±0.445^{a}	6.80±0.327^{abc}
B120	7.33± 0.485^{ab}	6.13± 0.524^{ab}	6.47± 0.413^{ab}	6.87±0.376^{ab}	6.60 ±0.363^{a}	6.60±0.400^{abc}	6.40±0.423^{ab}	7.40±0.349^{a}	7.07±0.521^{abc}
G.MB	**6.53 ± 0.210^{a}**	**6.05 ± 0.203^{a}**	**6.28 ± 0.188^{a}**	**6.61 ± 0.82^{a}**	**6.33 ±0.173^{a}**	**6.23 ± 0.184^{a}**	**6.00 ± 0.190^{b}**	**6.81 ± 0.176^{a}**	**6.85±0.158^{ab}**
A0	6.00±0.447^{bc}	5.73±0.345^{ab}	5.40±0.400^{b}	6.00±0.276^{ab}	6.20 ±0.355^{a}	6.20 ±0.380^{abc}	6.13±0.413^{ab}	6.13±0.401^{a}	6.40±0.445^{bc}
A30	5.53± 0.551^{c}	6.27±0.419^{ab}	5.87±0.446^{ab}	6.27±0.442^{ab}	6.80 ±0.355^{a}	7.13±0.350^{ab}	6.73±0.300^{ab}	6.93±0.345^{a}	7.20±0.296^{abc}
A60	6.20±0.460^{bc}	6.00±0.390^{ab}	5.87± 0.307$^{a b}$	6.00±0.324^{ab}	6.07 ± 0.452^{a}	6.27±0.384^{abc}	5.87±0.435^{b}	6.00±0.516^{a}	6.60±0.375^{abc}
A90	6.13±0.524^{bc}	6.27±0.358^{ab}	5.80±0.460^{ab}	5.87±0.350^{c}	6.60 ± 0.434^{a}	6.40±0.412^{abc}	5.73±0.530^{b}	6.07±0.539^{a}	6.13±0.542^{c}
A120	6.33±0.607^{bc}	5.93±0.581^{ab}	5.80±0.449^{ab}	6.07±0.473^{ab}	6.40 ± 0.476^{a}	5.73±0.605^{abc}	6.27±0.483^{ab}	6.27±0.463^{a}	6.60±0.375^{abc}
G.MA	**6.04 ± 0.229^{b}**	**6.04 ± 0.165^{a}**	**5.75 ± 0.182^{a}**	**6.04 ± 0.182^{b}**	**6.41 ± 0.184^{a}**	**6.35 ± 0.197^{a}**	**6.15 ±0.195^{ab}**	**6.28 ± 0.203^{a}**	**6.59 ±0.1854^{b}**
N Rates (Overall tef varieties**)**									
0	6.96 ±0.2461^{a}	6.31±0.220^{a}	6.16 ±0.248^{a}	6.69 ± 0.33^{a}	6.67 ±0.208^{a}	6.89±0.224^{ab}	6.24±0.262^{ab}	6.69±0.244^{a}	7.02±0.256^{a}
30	6.31±0.268^{ab}	6.13±0.243^{a}	6.20±0.230^{a}	6.20±0.287^{a}	6.36±0.270^{a}	6.95±0.328^{a}	6.80±0.198^{a}	6.67±0.244^{a}	7.20±0.171^{a}
60	6.13±0.270^{ab}	6.16±0.236^{a}	5.96 ±0.215^{a}	6.42±0.176^{a}	6.04±0.270^{a}	5.91±0.235^{c}	6.04±0.240^{b}	6.47±0.239^{a}	6.69±0.217^{a}
90	5.98 ± 0.302^{b}	5.73± 0.268^{a}	5.93±0.249^{a}	6.16±0.201^{a}	6.27±0.237^{a}	6.20±0.271b^{c}	5.87±0.257^{b}	6.44±0.218^{a}	6.60±0.258^{a}
120	6.62 ± 0.304^{ab}	6.04± 0.260^{a}	5.80 ± 0.259^{a}	6.53 ± 0.241^{a}	6.44 ± 0.237^{a}	6.33±0.258^{ab}	6.33±0.231^{ab}	6.84±0.218^{a}	6.96±0.222^{a}
G.M	6.40±0.127	6.08±0.110	5.75±0.105	6.40± 0.103	6.36±0.109	6.42±0.112	6.26±0.108	6.62 ± 0.108	6.89 ± 0.099

Results were reported as **mean ± SEM**, **VWR** = varieties of tef with N rates (kg N ha^{-1}), **GMK, GMB, KMA** = grand means of Kora, Boset and Asgori tef varieties respectively, **FC** = folding capacity, **ES** = eye size, **ED** = eye distribution, **TBS** = top and bottom surface, **OACC** = over all acceptability of injera, **SEM** = standard error of mean and **0, 30, 60, 90 and 120** are N rates for the treatment number of 1 to 15. Means in the same column and within the same treatment category followed by different letter are significantly different as judged by LSD at $p < 0.05$**. Note: G.M of Kora, Boset and Asgori varieties are considered as means of varieties (over all N rates). Values are means of triplicate experiments.**

4.7.8. Overall acceptability of *injera* quality

Overall acceptability is the results of the combinations of sensory evaluations by panelists of a product. The overall acceptability of the baked *injera* were significantly (P<0.05) affected by varieties and interactions, but not by N rates. However the analysis of variance and LSD values for the interactions of varieties with N rates indicated that overall acceptability of *injera* did not have much significance difference. However, the maximum and minimum values of acceptability of baked *injera* were recorded at K0 (7.80) and A90 (6.13), respectively. From the response of panelists almost all baked *injera* except K0, K30, K120, B120 and A30 (like-moderately) were rated as like-slightly (Table 13).

Grand means of varieties showed that, *injera* from Kora had maximum (7.24) value and rated as like-moderately, and had the same overall acceptance with Boset (6.85) like slightly. However, LSD values indicated that, *injera* from Kora (7.24) and Asgori (6.59) had significant differences. This minor difference in rated values on over all acceptance of 15 *injera* may become from the societies perception and comprehension of their appreciations to ward red tef *injera* (Asgori) as compared with white tef *injera* (Kora and Boset) preference. Habteab [143], who reported that, overall acceptability of injera prepared from tef were accepted 100% by the panelists and this is not agreed with our report that applications of N fertilizer causes significantly negative impacts on the overall acceptability of baked *injera.*

Regardless of varieties, the means of N rates did not significant difference on overall acceptability of injera. Considering all sensory attributes into account, there was a statistically difference among the injera prepared from the three varieties as influenced with N rates and all treatments scored a mean rating above 6 (like-slightly) (Table 13) and this is an indicative of the goodness of *injera.*

4.8. Total number of holes, filtered eyes and color (CIE L *a*b*) of *injera*

The color or physical appearance and number of holes of baked *injera* from three tef varieties as influenced with different rates of N fertilizer were presented in (Table 14).

4.8.1. Number of holes of *injera*

Number of holes of injera is the total number of holes or eyes that were present on surface of injera which was baked using griddle “mitad’’ having 50 cm diameter. The number of holes of *injera* prepared from three tef varieties influenced with different N fertilizer rates were highly significantly ($P<0.01$) affected by N rates and varieties as well as the interaction (Table 14). From the interactions of Kora tef variety and N rates, the maximum number of holes of injera were recorded from K30 (18350.00), K90 (18300.00) and K120 (18321.50) respectively. While, the minimum number of holes was obtained from K0 (14934.00) followed by K60 (16031.00). This analysis of result indicted that the number of holes of injera was not increased or decreased uniformly as the N rates of fertilizer was increased. Obtaining higher number of holes on the surface of injera may be due to the higher amount of carbon dioxide or gas bubbles in the fermented batter, the higher the number of holes or eyes produced on the surface of injera. Thus, number of holes is not in line with responses of the panelists (Table 14) on the eye size and distributions that the maximum eye size and distribution were obtained from K0 and K30 respectively which are not in agreement with number of holes results from injera eye software (Table 14). Therefore, as compared both results from panelists and the injera eye software, there was a significant difference among the parameters of the eye size and eye distribution (from panelists) and number of holes from the injera eye software technology. Being subjective sensory evaluation can vary from observer to observer, using instrument is better.

On the other hand, the number of holes of *injera* for Boset tef variety was ranged between 11172.00 (B90) and 27679.00 (B60) respectively. From the analysis result, both the control plot and plot with maximum N rate (120 kg N ha^{-1}) have the same effects on the number of holes of injera, indicated that as N rates becomes maximum, the number of holes of injera was not negatively affected and this also almost the same effects with the applications of 30 kg N ha^{-1}. The range of number of holes for Asgori tef variety was found from 12907.00 (A30) to 20545.50 (A0) and 20519.00 (A60) respectively. This indicates that the lower number of holes was recorded at 30 kg N ha^{-1}.

Grand means of Kora (G.MK), Boset (G.MB) and Asgori (G.MA) of the three tef varieties respectively indicated that the number of holes of injera was significant affected. The maximum (19609.20) number of holes was recorded from grand mean of Boset (G.MB) followed by grand mean of Kora (G.MK) (17187.00) and Asgori (G.MA) (17764.50) varieties respectively. Regardless of varieties, the average means N rate implies that, applications of 60 kg N ha^{-1} produced the maximum (21409.83) number of holes.

4.8.2. Filtered eyes of *injera*

The filtered eyes of *injera* were highly significant ($P < 0.01$) affected by N rates and varieties as well as the interactions (Table 14). For Kora tef variety, all N rates have almost the same filtered eyes on the surface of injera, except the minimum was obtained from K0 (7227.50) and the maximum at K30 (12476.50). This implies that the lower number of holes from the control plot (without N fertilizer) had the lower filtered eyes on the surface of injera i.e. the higher the number of holes of injera, the higher filtered eyes. Boset variety had the maximum (15927.50) filtered eyes of injera at B60, while the minimum (6348.50) was recorded from B90 followed by B0 (8028.00). On the other hand the ranges of filtered eyes of injera for Asgori tef variety was found between 7166.50 (A30) to 13807.00 (A60) respectively.

Regardless of the N rates, grand means of varieties were significant on the filtered eyes of injera. Thus, Asgori had better filtered eyes (11295.80) on the surface of injera followed by both Kora (10715.60) and Boset (10369.00, respectively. This may showed that carbon dioxide is produced during fermentation process and plays fundamental role in the formation of cellular structure leavened bread of Asgori [144]. The average means of N rates indicated that, maximum (13217.83) filtered eyes on the surface of injera was obtained at 60 kg N ha^{-1}, while the minimum (8741.17) at 0 kg N ha^{-1}. Based on this, N fertilizer rate had positive significant effects on the productions of eyes on the surface of injera and the optimum N rate for this could be 60 g N ha^{-1}, but it is not clear that the relation of N rates affected the formations of carbon dioxide or gas bubbles, it may the factor for eye formations and it needs further investigations.

4.8.3 Colors of *injera*

4.8.3.1. Lightness (L) color of *injera*

CIE-l*a*b measures the lightness, redness, yellowness of injera in the respective order of L, a, and b. The lightness (L-value) determines the better quality of injera production. The more the lightness (L* value), the lower the redness (a) and yellowness (b) value that have the better quality of i*njera.* The analysis of variance showed that the lightness of injera was highly significant ($P<0.01$) affected by N rates and varieties as well as interaction (Table 14). All L*values reported in this result were in the same range reported by Yam [109]. From the interactions of the three varieties with N rates, the L* values of injera did not show increased or decreased trends. Interactions of Kora with N rates had the same L* values of injera, but as LSD value indicated that a better L*value was obtained at K60 (56.82) and K90 (57.02) respectively.

However, Boset variety with N rate had the same effects on L*values of injera, but slightly increased with N rate and B90 (56.62) was the maximum. On the other hand the control plot and the maximum N rate (120 kg N ha-1) had the same effects on L*value, indicated that as N fertilizer becomes maximum its availability going to be decreased and cannot give responses for the plant. The minimum L*value of Asgori variety was recorded at the control plot (A0) 47.59, while the rest interactions had the same effects. Average means of varieties indicated that Kora variety had maximum (55.74) L*value followed by Boset (5471) and the least values recorded from Asgori varieties. Grand means of N rates showed that, applications of 30 kg N ha-1 could produce better L*value. Interaction of Kora and Boset with N rate had the same effects on red color of injera except Kora had minimum red color at control plot (K0), while maximum red color were obtained from Asgori.

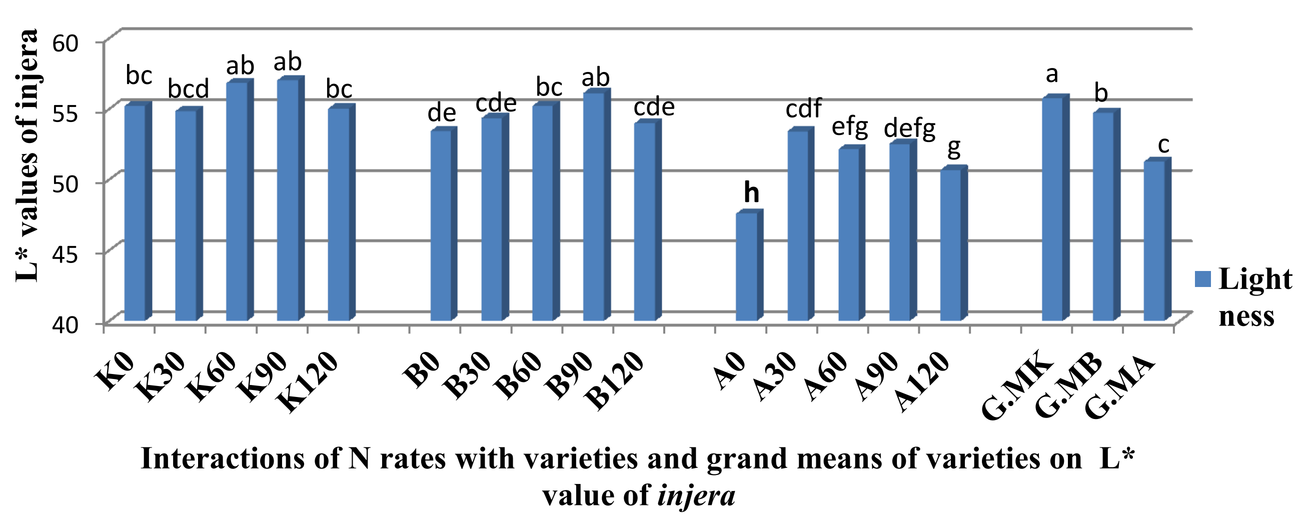

Figure 11: The interaction effects of varieties and N fertilizer rates and grand means of varieties on lightness color quality of injera using injera eye software, K= Kora, B =Boset and A =Asgori tef varieties, 0 to120 kg N 100 g^{-1} indicate five N rates, while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties.

4.8.3.2. Redness color of *injera*

The analysis of variance showed that redness color of *injera* were highly significant (P<0.01) affected by varieties and significantly (P<0.05) affected by N rates and the interaction with varieties (Table 14). From the average means of the interaction of tef with N rates, *injera* baked from Asgori tef variety had the maximum value in redness color than both Kora and Boset varieties. In accordance with this, redness color of *injera* from Asgori may be exists by genetic differences that the grain color of Asgori is red.

For both Kora and Boset tef varieties, applications of N fertilizer rates have the same effects on the redness of *injera* except the maximum (1.90) value was recorded at K0, therefore, this magnifies that the redness color of injera much depends on the grain color. Thus, the maximum redness value of *injera* was observed from Asgori tef variety at A0 (11.15) and A90 (11.22) respectively. Based on this result, the higher the values of redness color, the lower the acceptance of injera. This may the reason that *injera* prepared from red tef grain mostly gets lower chance to accept by the consumers.

Grand means (overall N rates) of Kora (G.MK), Boset (G.MB) and Asgori (G.MA) tef varieties indicated that the maximum (11.01) redness of *injera* was observed at Asgori followed by Kora (1.146) and with the least (0.949) was a recorded form Boset variety. In addition to this, regardless of tef varieties, the control plot had a better red color; rather the remains had the same effects on the redness of *injera*. This implies that the redness color of injera slightly decreases as the N fertilizer increases as compared with the control one. The lower values of redness color from both Kora and Boset (Figure 12) indicated that, injera prepared from Kora and Boset had a better acceptance as compare injera from Asgori.

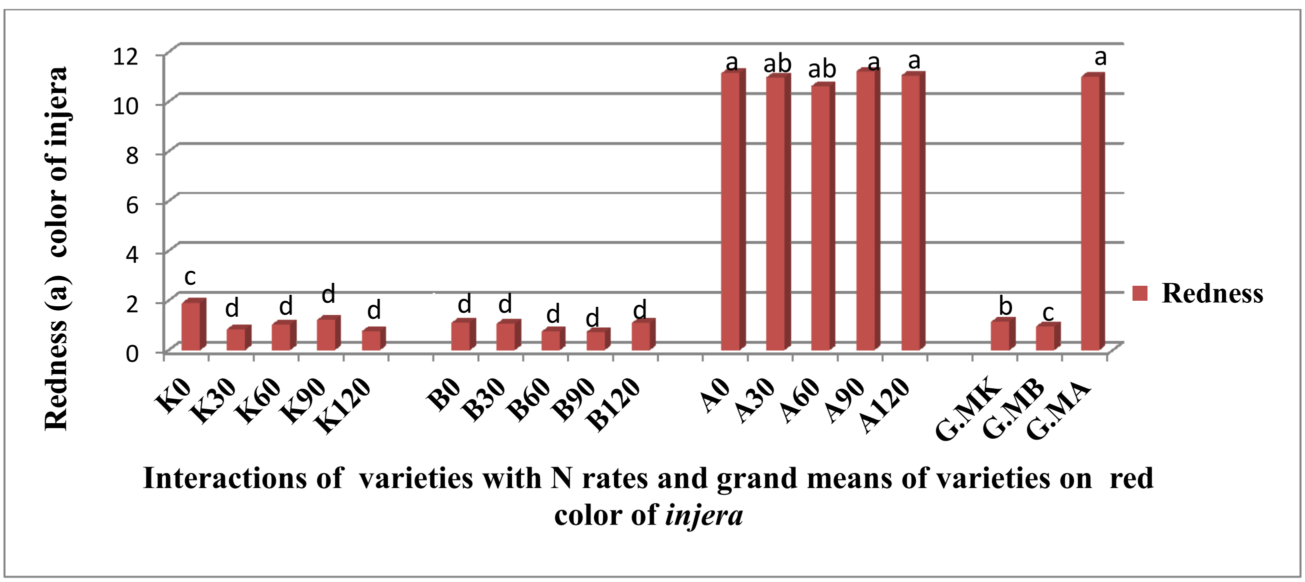

Figure 12: The interaction of varieties with N fertilizer rates, and the grand means of varieties on redness color of injera using *injera* eye software, K= Kora, B =Boset and A =Asgori tef varieties,

0,30,60,90 and 120 indicate five N rates (kg N ha^{-1}), while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori varieties respectively

Table 14: Holes/eyes and color values (CIE-l*ab) of injera of three tef varieties as influenced by N rates using *injera* eye software

Treatment	Parameters				
	Holes or eyes of injera		Color of injera		
VWR	Number of holes	Filtered eyes	Lightness	Redness	Yellowness
K0	14934.00±264.000^{ef}	7227.50±234.500^{fg}	55.20±0.173^{bc}	1.90±0.036^{c}	5.14±0.621^{e}
K30	18350.00±1119.000^{bcd}	12476.50±430.500^{c}	54.64±0.404^{bcd}	0.84±0.091^{d}	3.64±0.270^{f}
K60	16031.50±586.500^{de}	9919.00±215.000^{e}	56.82±0.197^{ab}	1.03±0.086^{d}	3.67±0.872^{f}
K90	18300.00±305.000^{bcd}	12131.50±84.500^{c}	57.02±0.013^{ab}	1.21±0.091^{d}	3.72±0.268^{f}
K120	18321.50±982.500^{bcd}	11823.50±416.500^{cd}	55.03±1.213bc	0.76±0.188^{d}	4.51±0.049^{ef}
G.MK	17187.40±537.769^{b}	10715.60± 659.992^{b}	55.74 ± 0.488^{a}	1.146±0.140^{b}	4.94±0.729^{b}
B0	20028.50±533.500^{b}	8028.00±423.000^{f}	53.42±0.140^{de}	1.11±0.288^{d}	6.23±0.200^{d}
B30	18930.50±1126.500^{bc}	10885.00±57.000^{de}	54.33±0.725^{cde}	1.06±0.289^{d}	4.93±0.189^{e}
B60	27679.00±1026.000^{a}	15927.50±199.500^{a}	55.21±0.195^{bc}	0.75±0.001^{d}	3.90±0.003^{ef}
B90	11172.00±1622.000^{g}	6348.50±555.500^{g}	56.62±0.151^{ab}	0.73±0.186^{d}	0.85±0.067^{g}
B120	20236.00±166.000^{b}	10656.00±66.000^{de}	53.97±0.032^{cde}	1.09±0.108^{d}	6.16±0.342^{d}
G.MB	19609.20 ± 1780.150^{a}	10369.00±1089.599^{b}	54.71 ±0.784^{b}	0.949 ±0.089^{c}	4.41±0.662^{c}
A0	20545.50±266.500^{b}	10968.00±785.000^{de}	47.59±2.073^{h}	11.15±0.147^{a}	7.37±0.648^{c}
A30	12907.00±495.000^{fg}	7166.50±203.500^{fg}	53.41±0.183^{cdf}	10.98±0.085^{ab}	9.95±0.266^{ab}
A60	20519.00±57.000^{b}	13807.00±252.000^{b}	52.14±0.184^{efg}	10.63±0.085^{b}	9.84±0.266^{ab}
A90	16934.00±87.000^{cde}	12767.00±76.000^{c}	52.51±0.000^{defg}	11.22±0.000^{a}	10.99±0.000^{a}
A120	17917.00±802.000^{bcd}	11770.50±373.500^{cd}	50.66±0.197^{g}	11.05±0.012^{ab}	10.36±0.010^{a}
G.MA	17764.50± 979.849^{b}	11295.80 ± 770.582^{a}	51.26 ±0.748^{c}	11.01 ±0.074^{a}	9.704±0.426^{a}
N Rates (Overall means of tef varieties)					
0	18502.67±1144.903^{b}	8741.17±757.572^{d}	51.40±1.489^{d}	4.72±2.041^{a}	7.58±0.587^{a}
0	16729.17±1287.067^{bc}	10176.00±1002.732^{c}	54.13±0.320^{bc}	4.29±2.116^{b}	6.17±1.223^{b}
60	21409.83±2166.755^{a}	13217.83±1117.176^{a}	54.72±0.874^{b}	4.14±2.056^{b}	5.81±1.299^{ab}
90	15468.67±1445.832^{c}	10415.67±1299.646^{c}	55.45±1.250^{ab}	4.39±2.163^{b}	5.19±1.909^{ab}
120	18824.83±560.057^{b}	11416.67±281.266^{b}	53.22±0.891^{c}	4.30±2.137^{b}	7.01±1.105^{a}

Results were reported as **mean ± SEM**, **VWR** = varieties (tef) with N rates (kg N ha^{-1}), **G. MK, G.MB, K.MA** = grand means of Kora, Boset and Asgori respectively, **SEM** = standard error of mean, K = Kora, **B**= Boset and **A =** Asgori tef varieties and **0, 30, 60, 90 and 120** are N rates for the treatment number of **1 to 5 for each variety**. Means in the same column and within the same treatment category followed by different letters are significantly different as judged by LSD at P<0.05. **NOTE: G.M of Kora, Boset and Asgori are considered also as grand means of varieties (overall N rates). Values are means of replicate experiments.**

4.8.3.3. Yellowness color of *injera*

The yellowness color of *injera* was highly significantly (P<0.01) affected by varieties and N rates including the interaction effects (Table 14). The ranges of yellowness of *injera* was found between 0.85 (B90) to 11.99 (A90) respectively. For Kora tef variety the maximum (5.14) yellowness of *injera* was observed at control plot, but for Boset it was recorded at B0 (6.23) and

B120 (6.16). This may imply as the applications of N rate becomes maximum, its availability could be reduced and this may also due to the fixation, leaching process and the control plot and maximum N rate had the same yellowness color of *injera.* While Asgori tef variety had the maximum (11.99 and 10.36) yellowness of injera recorded at A90 and A120 respectively. This yellowness color of injera indicated that *injera* prepared from Asgori tef variety had the least acceptance as compared with Kora and Boset varieties. This idea fits with the consumers preference they give superiority for *injera* of white color from white tef varieties.

Regardless of N rates, the rating means of tef varieties indicated that Asgori tef variety had the maximum (9.74) yellowness color of *injera* followed by Boset (4.41) and Kora (4.41) tef varieties (Figure 13). On the other hand the rating means (overall tef varieties) of N rates indicates that 0 (control plot) had slightly maximum redness color and 0 and 120 kg ha^{-1} had better yellowness color of *injera* (Figure 14).

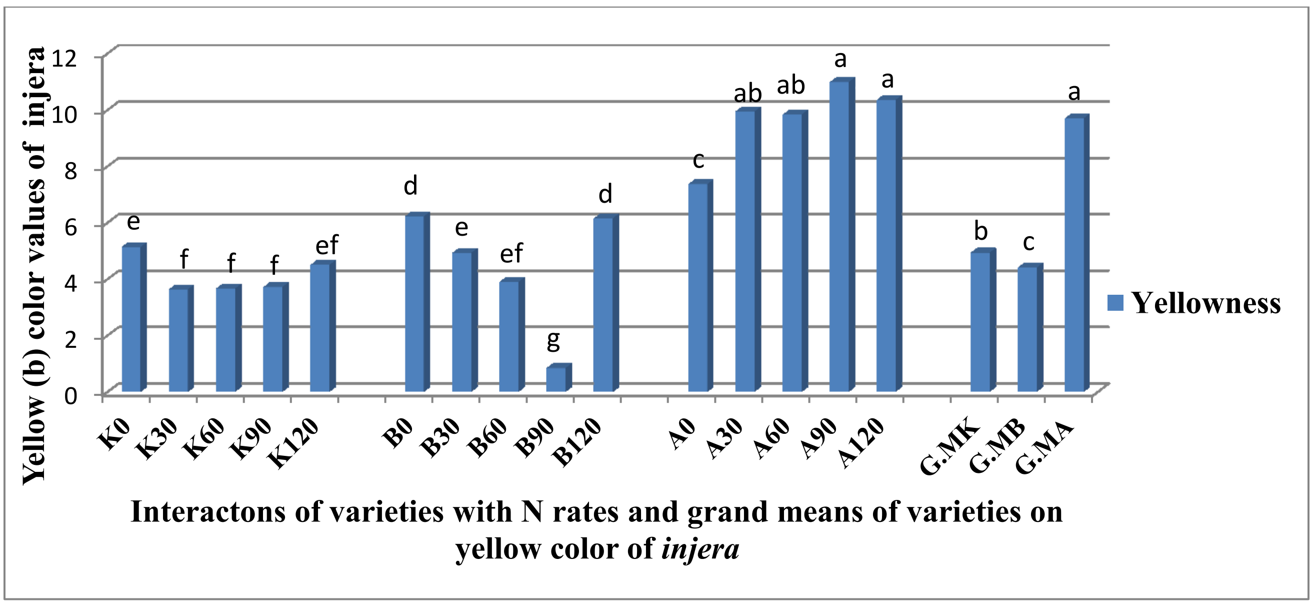

Figure 13: The interaction of varieties with N rates, and the grand means of varieties on yellowness color of *injera* using injera eye software, K= Kora, B =Boset and A =Asgori tef varieties, 0,30,60,90 and 120 indicate five N rates (kg N ha^{-1}), while G.MK, G.MB and G.MA = grand means of Kora, Boset and Asgori tef varieties respectively.

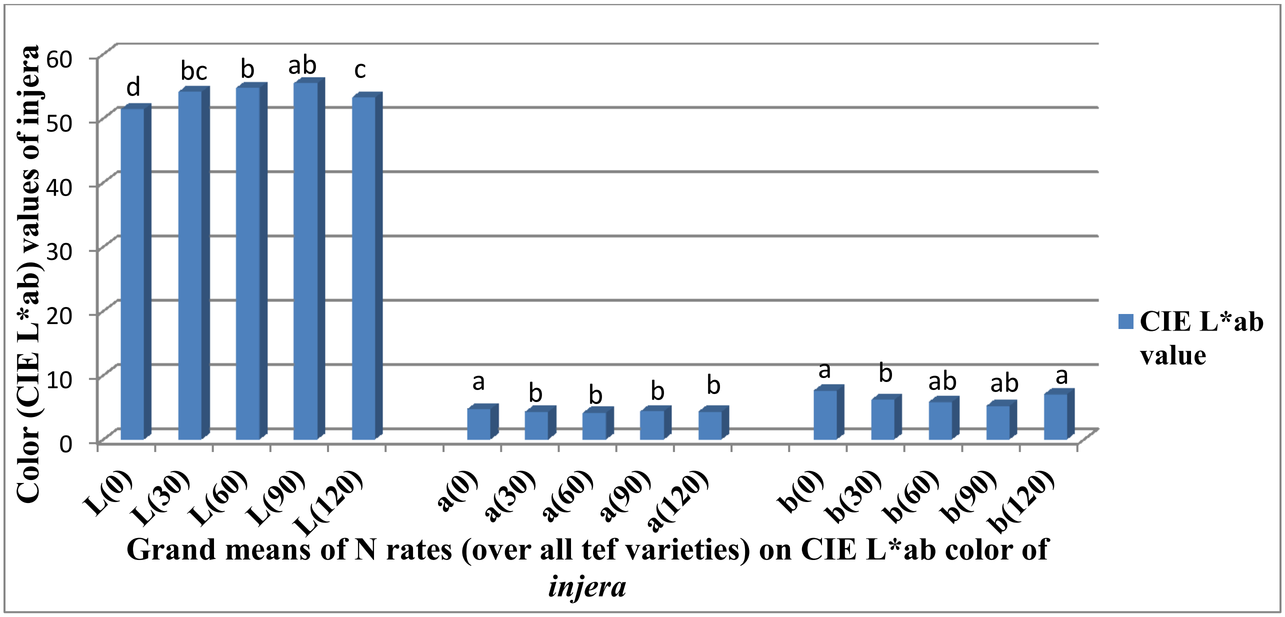

Figure 14: Effects of grand means of N fertilizer rates (overall tef varieties) on color values (CIE L*a*b) of injera from the three tef varieties (Kora, Boset and Asgori). L= lightness, a = redness and b = yellowness. 0,30,60,90 and 120 are five N rates in kg N ha^{-1}.

5.0 Conclusion and recommendations

5.1. Conclusion

The current study indicated that tef varieties and N fertilizer interaction affected phenological, yield and yield components. Grain yield was increased with N fertilizer but it was declined at 120 kg N ha^{-1}. Grain nutrition did not affected by varieties and N rates, but protein increased with N rates and carbohydrate was decreased. Phytic acid was affected by the interaction of two factors, but tannin content was only affected by varieties and this may due probably of genetic differences of varieties. The interactions of varieties with N rate did not show increasing or decreasing trends on mineral contents. From grand means of varieties, Boset and Asgori had higher Fe content, but Kora and Boset had maximum Ca content in mg 100 g^{-1}. However, injera sensory quality using panelists did not show much significantly $P<0.05$ difference at all interaction effects. Interactions of Kora at the control plot (K0) had better color, flavor, texture and taste values of *injera,* but slightly decreased with N rates. Boset and Asgori varieties did not show significant differences, but minima values of flavor and taste were obtained at 90 kg N ha^{-1}, but this may be due to variations of personal interests. Regardless of N rates, the mean varieties of color, flavor, texture and taste values did no significantly differences, except *injera* from Asgori had significant at $p<0.05$ on color and taste values. Grand means of N rates did not significant differences on flavor, texture and taste including color quality of injera.

Results from injera eye software, interactions of varieties with N rate did not show increasing or decreasing trends on colors of *injera.* The yellowness color of injera was slightly increased at Asgori variety. The color differences were exists due to varieties differences. The average means of varieties indicated that, maximum L*value was obtained from Kora variety followed by Boset, but the least L*value with maximum redness and yellowness color of *injera* were recorded from Asgori variety which, thus, had lower quality of *injera.* Regardless of varieties, control or 0 kg N ha^{-1} produce lower L* value and red color, but maximum yellow color of *injera.* Thus, from this study sensory quality and colors of injera have a little significant effect by the interactions of N rates with varieties. The varieties differences had significant effects on the color values of injera. Based on this it could not be concluded that N rates alone had significant effects on sensory quality and color of *injera*, rather further study could be needed which areas given in the recommendations below.

5.2. Recommendation

- There should be a further investigation on the effect of fertilizer rates on nutritional compositions of *injera* made from tef varieties
- There should be further investigations on the interaction effects of different N rates and the productions of carbon dioxide gas which have fundamental role for batter fermentations and the production of eyes on the surface of *injera*
- Changes of sensory attributes of *injera* may also be affect by the interactions of soil-microbial with the recommended fertilizer and micro-organisms which serves for food fermentation process, and this needs further study
- Studies should be conducted on the interaction effects of N fertilizer rats at different soil types across different location for different cereal food products
- A method optimization and development of acceptance ranges for the color of injera from the most common cereal based foods
- In addition to N fertilizer, further study should be recommended on the effects of blended fertilizer on sensory attributes of *injera*

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Appendix

Appendix I: Sensory evaluation sheet

Sensory evaluation sheet of injera prepared from tef varieties influenced with N rates

Evaluations of sensory acceptability of injera after 24 hrs the injera was produced

In this sensory evaluation of injera, you are given samples of injera for your evaluation. You are kindly requested to taste the samples and indicate your response by putting the values given below (nine point hedonic scale having values) in front of each attributes and don't forget to rinse your mouth after taste.

9- Like extremely 6- Like slightly 3- Dis like moderately

8- Like very much 5- Neither like nor dislike 2- Dis like very much

7- Like moderately 4- Dislike slightly 1- Dis like extremely

Table 15: Sensory evaluation sheet of injera

Sample Code	Sensory attributes								
	Color	Flavor	Texture	Taste	Folding capacity	Appearance			Overall acceptability
						Eye size	Eye distribution	Top &bottom surface	
680									
404									
290									
500									
350									
1002									
881									
208									
123									
908									
770									
102									
628									
480									
588									

Additional comments

____

______________________________. Thank you very much for your cooperation!!!

Appendix II: ANOVA tables of phonological data

Table 16: Analysis of variance showing mean squares for phenological parameters as influenced by N rate fertilizer and varieties

		Mean squares					
Source	**Df**	**DTH**	**DTM**	**PH**	**PL**	**TTN**	**PTN**
Block	2	2.4889	3.267	18.901	0.9416	0.822	0.422
Va	2	100.82**	88.867**	2578.394**	250.1749 **	25.622**	20.422**
Ra	4	8.4111**	29.800 *	355.256N**	1.4342 *	1.022NS	0.478NS
Va X Ra	8	2.5444NS	4.367 NS	8.274NS	0.6124NS	0.706NS	1.144NS
Error	28	0.9413	8.529	8.699	0.3392	1.703	1.541
Total	44						
%CV		2.1	2.7	2.4	1.3	14.9	17.3

**= highly significant, * = significant, NS= non-significant, df = degree of freedom, DTH =days to heading, DTM = days to maturity, PH= plant height, PL = panicle length, TTN = total tiller number and PTN = productive tiller number, Va = varieties (tef), Ra = Rates (nitrogen), Va X Ra = interactions of varieties with nitrogen rates and CV = coefficients of variance.

Appendix III: ANOVA tables of Yield and yield components parameters

Table 17: Analysis of variance for yield and yield component parameters as influenced by different N rate fertilizers rates and varieties

		Mean squares					
Source	Df	LI	AGSBM	GY	SY	HI	TSW
Block	2	79.59	287408.	17495.	181906.	0.0000711	0.000107
Va	2	4.58NS	2089102.**	422246.**	1898454.**	0.0080406**	0.010820*
Ra	4	203.47**	14303591.**	285203.**	11858020.**	0.0093192**	0.000886NS
Va X Ra	8	48.16*	1123724.**	81091.**	906766.**	0.0013553**	0.000659NS
Error	28	19.23	109115.	17495.	105041	0.0001583	0.001109
Total	44						
%CV		7.3	4.5	3.9	5.8	5.2	10.8

**= highly significant, * = significant, NS= non-significant, df = degree of freedom, LI = lodging index, AGSBM= above ground dry shoot biomass, GY= grain yield, SY = straw yield, HI = harvest index and TSW= thousand seed weight, Va = varieties (tef), Ra = Rates (nitrogen), Va X Ra = interactions of varieties with nitrogen rates and CV = coefficients of variance.

Appendix IV: ANOVA tables of proximate compositions parameters

Table 18: Analysis of variance for grain nutrition as influenced by different N fertilizer rates and varieties

		Mean squares						
Source	Df	%MO	%Ash	%Pr	C.fat	C.fiber	%CHO	EN(kal)
Block	2	0.00393	0.04012	0.5434	0.01990	0.3117	1.0419	0.007
Va	2	0.00038^{NS}	0.03424^{NS}	0.3245NS	0.01176^{NS}	0.4742^{NS}	1.0419^{NS}	1.524^{NS}
Ra	4	0.15334*	0.00670^{NS}	3.9288**	0.03289^{NS}	0.4254^{NS}	2.6440*	2.958^{NS}
Va X Ra	8	0.08279^{NS}	0.04128^{NS}	0.9364NS	0.04396^{NS}	0.4158^{NS}	0.9702^{NS}	1.304^{NS}
Error	28	0.04639	0.04192	0.5023	0.03078	0.3322	0.7749	1.614
Total	44							
%CV		2.2	2.4	1.3	8.0	4.9	1.2	0.4

**= highly significant, * = significant, ns= non-significant, Df = degree of freedom, Mo =moisture, Pr = protein, C.fat = crud fat, C.fiber = crude fiber, CHO = carbohydrate and EN (Kal) = energy in Kilocalorie, Va = varieties (tef), Ra = Rates (nitrogen), Va X Ra = interactions of varieties with nitrogen rates and CV = coefficients of variance.

Appendix V: ANOVA tables for anti-nutritional factors of tef grain

Table 179: Analysis of variance for ant-nutritional factors of tef varieties as influenced by different N fertilizers rates

		Mean squares	
Source	**Df**	**Phytic acid (mg /100g)**	**Tannin (CE mg/100 g)**
Block	2	138.31.	1.32
Va	2	51.10.^{NS}	243.86**
Ra	4	136.57.*	8.80 ^{NS}
Va X Ra	8	178.97.**	15.32^{NS}
Error	28	33.97	12.73
Total	44		
%CV		5.4	18.3

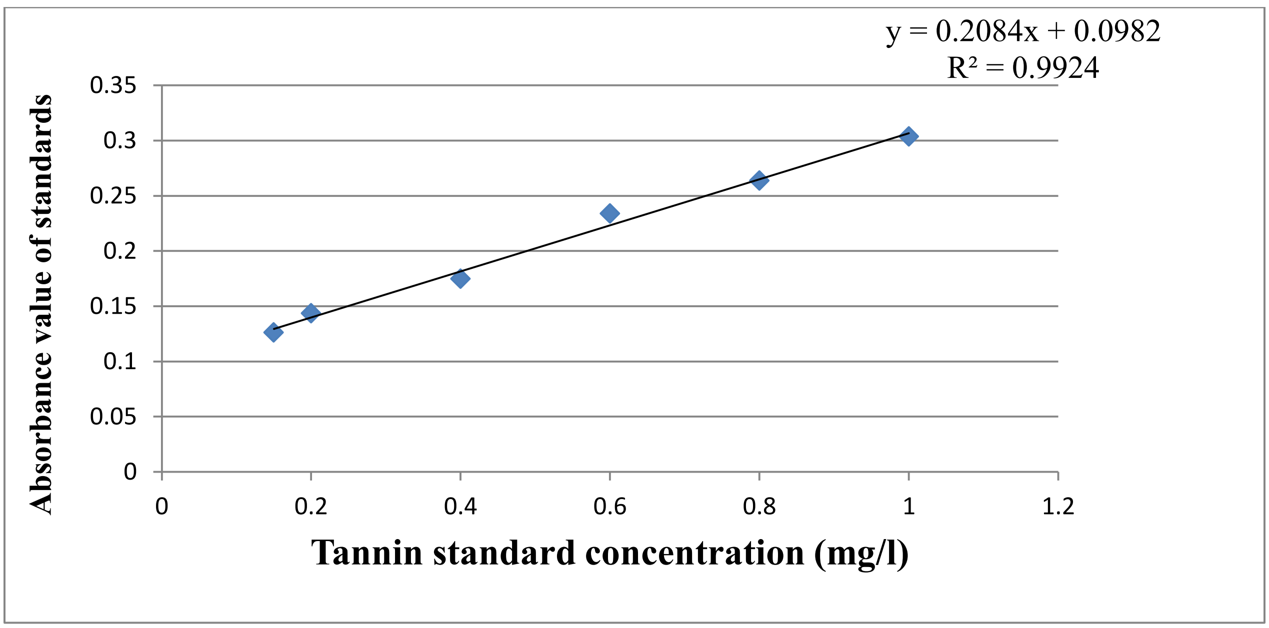
**= highly significant, * = significant, NS= non-significant, df = degree of freedom, Va = varieties (tef), Ra = Rates (nitrogen), Va X Ra = interactions of varieties with nitrogen rates and CV = coefficients of variance.

Appendix VI: ANOVA tables of mineral analysis parameters

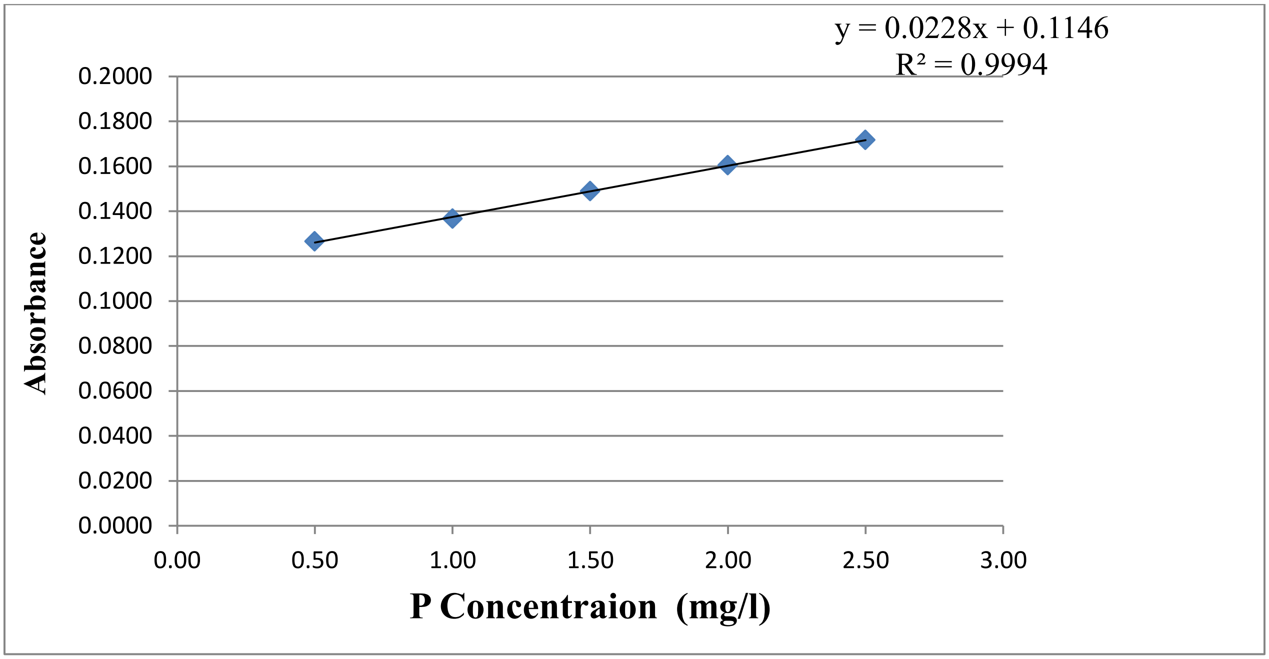
Table 20: Analysis of variance for mineral contents of tef grain as influenced by the varieties with different N fertilizer rates

		Mean squares		
Source	**Df**	P(ppm)	Fe (mg/100 g)	Ca (mg/100 g)
Block	2	0.4771	4.302	40.65
Va	2	0.1645^{NS}	35.433*	273.97*
Ra	4	0.9552**	67.685**	14.94^{NS}
Va * Ra	8	0.3772*	48.342**	104.15*
Error	28	0.1535	6.010	43.17
Total	44			
%CV		0.2	1.8	2.5

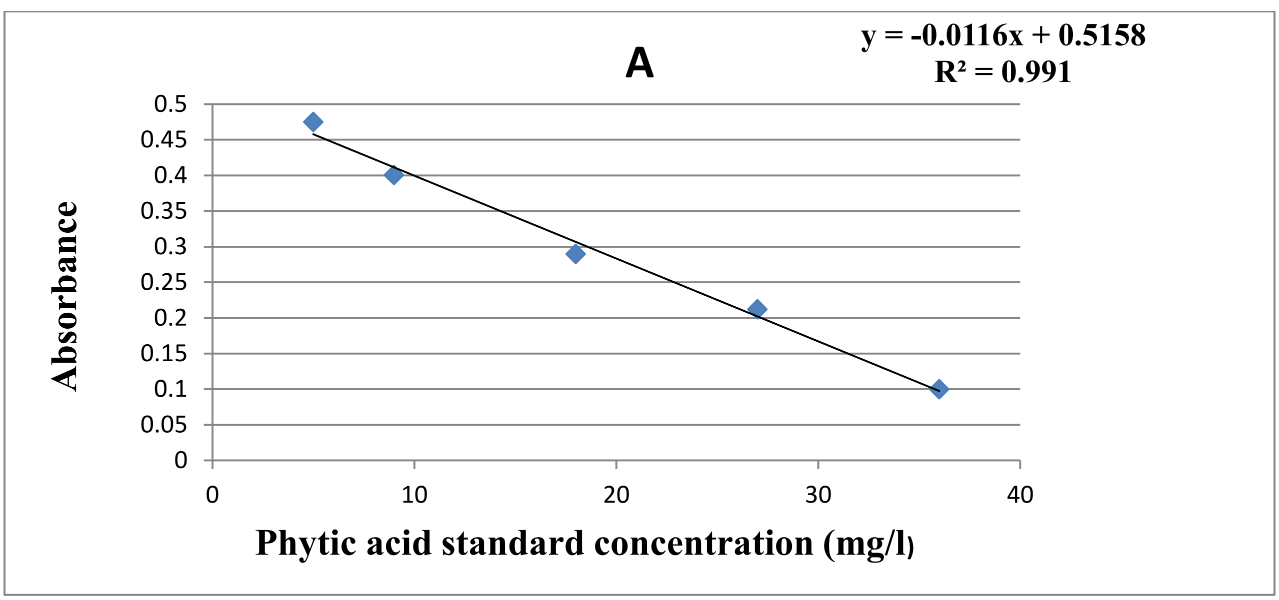
**= highly significant, * = significant, NS= non-significant, df = degree of freedom, Va = varieties (tef), Ra = Rates (nitrogen), Va * Ra = interactions of varieties with nitrogen rates and CV = coefficients of variance, P = phosphorus, Fe = Iron and Ca = calcium.



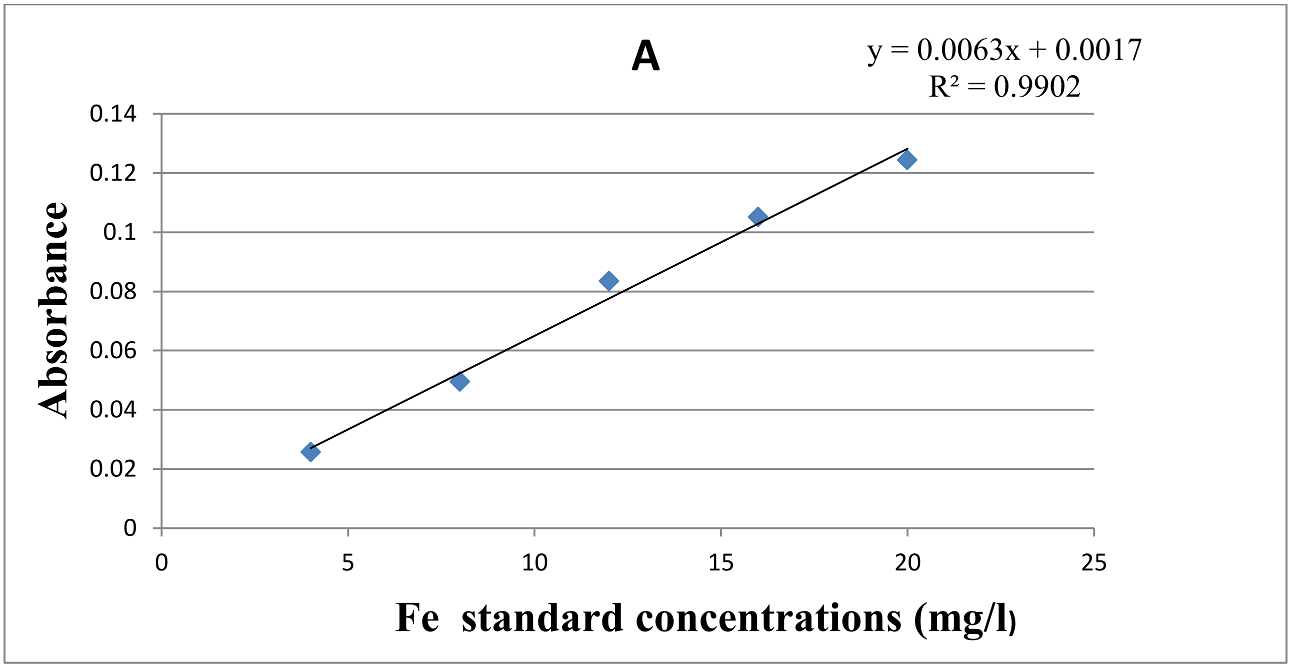
Appendix VII: Tannin standard calibration curves



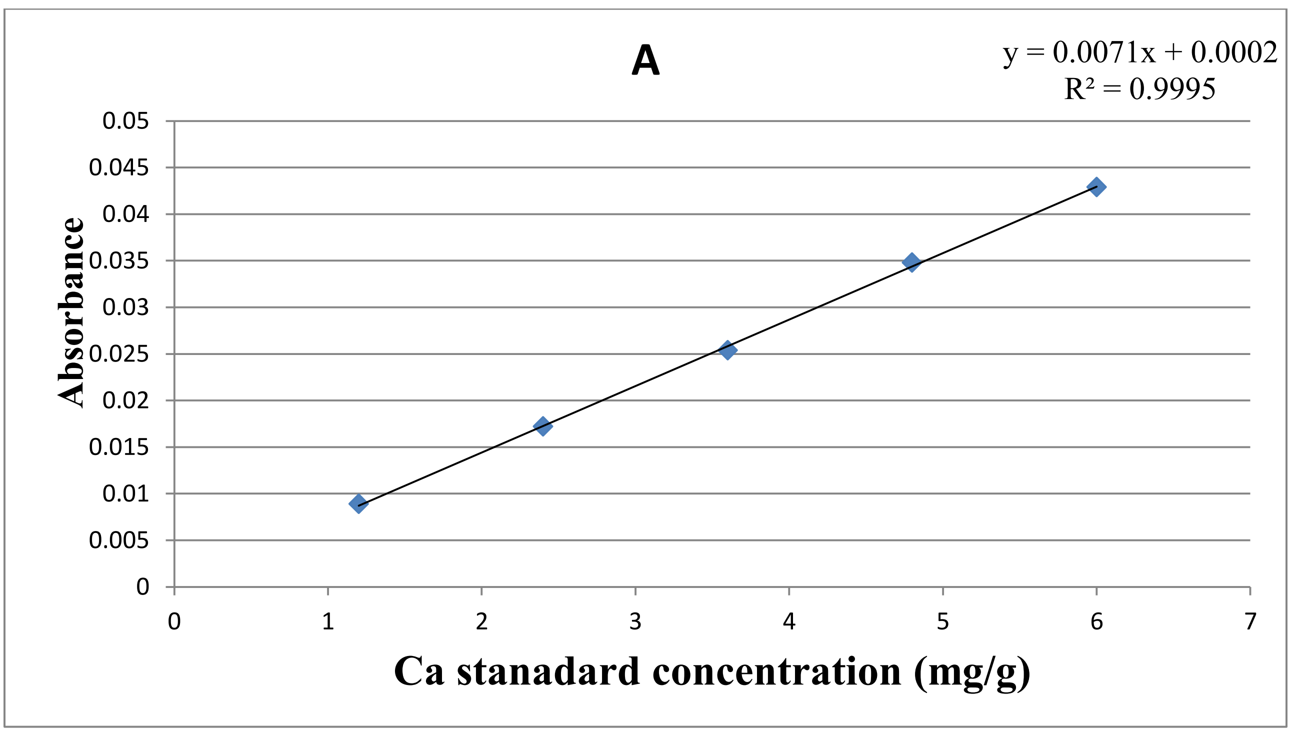
Appendix IX: Phosphorus standard calibration curve



Appendix XI: Phytic acid standard calibration curve



Appendix XII: Fe metal standard calibration curve



Appendix XIII: Calcium metal standard calibration curve

Appendix XIV: ANOVA tables of sensory evaluation parameters

Table 18 Analysis variance of sensory quality of parameters of injera of tef varieties as influenced with different N rates

		Mean squares								
Source	Df	color	Flavor	Texture	Taste	FC	ES	ED	TBS	OACC
Corrected Model	14	7.352	2.446	2.252	2.790	1.768	4.185	3.303	2.387	2.636
Va	2	7.453*	0.191^NS	6.084^NS	7.373*	0.191^NS	4.138^NS	8.058*	6.618^NS	8.093*
Ra	4	6.922*	2.062^NS	0.649^NS	2.267^NS	2.356^NS	7.582*	5.607*	1.256^NS	2.727^NS
Va * Ra	8	7.542*	3.202*	2.096*	1.907*	1.869^NS	2.499*	0.963*	1.896^NS	1.227*
Error	210	3.377	2.731	2.625	2.366	2.737	2.715	2.575	2.617	2.183
Total	225									
Corrected Total	224									

* = significant, NS= non-significant, Df = degree of freedom, FC =folding capacity, ES= eye size, ED = eye distribution, TBS = top and bottom surface of injera, OACC = overall acceptability of injera, Va = varieties (tef), Ra = Rates (nitrogen) and Va X Ra = interactions of varieties with nitrogen rates.

Appendix XV: ANOVA tables of number of holes, filtered eyes and color (CIE L*ab) of injera

Table 22: Analysis of variance on number of holes, filtered eyes, and CIE L*a*b (color) values of injera of tef varieties as influenced by different N rates

		Mean square				
Source	**Df**	**Number of holes of injera**	**Filtered eyes of injera**	**Lightness**	**Redness**	**Yellowness**
Corrected Model	14	29036896.748	14295997.390	16.651	47.424	19.253
Va	2	16001796.233**	2192869.733**	59.703**	330.789**	84.968**
Ra	4	30611618.450**	16502797.783**	20.825**	0.282*	5.442**
Va * Ra	8	31508311.025**	16218379.108**	3.801**	0.153*	9.730**
Error	15	1194530.700	249132.267	0.895	0.041	0.274
Total	30					
Corrected Total	29					

** =Highly significant,* = significant, DF = degree of freedom, VA = varieties (tef), Ra = Rates (nitrogen) and Va X Ra = interactions of tef varieties with N rates.