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Sensory Quality Attributes of Tef [*Eragrostis tef* (Zucc.) Trotter] Injera as Influenced by Genotype and Environment

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አህፅሮት

ጤፍ በአብዛኛው ለእንጀራ አገልግሎት ይውላል፡፡ በመካከለኛው ኢትዮጵያ የሚመረት ነጭ ጤፍ በሌሎች ቦታዎች ከሚመረተው በጥራቱ የተሸለ ነው ተብሎ ስለሚታመን በከፍተኛ ዋጋ ይሸጣል፡፡ ስለዚህ ይህ የምርምር ስራ ያተኮረው ነጭ ቀለም ያላቸውን ሶስት የተለያዩ የጤፍ ዝርያዎችን (ዕፀብ፣ ማኛ እና ቁንጮ) በአምስት የተለያዩ የመካከለኛውና ሰሜን ምዕራብ ኢትዮጵያ አካባቢዎች በመዝራት በእንጀራ ጥራት መስፈረቶች መሰረት በማወዳደር ያለቸውን የጥራት ልዩነታቸውን ለማወቅ እና ጥራታቸውን ከዝርያዎቹ የፍሬ እና ዱቄት ቀለም ጥራት እንዲሁም ከተመረቱበት አካባቢ የአፈርን የአየር ፀባይ ጋር ያለቸውን ዝምድና ለማጥናት ነው፡፡ በዚህ ጥናት በእንጀራ መጋገርና መብላት ጥልቅ ዕውቀት ያላቸውን 21 ሰዎችን በማስገምገም የተሰራ ስራ ነው፡፡ እነዘህ 21 የእንጀራ ጥራት ገምጋሚዎች በእንጀራ የላይ ገፅታ ቀለም የጀርባ ገፅታ ቀለም፣ የዓይን አደራደር፣ የመጠቅለል/ልስላሴ ባህሪ እና አጠቃላይ የእንጀራ ጥረታ ላይ ሲሳተፉ ከእነዚህ ውስጥ 11 ተመርጠው የጥፍጥና ጥናት ላይ ተሳትፈዋል፡፡ የልዩነት ትንተና ስሌቱ እንደሚያሳየው የእንጀራ ጥፍጥና ጤፍ በተመረተበት አካባቢ ብቻ ካሳየው ልዩነት ውጭ ሌሎች የእንጀራ ጥራት መስፈርቶች በሙሉ በዝርያ በተመረቱበት አካባቢ እና ዝርያዎች ከበቀሉበት አካባቢ ባላቸው መስተጋብር ከፍተኛ (P < 0.05 to P < 0.001) ልነቶች እንዳላቸው ያሳያል፡፡ የእንጀራ ጥራት ማለትም የላይ ገፅታ ቀለም፣ የጀርባ ገፅታ ቀለም፣ የዓይን አደራደር፣ የመጠቅለል፣ የጥፍጥና እና አጠቃላይ የእንጀራ ጥራት ልዩነት የመጣበትን የትንተና ልየታ ውጤት ስናይ ደግሞ፤ በበቀሉበት ቦታ ምክንያት የመጣው ልዩነት የ52.4በመቶ፣ 38.7በመቶ፣ 62.5በመቶ፣ 87.6በመቶ፣ 69.0በመቶ፣ እና 80.8በመቶ እንዲሁም ዝርያዎች ከተመረቱበት ቦታ ጋር ባለቸው መስተጋብር የ40.9በመቶ፣ 53.0በመቶ፣ 26.0በመቶ፣ 12.0በመቶ፣ 28.6በመቶ፣ እና 18.6በመቶ በተከታታይ ለልዩነታቸው ምክንያት ሲሆን በዝርያዎቹ ምክንያት የመጣው የጥራት ልዩነት ደግሞ (6.6በመቶ፣ 8.3በመቶ፣ 11.6በመቶ፣ 0.3በመቶ፣ 2.4በመቶ እና 0.6በመቶ ቅደም ተከተል) ዝቅተኛ ነበር ፡፡ የእንጀራ ጥራት ጤፍ ከሚበቅልበተ የአፈር ዓይነት (መረሬ/ዋልካ)፣ ኮምጣጣነት፣ የንጥረ-ነገር ቅይይር ብቃት፣ ካልሸዬም፣ ፖታሽየም፣ ማግኒዥየም መጠን ጋር እንዲሁም ከጤፍ ቀለም ፍካት/ብሩህነት/ (brightnes) *እና የተመረተበት ከባህር ጠለል በላይ ካለው ከፍታ መጨመር አወንታዊ/ቀጥተኛ የሆነ ግነኙነት አለው፡፡ የአፈር ውስጥ የናይተሮጅን እና የሳልፈር መጠን አሉታዊ/ተቃራኒ የሆነ ትርጉማዊ ግንኙነት እንዳላቸው ውጤቱ አሳይቷል፡፡ የዝናብ መጠን መጨመር የእንጀራ ጥራትን የመቀነስና ጤፍ የተመረተበት ቦታ ከባህር ወለል እየጨመረ ሲሄድ የእንጀራ ዓይንና ልስላሴ*

መጨመር ተስተውሏል። በአጠቃላይ የእንጀራ ጥራት ከዝርያ ይልቅ በሚመረቱበት አካባቢ የአፈርና የአየር ፀባይ እንዲሁም ዝርያዎች ጤፉ ከሚመረትበት ከባቢያዊ ሁኔታ ጋር ያላቸው መስተጋብር ይበልጥ ተፅዕኖ ይፈጥራሉ። ይህ ጥናት ሲደመደም መረሬ/ዋልካ አፈር የሆነና ከኮምጣጣነት ወደ አልካላይንነት የሚያደላ፣ በቤዝ ካታዮን/ብረተ-አስተኔ የበለፀገ ከሆነ የእንጀራ ጥራቱ እንደሚጨምር እና በቀይ አፈር ላይ በአንሰተኛ የአፈር በቤዝ ካታዮን/ብረተ-አስተኔ የተመረተ ጥራቱ እንደሚቀንስ አመላክቷል። ከአሁን በፊት ሰሜን ምዕራብ አማራ የተመረተ ጤፍ በእንጀራ ጥራቱ ከመካከለኛው የኢትዮጵያ ክፍል ከሚመረተው ያንሳል የሚለው አሰተሳሰብ በመረሬ/አፈር የተመረቱትን የጤፍ ዝርያዎችን አወዳድረን ስናይ ልዩነት አላቸው የሚል ድመዳሜ ላይ አያስደርስም። የበለጠ ግልፅና አስተማማኝ ውጤት ይኖር ዘንድ የአፈር ንጥረ-ነገር ማዳበሪያዎች ለጤፍ እንጀራ ጥራት ያፅላቸውን ተፅዕኖ የሚዳሰስበት ጥናት በተለያዩ ስነ-ምህዳሮችና አፈር ዓይነቶች መሞከር ተገቢ ነው።

Abstract

Tef is used to make injera (bubbly, pancake-like bread). It is believed that the white color tef grain produced in the central highlands of Ethiopia fetches the highest price as compared to the other areas due to its injera quality. Therefore, this experiment was conducted in the central and northwestern highlands of Ethiopia to evaluate Injera Sensory Quality Attributes (ISQA) on the three white-colored tef genotypes (Etsub, Magna, and Quncho) produced on five environments and to assess its relationship with edaphic factor, climatic factor, and grain and flour color of tef. The responses of the 21 knowledgeable consumer panelists' for top surface color, bottom surface color, malleability, eye appearance, and general rating; and 11 of them for taste subjected to Analysis of Variance (ANOVA). The ANOVA result showed that except taste significantly ($P < 0.05$) different only on the environment, other ISQA were significantly ($P < 0.05$ to $P < 0.001$) different on the genotype, environment, and genotype by environment interaction effects. The variance component result revealed that the environment (52.4%, 38.7%, 62.5%, 87.6%, 69.0%, and 80.8%) and genotype (40.9%, 53.0%, 26.0%, 12.0%, 28.6%, and 18.6%) contribution to the variation of BSC, TSC, eye appearance, Malleability, taste, and general rating were high, while the genotype was low (6.6%, 8.3%, 11.6%,-0.3%, 2.4% and 0.6%). There were also significant positive correlations of soil properties (black color/vertisols pH, CEC, ca, Mg, and K), grain and flour color V value, and altitude; while soil total nitrogen and sulfur as well as precipitation showed an indirect significant relationship with IQSA. These results concluded that tef grown on vertisols with slightly acidic to neutral soil pH and relatively high in basic cations have a better quality of injera as compared to tef grown in nitisols with low soil pH and basic cations. Based on our results, we argued that the quality of tef injera "as low quality" grown in Vertisols of the northwestern highlands couldn't be substantiated. A further study under controlled environment is recommended to evaluate the effects of different soil nutrients effect on ISQA under different soil types and agro-ecologies of Ethiopia.

Keywords: Tef, *Injera* sensory quality attributes, genotype, environment soil climatic factor

Introduction

Injera is the favorite, cultural and staple food for most Ethiopians. It is thin, bubbly leavened pancake-like flat circular bread with honeycomb *eyes/holes* on the top surface produced from the escape of carbon dioxide during fermentation and backing (Senayit, 2005). Yonas and Måns (2012) reported that tef *injera* is consumed in almost all of the country as a favorite food by over 66% of the Ethiopian population and it exceeds up to 89% in the main cities of the urban communities in Ethiopia.

Injera can be prepared from different cereals such as tef, maize, barley, sorghum, rice, and finger millet (Zewdu *et al.,* 2018; Tadessa, 2017; Senayit *et al.*, 2004). However, *injera* prepared from other cereals excluding tef has a low consumer preference due to lack of organoleptic properties (Tadessa, 2017). Tef is the most preferred grain for *injera* backing than other cereals due to its superior qualities such as i) *injera* with good water holding capacity, long shelf life, unique flavor (slightly sour but pleasant), pliability, smooth and glossy texture; ii) high returns in flour upon milling (99% compared to 60-80% from wheat) (Tedesse, 1969); iii) high returns of "*injera*" upon baking (Kebebew *et al*., 2011). Thus, the superior quality *injera* prepared from tef flour is highly demanded and equally an expensive grain in Ethiopia (Minten *et al.*, 2013; Kebebew *et al*., 2011; Senayit *et al*., 2005).

The commonly agreed *injera* quality attributes are based on surface color, eye appearance (number, distribution, and size), softness/malleability, and taste (Fitsum *et al.*, 2019; Zewdu *et al*., 2018; Senayit *et al.*, 2005). Its quality is purely the reflection of the grain and in some cases governed by preparation procedures such as skill, water quality and baking time (Anteneh *et al*., 2019b submitted).

Consumers' preference of tef for *injera* in Ethiopia is directly related to its grain color (whiteness) and production area (Kaleab, 2014; Tadessa, 2017). It is widely believed that the extremely white grain tef produced in the central highlands of Ethiopia is superior in color and injera quality sensory attributes to other areas like the northwestern highlands area of production, fetches the premium market price (Minten *et al.,* 2013). However, the variability of *injera* quality from the same tef genotypes grown in different locations has not been scientifically tested. To the best of the authors' knowledge, consumers' perceptions are not evaluated against measured biophysical data to investigate this general belief which has implications in market price determination for consumers, traders, and producers. Most of the works done on injera quality sensory were comparisons of tef *injera* with other cereals as a whole and in the proportion of tef to other cereals. This experiment was therefore initiated to evaluate three widely grown white tef genotypes across different locations with variable soil properties and agroecology on tef *injera* sensory quality attributes and its relationship with soil property and climatic factors. The relationship of tef grain and flour color with IQSA was also evaluated. *Injera,* a staple food of most Ethiopians is produced mainly from tef grain. I*njera* quality is believed to be influenced by tef grain quality (white-color) and its growing environments. The white-colored *injera* which comes from the white-colored tef grain is the most preferred type compared to the darker grain *injera* (Senayit *et al.*, 2004 and 2005). On the other hand, white tef produced from the central highland areas of Ethiopia has a better market value due to its color for *injera* (Minten *et al*., 2013, Mulat and De Marcantonio, 2013; Kaleab, 2014). The reason for the perceived tef as well as *injera* quality variability is still under question. Therefore, our results on climatic factor, edaphic factor, and the genotype effect, as well as the grain and flour color relationship on the injera quality sensory attributes, contribute to answering the abovementioned question.

Material and Methods

Generally, this experiment was conducted in two phases. In the first phase, tef genotypes were grown in different environments in the central and northwestern parts of the country which are believed to be the major tef growing areas. Following the selection of the experimental sites, three different tef varieties (*etsub*, *magna,* and *quncho*) were cultivated using recommended agronomic practices. In the second phase, grain color, *injera* backing, and sensory quality evaluations were executed.

Description of the study area

Tef was grown in the two main tef producing regions (Figure 1) of Ethiopia, in the northwestern region of Amhara and the central highland region of Oromia (CSA, 2018). These regions were selected based on the perceived variability of tef grain quality across the environments (Mulat and Di Marcantonio, 2013; Anteneh *et al.* 2019b). The experimental environments were Minjar and Debre Zeit Vertisols from the central highlands, Bichena Vertisols, Adet Nitisols, and Zenzelima (Bahir Dar) Nitisols from the northwestern highlands of Ethiopia (Figure 1). Coordinates, major crops grown, annual and seasonal rainfall, minimum and maximum temperatures of the experimental sites are presented in Table 1.

Table 1: Description of the experimental sites in Amhara and Oromia regional states of Ethiopia during 2017

Environment	Coordinates (WGS84/UTM Zone 37N)		Major crops grown	Altitude (masl)	Rainfall (mm)		Maximum temperature (oc)		Minimum temperature (oc)	
	X	Y			Annual	Seasonal*	Annual	Seasonal	Annual	Seasonal
Debre Zeit	500028	969098	Tef Wheat Chickpea	1887	779.3	545.3	29.5	24.6	8.0	13.5
Adet	334150	1248264	Tef, wheat, maize,	2207	1132.3†	782.8	26.8	24.7	11.4	12.2
Bichena	412184	1156589	Tef, Barely, Grass pea,	2543	1111.4	861.9	23.9	23.5	12.3	10.9
Minjar	546572	985844	Tef, Wheat,	2152	1118.0	772.5	31.1	29.1	13.5	13.5
Zenzelima	331616	1284770	Finger millet, Maize	1920	1354.8	1332.5	27.7	26.5	12.3	14.9

*seasonal/growing season for Bichena was from July to November, but for the rest of the sites from July to October 2017 (Source National and Northwestern Ethiopia meteorology agency of Ethiopia). † = a 10 year (2008 2017) average and one-year growing season only for 2017

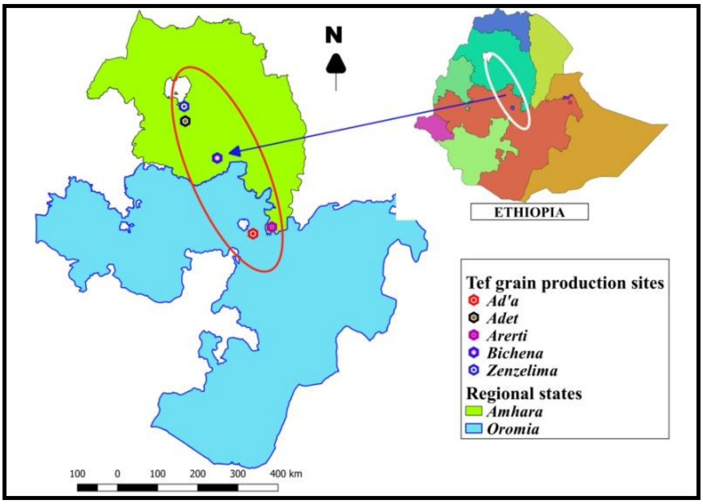

Figure 1: Map of the experimental locations in northwestern and central highlands of Ethiopia during 2017 main cropping season

Experimental design and management

Three white grain popular tef genotypes (*etsub*, *magna*, and *quncho*) were selected as test varieties. The varieties were sown in five different locations and two soil types purposively for *injera* making from July 17 to 26, 2017. The tef sowing was done in 20 cm row spacing and a seed rate was 10 kg ha^{-1} for Nitisols and 15 kg ha^{-1} for Vertisols (Fanuel *et al.*, 2012). Two mineral fertilizers, Di-ammonium Phosphate (DAP) as a source of phosphorus and urea as the source of nitrogen was applied at the recommended rate of 40/60 and 60/60 kg ha^{-1} (N/P_2O_5) for Nitisols and Vertisols, respectively (Alemayehu *et al.*, 2007). DAP was applied during sowing and urea in splits, half at sowing and half at tillering. At maturity, tef grain was hand-harvested, labeled and air-dried in polypropylene (PP) bags. Each of the harvested plots of tef was threshed manually inside the polyethylene bags on the cemented ground to avoid contamination. The threshed grain samples were cleaned and stored in a cool place inside cloth bags until the next experiment of *injera* preparation.

Soil and grain sample preparation and analysis

Soil samples from each experimental site were collected randomly from six sampling points prior to the application of treatments. The six samples from each location were mixed into a composite sample for uniformity. The collected soil samples from each location were air-dried, ground and sieved through a 2 mm mesh sieve for mineral analysis. The soil organic carbon (SOC) was determined by acid digestion method (Walkley and Black, 1934), pH by a potentiometer technique (Rayment, and Higginson, 1992), and total nitrogen (TN) using Kjeldahl method as modified by Iswaran and Marwaha (1980). Minerals such as

P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, and Na were analyzed using the Mehlich III extraction methods (Mehlich, 1984) using 0.2M CH3COOH, 0.25M NH4NO3, 0.015M NH4F, 0.013M HNO3, and 0.001M EDTA; adjusted to pH 2.5. The analysis was made using inductively coupled plasma atomic emission spectroscopy (Spectro CIROS ICP–AES, Spectro Analytical Instruments, Kleve, Germany).

The grain and flour samples from each genotype per environment images were captured using a Tecno-Canon mobile 24 mm pixel camera (Techno Mobile, Hong Kong). The grain and flour color H, (Hue), S (Saturation), and V (value or brightness) color space value directly detected by the Tecno-Canon mobile 24 mm pixel camera using a 'color grab' free software (https://loomatix.com). The use of HSV color space for tef grain color is due to the ease of understanding color with the human eyes rather than R G B or L A B color spaces values (Ibraheem *et al*., 2012; Deswal and Sharma, 2014). Each of the HSV color space used to measure its specific color values. The purity of a particular color as hue (H), degree of white color embedded in a specific color as saturation (S), and intensity of given colors as value or brightness (V) (Ibraheem *et al*., 2012; Deswal and Sharma, 2014). In addition, the authors described the V value, which can be used to determine luminance as color brightness (brightness/lightness or dimness). The value of H is expressed in degree, while the values of S and V are expressed in percentages.

Injera preparation

Grains weighing 1.5 kg from each of the three replications was mixed and pooled. The weighed grain samples from each site and genotype were ground separately with a rotary grinder (Pertten Instruments type 120 Hudding, Sweden; manufactured in Finland) at the Amhara Agricultural Research Institute Grain Quality Lab. Each of the tef flour samples was packed into polyethylene bags, coded, and sent to Bahir Dar Food Science and Post-harvest Handling Research lab for baking purposes. The *injera* was prepared using the method described by Ashagre and Dawit (2012) with minor modifications as following. From the15 tef flour samples, sourdough was prepared by sifting the flour and mixing 1 kg of each flour sample with 1.5 liters (L) tap water in fermenting plastic bucket in 1:1.5 ratios. In order to trigger the fermentation process, a starter culture called "*Ersho*" (10% of the main dough) was used to inoculate the sample dough. The flour samples were kneaded by hand in a bowl in the traditional way. The resulting dough was fermented for three days at ambient temperature (23^oC). After the primary fermentation, the surface water on the top of the dough was discarded and 500 ml of boiled water was added to the dough for secondary fermentation. After two hours of secondary fermentation, the main dough was thinned by adding water equal to the original weight of the flour and stirred until the mixture became homogeneous. Finally, about 600 ml of batter was poured onto the hot clay griddle (*Mitad*), traditional baking equipment, in a circular motion from the outside towards the center and covered with griddle lid. After 2-3 minutes, *injera* was removed and stored in a traditional basket container locally called '*Mosseb*'.

Sensory evaluation

The *injera* organoleptic traits or *injera* sensory quality attributes (ISQA) were established with a minor modification of the methods developed by Senayit *et al.* (2004) and Habteab *et al.* (2016). The five-point hedonic scale system was used where a ranking of "1" means extremely dislike and a ranking of "5" means extremely liked for all sensory attributes. Table 2 shows the ISQA evaluations. bottom surface color (BSC) and top surface color (TSC), described as the sensation during observation of the color and brightness of *injera*, ranged from a low of 1 (brown) to a high of 5 (very white). This is due to the consumers' preference and agreement of the panelists during discussions that white color is the most important attribute that influences consumers' preference (Zewdu, 2018). Eye appearance, based on visual appearance, relating to the number of eyes, eye size, and distribution of eyes on the top surface of *injera* ranged from 1 (few, large, and scattered eyes, respectively) to 5 (many, small, and evenly spread eyes, respectively). Softness or malleability which relates to the texture and malleability of *injera* ranged from 1 (rough and breakable during rolling or folding) to 5 (extremely soft and malleable during rolling or folding). Taste, which relates to the sensation during chewing, also ranged between 1 (poorly tasty) and 5 (much tasty). General rating applies to the visual appearance of the physical characteristics of *injera* before testing. The general rating was between 1 (poor) and 5 (excellent). Twenty-one knowledgeable *injera* consumer panelists were selected to perform the sensory evaluations. Of the 21 panelists who were participated in the sensorial quality evaluation, only 11 have participated in the taste sensorial quality evaluation. The panel comprised a 3:1 female to male ratio and their ages ranged from 19 to 60 years old. Three pieces of *injera* from each of the fifteen samples were randomly served inside the basket or "*Mosseb*" at the Amhara Agricultural Research Institute (ARARI) mini hall. Water was used for rinsing the mouth in between each taste. The evaluations from milling to the sensory evaluations were conducted in a blind manner with all the samples coded from 1-15 and only the principal researcher had prior knowledge of the sample identifications. A food science expert familiar with the pre-prepared evaluation format completed the sensory profile training along with the selected panelists. Finally, each panelist rated each *injera* sample using the prepared format as described in Table 2.

Table 2: Injera sensory quality attributes scales and descriptions

Attribute	1 Dislike very much	2 Dislike moderately	3 Neither like nor dislike	4 like moderately	5 Like very much
BSC	Brown	Light brown	Moderately white	White	Vey white
TSC	Brown	Light brown	Moderately white	White	Vey white
IEC	Few, large, scattered	Few, medium, scattered	Many, medium, moderately spread	Many, small, moderately spread	Many, small, evenly spread
S/M	Rough and breakable	Moderately rough and slightly cracked	Soft and malleable	Very soft and malleable	Extremely soft and malleable
Taste	Poorly tasty	Moderately tasty	Tasty	Sufficiently Tasty	Much tasty
GR	Poor	Fair	Good	Very good	Excellent

§ BSC = Bottom surface color, TSC = Top surface color, IEC = Injera eye characteristics, S/M = Softness or malleability, GR = General rating.

Statistical analysis

The genotype (G), environment (E), and genotype by environment interaction (G*E) effects for ISQA were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM). The variance components of G, E, and G by E interaction effects were also executed using Proc Varcomp. Multiple comparisons using Fisher's LSD test was also performed, where significant ($p < 0.05$) differences were obtained on the main and interaction effects. The *injera* quality sensory evaluation results with soil property, climatic factors, grain color, and flour color of tef were correlated using Pearson's correlation coefficient. The SAS 9.4 software (SAS, 2017) was employed for all statistical analyses.

Results and Discussions

The tef grain and flour HSV color values were highly significantly ($P < 0.001$) different on genotype (G), environment/location (E) and genotype by location (G x E) interaction effects, except grain S color space value significantly ($P < 0.01$) different on environment and H color space value not significantly ($P > 0.05$) different on genotype (Table 3). From *Injera* sensory quality attributes taste was not significantly ($P > 0.05$) different on genotype, while bottom surface color and malleability on genotype, and taste on genotype by location interaction effects at $P < 0.05$), and eye appearance on genotype at $P < 0.01$ significantly different. However, bottom surface color, top surface color, eye appearance, malleability, taste, and general rating were highly significantly ($P< 0.001$) different on genotype, location, and genotype by location interaction effects (Table 3).

Table 3: Mean squares from the analyses of grain and flour HSV color values and Injera sensory qualities attributes

Grain physico-chemical properties	Mean squares					CV (%)
	Location (L) (DF= 4)	L*Rep (DF = 8)	Genotype (G) (DF = 2)*	L x G Interaction (DF = 8)	Error (DF = 20)	
Grain H	24.98***	3.60ns	10.10ns	28.01***	3.51	4.517
Grain S	32.66**	5.58ns	499.79***	136.32***	6.14	7.42
Grain V	441.27***	1.09ns	100.66***	28.14***	1.73	1.61
Flour H	12.26***	1.71ns	14.47***	22.35***	0.91	2.1
Flour S	146.70***	2.03ns	117.76***	29.37***	1.31	6.54
Flour V	87.98***	0.98ns	49.40***	21.68***	1.46	1.36
	(DF= 4)	(DF=80, 40‡)	(DF = 2)*	(DF = 8)	(DF= 200)	
BSC	49.81***	1.17***	2.69*	10.89***	0.59	25.6
TSC	42.56***	0.88***	3.41***	13.73***	0.46	22.17
Eye appearance	12.38***	0.87ns	5.07***	2.09**	0.75	24.13
Malleability	35.31***	0.75**	1.88*	2.09***	0.49	20.81
Taste	6.42***	0.98*	1.15ns	1.43*	0.65	19.96
General Rating	50.56***	0.79**	3.58***	4.14***	0.49	23.63

*, **, ***, and ns indicate significance at P ≤ 0.05, P ≤ 0.0.1, P ≤ 0.001, and not significantly different (P >0.05), respectively

‡ = degree of freedom of rep * location for taste.

Soil property

The soil's physicochemical properties of the experimental sites were variable and presented in Table 3. According to Hazelton & Murphy (2007) in their soil chemical/nutrient ratings, pH of the experimental soils ranged from strongly acidic (5.50 and 5.3) for Adet and Zenzelima respectively to mildly alkaline (7.74) on Minjar soil. Cation exchanging capacity (CEC) of the soils was high (28 to 41 meq 100^{-1} g soil), while total nitrogen (TN) was very low (0.085 to 0.138%) for all sites. The soil P concentration of the experimental fields was low for Adet (7.6 mg kg^{-1}), Bichena (12.7 mg kg^{-1}), and Zenzelima (8.5 mg kg^{-1}), while high for Debre Zeit (44.8 mg kg^{-1}) and Minjar (54.2 mg kg^{-1}) as per the soil fertility rating of Horneck *et al.* (2011). The extractable K concentration of the experimental soils was medium, high and very high for Adet (205 ppm), Zenzelima/Bichena (255-324 ppm), and Debre Zeit /Minjar (728-887 ppm), respectively. Soil organic carbon (SOC) was low to moderate (Table 3). Despite some variations across sites, generally, Nitisols were low in soil pH, CEC, available P and some basic cations (K, Ca, Mg and Na) while Vertisols showed low TN and available S (Table 3).

Table 4: Soil properties of the experimental sites in northwestern and central highlands of Ethiopia sampled before sowing of tef during 2017

Location	Soil type	pH	CEC	SOC	TN	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Mo	Co	Na
			Meq $100g^{-1}$	---- %------		--- mg kg^{-1} ---											
Adet1	Nitisols†	5.3	34.30	1.12	0.102	7.6	205	2144	463	23.9	136	183	1.69	4.46	0.29	4.30	12.70
Bichena	Vertisolsǂ	6.2	41.16	0.82	0.097	12.7	324	6304	1330	10.6	166	79	1.38	3.99	0.30	2.67	26.90
Debre Zeit	Vertisols‡	7.3	39.90	0.71	0.085	44.8	728	4811	1219	12.7	182	225	4.67	7.12	0.32	4.00	79.60
Minjar	Vertisols‡	7.5	41.00	0.89	0.109	52.3	887	8130	806	13.3	64	283	2.05	3.78	0.30	4.68	39.90
Zenzelima	Nitisols	5.5	28.34	0.79	0.138	8.5	255	1299	328	22.5	78	161	1.14	2.47	0.31	2.87	13.00

† EIAR, 2006. ǂ Yihenew G/Silasie, 2002; ‡ Yfru Abera and Mesfin Kebede, 2013.

Grain and flour color

The genotype *Etsub* produced the highest grain H, grain S, and flour S color values without considerable difference on grain H value with *Magna* genotype. The highest grain V, flour H and flour V values were produced from *Magna and Quncho* varieties (Table 5). Tef grain produced from Adet and Zenzelima Nitisols, and Minjar Vertisols ranked highest grain H color value. The lowest grain H color produced at Bichena Vertisols location. Adet and Zenzelima Nitisols together with Bichena Vertisols areas produced tef scored the highest grain S value, while Debre Zeit and Minjar vertisols the lowest. The highest grain color V value produced at Bichena and Minjar Vertisols, while the lowest at Zenzelima Nitisols. Bichena Vertisols produced tef showed the highest rank in flour H and V color space values. Adet Nitisols produced tef was the highest in flour S value, while Bichena Vertisols was the lowest (Table 5).

Table 5: Means of grain and flour H, S, and V color space values of the white tef varieties produced in the central and northwestern Ethiopian highlands used for *Injera* baking

Treatments	Grain color			Flour color		
	H (O)	S (%)	V (%)	H (O)	S (%)	V (%)
Means of genotypes (over five locations)						
Etsub	42 .3^{a}	39.6^{a}	78.9^{b}	43.9^{b}	20.6^{a}	86.9^{b}
Magna	41.5^{ab}	32.0^{b}	83.6^{a}	45.7^{a}	15.1^{c}	90.3^{a}
Quncho	40.6^{b}	28.2^{c}	83.1^{a}	45.6^{a}	16.8^{b}	89.7^{a}
LSD >0.05	1.427	1.888	1.003	0.727	0.872	0.919
SEM(±)	0.486	1.101	1.064	0.382	0.7465	0.579
Means of locations (over three white grain color tef genotypes)						
Adet Nitisols	42.8^{a}	34.5^{a}	79.7^{c}	44.2^{c}	21.9^{a}	85.9^{c}
Bichena Vertisols	38.9^{c}	33.9^{a}	87.2^{a}	46.9^{a}	11.6^{d}	92.6^{a}
Debre Zeit Vertisols	40.7^{b}	31.1^{b}	84.5^{b}	45.6^{b}	17.1^{c}	90.0^{b}
Minjar Vertisols	42.8^{a}	31.4^{b}	87.4^{a}	44.1^{c}	16.4^{c}	90.8^{b}
Zenzelima Nitisols	42.1^{ab}	35.4^{a}	70.6^{d}	44.6^{c}	20.6^{b}	85.4^{c}
LSD >0.05	1.842	2.437	1.295	0.939	1.126	1.186
SEM(±)	0.486	1.101	1.064	0.382	0.746	0.579

† within the columns, means followed by small lowercase letter superscripts are not different (P < 0.001).

Partitioning the G x E interaction effect the tef grain H color value ranged from 36.7^{o} *Magna* genotype produced at Bichena location to 45.7^{o} Q*uncho* at Adet for and *Etsub* at Minjar locations. Similarly, the lower flour H color value ranged from 42^{o} was found for *magna* at Adet to 48.3^{o} for *magna* at Zenzelima. The highest grain S color values (43%) were found on *Etsub* genotype at Zenzelima location and the lowest (20%) on *Quncho* at the same location. Both the lowest (10%) and the highest (25%) tef flour S color values were detected from *Quncho* variety but at two different sites (Bichena Vertisols and Adet Nitisols, respectively) (data not shown). The grain V color value (brightness) ranged from 69% for *Quncho* genotype at Zenzelima to 90.33% on the same genotype at

Bichena location. The highest flour V color value (94.3%) was obtained from *magna* at Minjar while the lowest (80.7%) from *Etsub* at Adet (data not shown). Almost all of the flour V color values of tef were brighter than the grain colors. For example, the *Etsub* genotype grown in Bichena showed similar grain and flour color brightness whereas the flour V color value of *magna* and *Quncho* genotypes in the same environment was higher than the grain V color value. *Etsub* genotype grown in the Bichena environment showed similar grain V color value with *magna* and *Quncho*, whereas in the rest of the environments its grain V color value was darker than the flour color. This results confirms previous studies on the same genotype of hard white spring wheat produced in different environments showed variations in grain colorization (Lukow *et al.*, 2013). A study conducted in Canada also showed that beyond the genetic factor, the environment also contributed to the variability of grain color (brightness and yellowness) (Wu *et al*., 1999; Lukow *et al*., 2013). Research reports also showed that the same variety/genotype of tef and wheat grown in different soil types and agro-ecologies showed variability in grain mineral composition and grain color (Anteneh Abewa *et al.*, 2019; Wu *et al*., 1999).

Sensory Evaluation

The highest bottom surface color, top surface color, eye appearance, malleability, taste, and general rating of *Injera* sensory quality attributes were highest on tef grain produced at Minjar and Bichena followed by Debre Zeit locations. Tef grain produced at Zenzelima location was the lowest in all the tested *Injera* quality attributes (Table 5). From the tasted three genotypes, The highest scores of BSC, TSC, eye appearance and general ratings were recorded on the *Magna* genotype, while in *Injera* malleability *Magna* was not significantly different from *Etsub*. *Etsub* was not also different from Quncho on *Injera* malleability. Taste of injera was not significantly different on the three tef genotypes (Table 6)

Table 6: Mean *Injera* sensory quality attribute ratting values (1 - 5 scale) of the three tef varieties grown on five locations in the central and northwestern highlands of Ethiopia during 2017 cropping season

Genotype	BSC	TSC	Eye	Malleability	Taste	General Rating
Means of genotypes (over five locations)						
	---------- Scale ----------					
Etsub	2.89[b]†	2.94[b]	3.49[b]	3.34[ab]	4.15	2.88[b]
Magna	3.19[a]	3.28[a]	3.83[a]	3.50[a]	4.09	3.18[a]
Quncho	2.95[b]	2.99[b]	3.42[b]	3.23[b]	3.87	2.85[b]
LSD (p<0.05)	0.24	0.21	0.24	0.20	Ns	0.21
SEM(±)	0.073	0.069	0.061	0.059	0.078	0.066
Means of locations (over three white grain color tef genotypes)						
Adet	2.05[c]†	2.37[c]	3.32[b]	2.86[c]	3.91[c]	2.22c
Bichena	3.78[a]	3.89[a]	4.13[a]	4.05[a]	4.36[ab]	3.79[a]
Debre Zeit	3.21[b]	3.10[b]	3.30[b]	3.14[b]	4.06[bc]	2.90[b]
Minjar	3.90[a]	3.87[a]	3.98[a]	4.22[a]	4.48[a]	3.95[a]
Zenzelima	2.11[c]	2.13[c]	3.16[b]	2.51[d]	3.36[d]	1.97[c]
LSD (p<0.05)	0.271	0.239	0.303	0.245	0.394	0.246
SEM(±)	0.0723	0.069	0.061	0.059	0.078	0.066

† within the columns, means followed by small lowercase letter superscripts are not different (P < 0.5).

The G x E interaction effect of the mean highest ISQA of BSC score (4.2) was obtained from *Quncho* genotype at Minjar location, while the lowest BSC score (1.5) was on *Etsub* genotype at at Zenzelima and Adet locations. Tef produced on *Magna* genotype at Debre Zeit location scored the higher TSC score (4.2) of *Injera*, while the lowest (1.52) from *Etsub* genotype at Zenzelima location. Generally, the higher BSC and TSC color scores were recorded from all the tested genotypes on Debre Zeit, Bichena, and Minjar, except *Quncho* on Debre Zeit environment. The lower BSC and TSC were obtained from all the three genotypes on Adet and Zenzelima including *Quncho* genotype produced at Debre Zeit environment (data not shown). The variability of the 15 top surface *Injera color* picture is clearly seen in figure 2.

Figure 2: *Injera* pictures of the three tef genotype, which was grown in five different environments during 2017 cropping season

The highest *injera* eye characteristics score of 4.33 was obtained from *Magna* at Bichena, followed by *Etsub* genotype (4.14) on the same location and *magna* and *Quncho* at the Minjar site. The lowest scores of 2.81 and 2.90 were recorded from *Quncho* at Zenzelima and Adet locations respectively. From locations, Bichena, Minjar, and Debre Zeit produced tef better *Injera* eye quality, while Adet and Zenzelima Nitisols produced tef were poor in *Injera* eye quality. The range of variability of eye appearances was minimal as compared to BSC and TSC in the main and interaction effects. .

The highest *injera* malleability/rollability score (4.4) was obtained from both *Etsub* and *Magna* genotypes but from Minjar location followed by the same varieties at Bichena, whereas the lowest malleability score (2.1) was found on *Etsub* genotype at the Zenzelima location. Similar to other ISQA the *injera* taste was also variable on G x E interaction effect, however, the range of variability was low as compared to other ISQA. The *injera* tastes sensory quality evaluation results showed that the *magna* and *Etsub* genotypes produced on Bichena and *magna* on Minjar scored the highest value (4.45), whereas *Etsub* on Zenzelima scored the lowest (3.0).

Tef grain produced on *Magna* genotype both at Bichena and Minjar environments (4.10), followed by *Etsub* genotype at Minjar, and Bichena environments were highest (4.0, and 3.9) in *Injera* general ratting score. Whereas, *Etsub* genotype produced at Zenzelima location ranked the lowest general rating score (1.57) (data not shown). Generally, the highest *Injera* general rating scores were recorded at Bichena and Minjar for all the tef genotypes followed by Debre Zeit location except *Quncho* genotype that showed a lower score. The lowest general rating scores were recorded from all the three genotypes produced at Adet and Zenzelima Nitisols. Tef grain produced on Vertisols showed better *Injera* quality as compared to tef produced on Nitisols, except *Quncho* variety produced on Vertisols showed relatively poor *Injera* quality.

Environment alone contributed about 52.4%, 38.7%, 62.5%, 87.6%, 69.0%, and 80.8% for the variation of BSC, TSC, eye appearance, malleability, taste, and general rating, respectively. The G x E effect also contributed for 40.9%, 53.0%, 26.0%, 12.0%, 28.6%, and 18.6% for the variation of BSC, TSC, eye appearance, malleability, taste, and general rating, respectively. The contribution of genotypes for the variability of BSC, TSC, eye appearance, malleability, taste, and general rating were poor (6.6%, 8.3%, 11.6%, 0.3%, 2.4%, 0.6%, respectively). Generally the genotypes ISQA changed due to growing location environmental factors. The white-colored grain tef genotypes source of variation was due to the variability of the growing environment (soil properties and climatic factors). Even though there are no as such published literature that compared different genotypes of tef grains produced at different locations for *Injera* quality, in agreement with our result, wheat grain produced in different environments of Sudan showed variability in baking quality across growing environments (Mutwali *et al.,* 2018).

The contribution of G by E interaction effects with a higher percentage of ISQA was also due to the modification of the performance of the genotypes by the influence of the growing environmental soil and climatic factors. In agreement with this, Panthee *et al.* (2012) reported that the quality trait of some tomato genotypes showed a change of as much as 211% performance in a certain location as compared to their mean performances of the genotypes as a result of location. The lower variance recorded due to genotype on ISQA suggests that the same color but different tef genotypes grown in the same environment exhibited more or less similar *injera* quality sensory attributes as compared to one genotype grown in different location.

The environmental factor described by soil properties and climatic factors showed strong to poor correlation (Table 7, 8). There was a significant correlation between ISQA and soil properties (Table 7). The results were significantly positive between black soil color, pH, Ca, Mg, and K, and sensory attributes (r= 0.55 to

0.90; $P < 0.05$ to $P < 0.001$). Total nitrogen and sulfur exhibited from strong to poor negative correlation with sensory attributes of BSC, TSC, eye, malleability, taste and general rating (r = 0.62 to -0.83; P <0.05 to 0.001) (Table 7). Soil Mo exhibited significantly positive correlation with *injera* eye characteristics (r= 0.61; P < 0.05), and malleability (r=0.54; P < 0.05) only. Soil Na and Cu concentrations showed significantly positive correlations with *injera* sensory attributes of BSC (r= 0.53; P < 0.05) and taste (r=0.56; P < 0.05), respectively (Table 7). From the tested soil minerals, SOC, P, B, Co, Fe, Mn, and Zn; did not show significant correlation with *injera* sensory attribute (data not shown).

These results clearly indicate that the soil properties (soil color, pH, CEC and exchangeable cations (Ca, Mg and K) showed a significant positive association with all of the ISQA. The association is consistent with observed characteristics of soils. For example, Vertisols or black soils have higher soil pH, CEC and other basic cations; usually found under poor drainage conditions as compared to the weathered Nitisols. Nitisols are associated with the presence of iron or iron oxides (hematite) which are usually acidic to slightly acidic soils, found in a relatively high rainfall areas and thus subject to excessive leaching processes (IUSS, 2015). Therefore, better *injera* sensory quality attributes were associated with the neutral soil pH and higher CEC and relative abundance of basic cations. Soil total nitrogen and available sulfur were however less associated with the two soil types rather they were more linked with the soil organic matter content. However, the SOC was not significantly correlated to IQSA. The higher positive r values of the tested ISQA with soil pH, CEC and Ca concentration and negative for TN and S suggest that the nutrient concentration in the soil directly influences the brightness of *injera* color and other ISQA. This means that the brightness or darkness of *injera* color may be associated with the abundance and/or deficiency of soil nutrients. The color change of the top and bottom surfaces of *injera* was seen from the same genotype of tef due to the variability of the environment specifically soil nutrients (Figure 2 and Table 6).

Table 7: Pearson's correlation on genotype * environment interactions of 15 *injera* types of quality sensory attributes and soil properties during 2017

Injera sensory quality attributes	Soil properties											
	Color	pH	CEC	TN	Ca	Mg	K	Na	P	S	Cu	Mo
BSC	0.79***	0.74**	0.81***	-0.63*	0.81***	0.68**	0.65**	0.53*	0.43	-0.81***	0.30	0.44
TSC	0.70**	0.65**	0.76**	-0.63*	0.75***	0.64*	0.55*	0.44	0.31	-0.73**	0.39	0.44
Eye appearance	0.56*	0.51*	0.72**	-0.56*	0.69**	0.55*	0.36	0.23	0.03	-0.62*	0.47	0.61*
Malleability	0.77***	0.77***	0.88***	-0.77**	0.90***	0.67**	0.63*	0.38	0.27	-0.83***	0.50	0.54*
Taste	0.67**	0.66**	0.73**	-0.78***	0.76***	0.62*	0.57*	.040	0.34	-0.70**	0.56*	0.28
General Rating	0.81***	0.79***	0.89***	-0.74**	0.90***	0.71**	0.66**	0.47	0.36	-0.86***	0.45	0.51

*BSC = Bottom Surface Color, TSC = Top Surface Color. *, **, and *** are significantly correlated at P < 0.05, 0.01, and 0.001, respectively.*

Generally, tef which was grown on Vertisols which has relatively higher pH, CEC, Ca, Mg, K and lower TN and S, were better in grain color brightness and *injera* sensory quality attributes as compared to Nitisols with a relatively low pH, CEC, Ca, Mg, K and high TN and S area produced tef. In confirmation with our result, Kim *et al*. (2003) reported that lower soil cation exchangeable cation contributed for the yield and quality reduction on crops. The color of the soil is an indicator of many of the inherent soil properties including mineral concentration and hydraulics properties of the area. Tolera *et al.* (2009) and Achalu *et al.* (2012) also reported that those soil properties affect the growth, yield, and quality of the crops grown

The results of the climatic factors with most of the ISQA relationship were poor and not significant. Only a significant direct relationship of eye characteristics and malleability of injera with altitude (r = 0.64; P < 0.05, r = 0.64; P < 0.05); and amount of rainfall an indirect significant relationship (r = 0.52; P < 0.05, r = 0.53; P < 0.05, r = 0.53; P < 0.05), with bottom surface color taste, and general ratting were observed (data not shown). Our results not in confirmation with the results from previous studies of Majoul *et al*. (2003) and Jing *et al*. (2007), who confirmed that temperature and light affected the anthocyanin content of the grain and so the color of the product. Therefore, the reason for the variability of *injera* sensory quality could be associated with the soil property, rather than climatic factors.

As the amount of rainfall increased, the *injera* sensory attribute decreased suggesting that there might be leaching of soil minerals and/or an association with the lodging of tef with excess rainfall at maturity which could affect the grain color of tef. Kebebew *et al. (*2015) reported that high rainfall after seed setting aggravates tef lodging. In our experiment, some locations like Adet, Minjar, and Bichena had more or less similar amounts of rainfall during the growing season. The poor significant positive relationship of *injera* bottom surface color, taste and general rating with rainfall amount; significantly negative poor relationship of eye characteristics and malleability and no significantly relationship with others ISQA with altitude; and the non significant relationship of temperature with all the evaluated ISQA suggesting that as there were other factors which contributed to ISQA better than the climatic variability.

The Pearson's correlation matrix result showed that TSC, BSC, eye appearance, malleability, taste and general rating showed direct significant relationship (r = 0.57; P < 0.05, r = 0.56; P < 0.05, r = 0.68; P < 0.01, r = 0.69; P < 0.01, r = 0.59, P < 0.05, and r = 0.70; P < 0.01, respectively) with grain color V value. Similarly except eye appearance which did not show significant relationship with flour color V value others ISQA (TSC, BSC, malleability, taste and general rating) showed indirect significant relationship (r = -0.65; $P < 0.01$, r = -0.62; $P < 0.05$, r = -0.71; $P < 0.01$, -r = 0.57; $P < 0.01$, and r = -0.74; $P < 0.01$, respectively) with flour V color space value. The brightness of grain and flour color (V values) positive significant relationship with *injera* quality sensory attributes implying that the grain and flour color brightness had a direct effect on the *injera* quality. An exception to this generalization was the characteristics of the *injera* eye with flour color V value (Table 8). Flour color S value of tef correlated negatively and significantly with three of the eye appearance, malleability and general rating (Table 8). This result suggesting that as the concentration of color increases (saturated), *Injera* eye number and distribution as well as its softness decreases. However, other grain and flour color values did not have significant relationship with ISQA in this study.

Table 8: Pearson's correlation between Grain and flour color and *injera* sensory attributes

	Grain color values			Flour color values		
	H	S	V	H	S	V
Bottom surface color	-0.10	-0.07	0.57*	0.37	-0.41	0.65**
Top surface color	-0.08	-0.04	0.56*	0.36	-0.37	0.62*
Eye appearance	-0.27	0.09	0.68**	0.23	-0.61*	0.45
Malleability	-0.04	-0.14	0.69**	0.33	-0.53*	0.71**
Taste	0.09	-0.01	0.59*	0.38	-0.29	0.57*
General Rating	-0.06	-0.15	0.70**	0.34	-0.53*	0.74**

** and ** are significantly correlated at $P < 0.05$ and 0.01, respectively.*

Conclusion

Tef growing locations environmental factors like soil and climatic factor contributed largely for the variation of white color grain tef genotypes *Injera* quality.

Different white grain tef genotypes produced in the same location seams similar on Injera sensory quality attributes, while single genotypes produced in different locations with variable soil type showed considerable variation in ISQA.

Best and consumer preferred *Injera* quality tef would be produced on Vertisols, while poor quality on Nitisols.

For better understanding, evaluation of different soil nutrient types and rates for *Injera* quality is recommended under different soil types and agro-ecologies in Ethiopia.

Based on our results, we argued that the quality of tef *injera* “as low quality” grown in Vertisols of the northwestern highlands couldn’t be substantiated.

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