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Physicochemical Characteristics of Grain and Flour in 13 Tef [*Eragrostis tef* (Zucc.) Trotter] Grain Varieties

Geremew Bultosa

Department of Food Science and Post harvest Technology, Box 22,
Haramaya University Campus, Ethiopia.

Abstract: In view of the limited information on tef grain and flour quality factors, 13 tef (*Eragrostis tef*) grain varieties were characterized for grain physical, proximate%, amylose% and flour starch pasting. The grain length (width) were ranged 1.30 (0.67)-0.51 (0.10) [mean = 1.17 (0.59)-0.61 (0.13)] mm, grain mass retained on 600 + 300 microns were about 98% and thousand kernel weight (TKW, g) were between 0.285-0.241 (mean = 0.264). The % proximate compositions are of typical for tef grain reported elsewhere. Both amylose% [25.8-20.0 (23.0)] and amylograph flour starch pasting showed that no *waxy*- or *amylo*-type starch traits in the varieties. The pasting temperature (PT) is high, because tef is a tropical C4 cereal. Tef flour starch showed less thickening ability, more shear tolerance and slow setback compared to maize starch. A variety (DZ-01-1285) with least grain protein (GPC) showed highest peak (PV), cold (CPV) and setback (SB) viscosities. The GPC was negatively weak correlated with PV ($r = -0.461$, $p < 0.01$), hot paste viscosity (HPV) $r = -0.365$ ($p < 0.05$) and break down (BD) ($r = -0.360$, $p < 0.05$) as similar reported for wheat flour starch pasting. Negative correlation ($p < 0.01$) between amylose%: PT ($r = -0.606$) and pasting time (Pt) ($r = -0.460$) were observed as with the normal cereal starches. However, in tef flour starch pasting, a subtle increase in the amylose% was weakly correlated toward increase of amylograph setback viscosity (SB, gelation tendencies) in part probably because of interferences of other flour components on the gelation tendency of amylose.

Key words: Amylograph, Amylose, *Eragrostis tef*, Flour starch pasting, Grain plumpness, *Injera*, Proximate composition

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is indigenous cereal crop in Ethiopia with largest share of area (22.7 %, 2.4 million hectares) under cereal cultivation and third (i.e. after maize and wheat) in terms of grain production (16.3 %, 24.4 million quintals)[12]. Tef grain flour is widely used in Ethiopia for making *injera* (staples for the majority of Ethiopians, a fermented, pancake-like, soft, sour, circular flatbread), sweet unleavened bread, local spirit, porridges and soups[16,19]. Tef grain commands premium price among other cereals cultivated in Ethiopia. There is a growing interest on tef grain utilizations because of nutritional merits (whole grain), the protein is essentially free of gluten the type found in wheat (alternative food for consumers allergenic to wheat glutens)[15]. The grain proteins are also presumed easily digestible because prolamins are very small[5,11,25]. Tef grain micronutrient is also apparently high[22], particularly in iron, a result of agronomic practices used in Ethiopia and fermentation on *injera* making[3,33]. Because of this, the prevalence of iron deficient anemia among tef *injera* consumers in Ethiopia is low.

Information on the *injera* natures[27,16], nature of micro-organisms involved in the tef fermentation for *injera* making [18,20] and changes in the physicochemical properties with fermentation and on *injera* baking[26,30,31,32] are available. Various studies[35,34] showed that in its *injera* making and keeping quality features, tef grain appeared superior among other cereal grains. Up to the year 2002, 13 tef grain varieties were released by the Ethiopian tef improvement program for production in the different agroecological locations in Ethiopia[4]. The fundamental physicochemical and functional properties of tef starches that predicts the processing and preservation of tef grain products seems available for only five tef varieties[8,9,10].

Problem: Predictive grain and flour quality factors for tef grain are limited and there are some complaints also that tef grain varieties are not the same in their *injera* making and keeping quality features (some poor and some good).

Corresponding Author: Geremew Bultosa, Department of Food Science and Post harvest Technology, Box 22, Haramaya University Campus, Ethiopia,
E-mail: Bultosageremew@yahoo.com. Fax: 251-025-5530325 or 251-025-5530331

Objectives: To assess tef grain and flour characteristics of the 13 varieties, particularly tef grain plumpness (sizes, %mass on various test sieves and test weight), proximate composition, flour starch amylose%, pasting and correlation among the properties.

MATERIALS AND METHODS

Tef Grain Samples: Thirteen (Table 1) released tef grain varieties were collected from the harvest of 2004-05 of Debre Zeit tef improvement program (DZTIP) form the breeder seed (Debre Zeit Agricultural Research Center, Ethiopia). The grain sample was manually cleaned by siftings and winnowing to ensure is free from chaffs, dust and other impurities.

Grain physical characteristics:

Grain Size, % Mass on Test Sieves and Thousand Kernel Weight (TKW): Grain samples (*ca*. 500g) were sieved for 5 min with the help of a test sieve shaker (Wykeham France Engineering Ltd., England) through a range of sieves (250, 300, 600, 710 & 1000 microns) connected in tandem. Grain size (length and width) on each test sieves were determined by digital caliper (±0.01mm). Grain mass (%) was determined after measuring the mass retained on each test sieves on electronic balance (± 1mg). Thousand-kernel weight was determined on analytical balance (± 0.1mg) after counting 1000 tef grains by a seed counter (Numigral II Chopin seed counter, France). The results on grain size, grain mass% and TKW were reported on 12.5% moisture basis.

Grain Proximate Composition and Flour Starch Amylose%:

Proximate Composition: Tef grain samples were milled by disk attrition mill to whole flour to the fineness level used traditionally for *injera* making at the cottage tef grain-milling house (Dire Dawa, Ethiopia). The flour was then kept in an air tight sealed plastic bucket at refrigeration temperature (*ca* 5^{O}C) over the analysis duration. Moisture was determined by drying approx. 2.5g flour samples by air draft drying oven method at 130^{O}C for 1h (AACC Method No 44-15A)[1]. Ash was determined after ashing about 3g flour samples in a muffle furnace at 550^{O}C for over 24 h until ashing was complete (AACC Method No 08-01)[1]. Grain protein content (GPC) was determined by taking approx. 0.3g flour sample by micro-Kjeldahl method of nitrogen analysis (AACC Method No 46-11)[1] and urea was used as a control in the analysis. %Protein = %N x 6.25. Crude fat was analyzed after HCl acid (25 + 11) hydrolysis of about 2g flours sample and extraction of the released lipids with petroleum ether (16mL x 3) (AACC Method No 30-10)[1]. Crude fiber was determined by taking approx. 3g flour samples as the portion of carbohydrate that resisted dilute sulfuric acid (1.25%) and dilute alkali (1.25%) digestions followed by subsequent sieving (75 microns), washing, drying and ignition (AACC Method No 32-10)[1].

Flour Starch Amylose%: Amylose (%) was analysed colorimetrically by iodine binding with amylose by taking 30-40 mg flour samples according to Charastil [13]. Normal maize (Merck UniLAB, code: 587 14 00) and tef (DZ-Cr-37) starches of 27.8 and 27.2% amylose, respectively were used as a control[8]. Amylose (%) was determined from the standard (0-100% amylose of 10% variations) calibration curve. Data were evaluated on moisture and protein percentages free basis.

Brabender Amylograph Tef Flour Starch Pasting: The Amylograph was obtained on 10% flour (db) basis with Micro Visco-Amylograph®[7] (Brabender® OHG 2003, Brabender Measurement and Control Systems, Germany) operated at 250 revmin^{-1}, held at 30^{O}C for 1min, heated to 90^{O}C for 5min. at a rate of 7.5^{O}C per min., held at 90^{O}C for 5min. and cooled to 50^{O}C at a rate of 7.5^{O}C per min. From the resulting amylograph pasting curve, temperature at initial viscosity increase (PT, ^{O}C), pasting time (Pt, min), peak viscosity (PV, BU), hot paste viscosity (HPV, BU) (minimum viscosity recorded during holding duration at 90 ^{O}C), breakdown viscosity (BD, BU) (PV - HPV), cooled paste viscosity (CPV, BU) (viscosity at the end of cooling period) and setback viscosity (SBV, BU) (CPV- HPV) were determined by Micro Visco-Amylograph software (Windows version 72300, Brabender® Measurement and Control Systems, Germany).

Statistical Analysis: At least three replicate data were analyzed by one-way analysis of variance (ANOVA), means were compared at $p < 0.05$ using DMRT and Pearson correlation coefficients (r) were calculated among the properties by using SPSS 10.0.1 statistical package (SPSS Inc., 1989-1999, Chicago, USA).

RESULTS AND DISCUSSIONS

Grain Size, %Mass on Test Sieves and TKW: Tef grain sizes are extremely small. The size variations assessed after passing through test sieves (1000, 710, 600, 300 and 250 microns) showed that virtually no grain had remained on 1000 micron. The length (L, mm) and width (W, mm) on the highest (710 micron) and the least (300 and 250 microns) were reported in this paper (Table 1). The varieties had grain length

Table 1: Grain characteristics (size, mass (%) on test sieves and TKW) of the 13 released tef varieties

Variety (Color)-Release year	Size# L (W) (mm)	Mass (%)# 710 microns	600 microns	300 microns	250 microns	TKW (g)#
DZ-01-354 (Pale white)-1970*	1.29cd(0.67)d -0.62ab(0.13)a-d	0.73 ± 0.05bc	51.75 ± 0.68cd	47.48 ± 0.65e	0.05 ± 0.01a	0.278±0.003d-f
DZ-01-99 (brown)-1970	1.30d(0.62)c -0.51a(0.12)a-d	1.31 ± 0.07e	55.64 ± 0.14h	42.87 ± 0.05c	0.05 ± 0.01a	0.283±0.003e-f
DZ-01-196 (Very white)-1970	1.17a-c (0.60)a-c-0.83(0.41) Δ	3.33 ± 0.07i	61.79 ± 0.27j	34.82 ± 0.33a	-	0.266±0.006c-e
DZ-01-787 (Pale white)-1978	1.20b-d (0.62)bc -0.93(0.40) Δ	0.47 ± 0.06a	53.96 ± 0.56fg	45.30 ± 0.61d	-	0.268±0.009cd
DZ-Cr-44 (White)-1982	1.14ab(0.56)a -0.66b(0.10)a	0.81 ± 0.10c	59.70 ± 1.13i	39.22 ± 1.09b	0.11 ± 0.01a	0.241±0.003a
DZ-Cr-82 (White)-1982	1.10ab(0.57)ab -0.64ab(0.14)cd	1.58 ± 0.10f	45.98 ± 0.90a	52.24 ± 0.94g	0.59 ± 0.81b	0.260±0.006bc
DZ-Cr-37 (White)-1984	1.17a-c (0.56)ab-0.65ab(0.15)d	1.83 ± 0.03g	54.60 ± 1.00gh	43.44 ± 1.00c	0.05 ± 0.01a	0.261±0.008bc
DZ-Cr-255 (White)-1993	1.13ab(0.60)a-c -0.68b(0.15)d	1.12 ± 0.05d	52.73 ± 0.57de	45.98 ± 0.64d	0.10 ± 0.01a	0.252±0.009ab
DZ-01-974 (White)-1995	1.11ab(0.58)a-c -0.60ab(0.14)cd	0.56 ± 0.04a	48.90 ± 0.21b	50.42 ± 0.26f	0.06 ± 0.01a	0.253±0.008ab
DZ-Cr-358 (White)-1995	1.16a-c(0.57)a-c -0.54ab(0.14)b-d	1.72 ± 0.25fg	53.04 ± 0.67ef	45.15 ± 0.90d	0.08 ± 0.06a	0.269±0.003c-e
DZ-01-1281 (White)-2002	1.12ab(0.59)a-c -0.68b(0.15)cd	2.88 ± 0.09h	53.17 ± 0.29ef	43.70 ± 0.23c	0.17 ± 0.01a	0.262±0.005bc
DZ-01-1285 (White)-2002	1.05a(0.58)a-c -0.58ab(0.12)a-c	0.59 ± 0.06ab	51.51 ± 0.77c	47.67 ± 0.70e	0.18 ± 0.01a	0.250±0.003ab
DZ-01-1681 (Dark brown)-2002	1.23b-d(0.59)a-c -0.58ab(0.11)ab	1.36 ± 0.03e	51.34 ± 0.19c	47.13 ± 0.17e	0.07 ± 0.01a	0.285±0.020f
Mean	1.17 (0.59) -0.61(0.13)	1.12 ± 0.05	52.73 ± 0.57	45.34 ± 5.5	0.12 ± 0.23	0.264 ± 0.010
Range	1.30(0.67) -0.51(0.10)	3.33-0.47	61.79- 45.98	52.24-34.82	0.01-0.59	0.241-0.285

*Personal communication from tef improvement program of the DZARC & Belay et al. (2005). #Values within the same column with different letters are significantly different ($p < 0.05$) and are means of at least 3 determinations. Grain length (L) and width (W) are values on maximum (710) and minimum (250) microns sieve; Δ is value on 300 microns sieve; TKW is thousand kernel weight.

(width) ranged 1.30 (0.67)-0.51 (0.10) with mean of 1.17 (0.59) -0.61 (0.13). In earlier works, lengths (mm) were reported to be ranged: 1.7-0.9 (width = 1.0-0.7 mm) [17]. However, Umeta & Parker [32] had noted length to be 1.2-1.0 mm. Also the DZTIP tef breeding recent progress report had classified tef sieve-size grades on 350, 425, 500, 600 and 710 microns[29], which is familiar to this finding. On 710 micron, the highest grain length was for DZ-01-99 and the least was for DZ-01-1285. In tef grain varieties DZ-01-196 and DZ-01-787 no thoroughs on 300 micron were recorded. The % tef grain mass retained on 710 micron test sieve was small (3.33-0.47) with mean 1.12 ± 0.05 and the highest %mass was recorded for DZ-01-196 and the least was for DZ-01-787 and DZ-01-974 ($p< 0.05$). The %mass on 600 micron had ranged 61.79-45.98 with mean 52.73. Tef grain DZ-01-196 is most preferred for market because of its grain size and white color[4,29] and the highest %mass on 600 micron was observed in this variety and the least was for DZ-Cr-82. On 300 micron, the % mass retained had ranged 52.24-34.82 with mean 45.34; the highest was for DZ-Cr-82 and the least was for DZ-01-196. The mean grain mass retained on 600 + 300 microns was about 98%. The mass that had passed through 300 microns and retained on 250 microns were very small (0.59-0.01%).

The TKW for the varieties had ranged 0.285-0.241g with mean 0.264g, which is in the range (0.42-0.19 g) reviewed for tef grain in [2]. The highest TKW was observed among DZ-01-354, DZ-01-99 and DZ-01-1681 and the least was among DZ-Cr-44, DZ-Cr-255, DZ-01-974 and DZ-01-1285 ($p< 0.05$). On the preliminary report of Tefera & Sorrells[29], with an increase in the grain size an increase in TKW and grain yield was the trend. On this basis and the report in [17] probably size among tef grain populations few might be larger than this finding or in part might be a manifestation of the moisture level variations.

Grain Proximate Composition and Flour Starch Amylose%: The proximate composition and amylose% of the 13 released tef grain varieties are given in Table 2. The moisture had ranged 11.22-9.30% with mean 10.53%, which is in the normal range for field dried tef grain [11]. The grain protein (GP) of the varieties are ranged 11.1-8.7% with mean 10.4%. The GP in DZ-01-354, DZ-01-99, DZ-01-787, DZ-Cr-44, DZ-Cr-82, DZ-Cr-37, DZ-Cr-255 and DZ-01-1281 was the highest; and in DZ-01-1285 was the lowest ($p < 0.05$). The GP for tef varieties were reviewed to range 13-9% with mean 11 %[11]. Belay *et al.*[4] had reported for these 13 released tef varieties in the range of 12.4-8.7% with mean 11.0% and the highest was for DZ-01-99 and the least was as for this finding (i.e. DZ-01-1285). The ash content had ranged 3.16-1.99% with mean of 2.45%. Ash in the brown tef varieties (DZ-01-99 = 3.16% and

Table 2: Proximate composition and flour starch amylose % of the 13 tef grain varieties

Variety	Moisture (%)	Grain protein (%)&	Ash (%)&	Crude fat (%)&	Crude fibre (%)&	Amylose (%) from flour&
DZ-01-354	11.07± 0.02hi*	10.6 ± 0.7c-f	2.18 ± 0.0b	2.1 ± 0.2a	3.3 ± 0.2c-e	25.8 ± 0.7d
DZ-01-99	10.83± 0.13fg	10.8 ± 0.3d-f	3.16 ± 0.0f	2.1 ± 0.0a	3.8 ± 0.3e	22.9 ± 1.2bc
DZ-01-196	9.69± 0.03b	10.4 ± 0.6b-e	2.14 ± 0.0b	2.4 ± 0.7ab	3.2 ± 0.2bc	22.1 ± 1.0bc
DZ-01-787	10.85± 0.12fg	10.4 ± 0.5c-f	2.06 ± 0.0a	2.5 ± 0.5ab	3.5 ± 0.1c-e	23.8 ± 2.1cd
DZ-Cr-44	9.30± 0.04a	10.7 ± 0.0c-f	2.82 ± 0.1d	2.6 ± 0.6ab	2.7 ± 0.1ab	25.6 ± 0.3d
DZ-Cr-82	10.79 ± 0.14f	10.6 ± 0.3c-f	2.15 ± 0.0b	3.0 ± 0.4b	3.5 ± 0.2c-e	22.3 ± 1.6bc
DZ-Cr-37	11.15± 0.08i	11.0 ± 0.2ef	2.54 ± 0.0c	2.0 ± 0.3a	3.3 ± 0.4cd	22.7 ± 0.6bc
DZ-Cr-255	10.24± 0.08d	11.1 ± 0.1ef	3.10± 0.1f	2.5 ± 0.6ab	2.6 ± 0.2a	20.0 ± 0.4a
DZ-01-974	10.33± 0.10d	10.0 ± 0.5bc	2.16 ± 0.0b	2.1 ± 0.2a	3.5 ± 0.3c-e	22.7 ± 0.6bc
DZ-Cr-358	10.49 ± 0.06e	10.1 ± 0.2b-d	1.99 ± 0.0a	2.2 ± 0.0ab	3.5 ± 0.4c-e	22.4 ± 0.5bc
DZ-01-1281	11.22± 0.11i	11.1 ± 0.2f	2.52 ± 0.0c	2.5 ± 0.7ab	3.4 ± 0.5c-e	22.7 ± 1.4bc
DZ-01-1285	9.96 ± 0.06c	8.7 ± 0.1a	2.02 ± 0.0a	2.5 ± 0.6ab	3.1 ± 0.4bc	24.2 ± 2.1cd
DZ-01-1681	10.96± 0.04gh	9.7 ± 0.3b	2.99 ± 0.0e	2.0 ± 0.0a	3.7 ± 0.1de	21.2 ± 0.5ab
Mean	10.53 ± 0.58	10.4 ± 0.7	2.45 ± 0.42	2.3 ± 0.5	3.3 ± 0.4	23.0 ± 1.8
Range	11.22-9.30	11.1-8.7	3.16-1.99	3.0-2.0	3.8-2.6	25.8-20.0
Maize starch (n=7)						28.4 ± 2.0
Tef (DZ-Cr-37) starch (n=7)						27.7 ± 1.9

*Values within the same column with different letters are significantly different ($p < 0.05$) and are means of at least three determinations. &Values are on dry matter basis

DZ-01-1681 = 2.99%) and in DZ-Cr-255 was comparatively high and in tef varieties DZ-01-787, DZ-Cr-358 and DZ-01-1285 appeared lowest ($p < 0.05$). A review report of the ash level in tef grain had ranged 3.00-2.66% with typical value 2.8% [11]. Apart from the genetics, the ash levels in tef grain are influenced by the agronomic practices used (i.e., by the degree of tef grain unseen surface contamination mostly from the threshing floor)[3]. Tef grain used in this study were from breeders and comparatively clean than purchased from the market, hence the slightly less ash level observed in this study are probably related to this scenario. The crude fat had ranged 3.0-2.0% with mean of 2.3% and the value is similar with the review report of 3.09-2.00% of previous works[11]. 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 ($p < 0.05$). Eventhough, germ in tef is known to occupy large proportion as in other small grain its crude fat is known to be not as such high. The crude fiber (CF) had ranged 3.8-2.6% with mean 3.3%. Apparently the crude fiber observed in these 13 varieties are almost similar with the earlier report of 3.5-2.0% with typical value 3.0% [11]. The CF was high among tef varieties DZ-01-354, DZ-01-787, DZ-Cr-82, DZ-01-974, DZ-Cr-358 and DZ-01-1281 and was highest in brown tef varieties (DZ-01-99 = 3.8% and DZ-01-1681 = 3.7%) ($p < 0.05$). The CF for DZ-Cr-44 and DZ-Cr-255 were the lowest. Tef is consumed as a whole grain, bran and cell wall materials were reported not affected as such on tef fermentation on *injera* making[26]. The CF comprises materials that had resisted digestions (dilute acid and base). These are presumably major contributor for the dietary fiber of characteristic large stools bulk on tef *injera* consumption.

The tef flour starch amylose% had ranged 25.8-20.0% with mean 23.0%. Amylose in maize and tef (DZ-Cr-37) starches analyzed along with the tef flour varieties were 28.4% and 27.7%, respectively. The amylose% in four tef starch varieties (DZ-01-99, DZ-01-196, DZ-Cr-37 and DZ-01-1681), which their flour included in this work were reported to range 28.8-27.2%[8]. The lower % amylose observed in tef flour than in tef starch of the same variety is because other trace flour components in the flour sample somehow slightly interferes and suppresses the starch sample dissolution and the iodine binding with amylose of the blue color formation similar as reported in other cereals[13,21]. In addition, ash, fat and fiber contributions to the total mass% sampled were also not precluded. Among the tef flours the highest amylose% was for DZ-01-354, DZ-01-787, DZ-Cr-44 and DZ-01-1285 and the lowest were for DZ-Cr-255 and DZ-01-1681 ($p < 0.05$). The starch in these 13 tef varieties appeared normal type and no *amylo*- or *waxy*- starches were observed and the flour starch pasting also support this (Table 3, Figure 1). In tef grain food products, like in tef porridges (*marqaa*), unfermented tef breads (*bixxille*), pancakes, biscuits, soups and cookies, all these tef grain varieties would be expected to have a normal short stiff paste texture that would slightly vary from each other probably by the influence of the narrow range amylose% variations.

Brabender Amylograph Tef Flour Starch Pasting: The pasting character predicts the processing qualities (cooking temperature and time, thickening ability, temperature-pressure-shear induced viscosity breakdowns, gelling and retrogradation tendencies over the storage durations) of starch based raw material food ingredients. The pasting character is fundamentally determined by the starch granule composition and its nature (ultra-structures) and is also influenced by the non-starch flour components. The pasting data and pasting curves for the 13 tef grain flour starch varieties are shown in Table 3 and Figure 1, respectively. The pasting temperature (PT, ^{O}C) (approx. gelatinization temperature) had ranged 75.9- 67.7 with mean 72.7. The pasting temperature is high because tef is a C4 tropical cereal grain. The PT found in this work is somehow similar to the reported RVA pasting temperatures (74.8 -72.1^{O}C) for five tef starches [8] and to the starch gelatinization temperatures (64-82 ^{O}C = DSC method and 68-80^{O}C = *Kofler* hot stage method)[9]. The highest PT was for tef varieties DZ-Cr-82 and DZ-01-1681 and the lowest was for DZ-Cr-44 ($p< 0.05$).

The TKW of the varieties (Table 4) were positively correlated with PT ($r = 0.457$, $p< 0.01$) and pasting time, pt ($r = 0.370$, $p< 0.05$) but negatively to the BD ($r = -0.352$, $p< 0.05$). The PT was reported high for high amylose and vice versa among normal starches [14]. In this work also significant ($p < 0.01$) negative correlation between amylose and PT ($r = -0.606$) and between amylose and pasting time (Pt, $r = -0.460$) were observed. The highest PT for DZ-Cr-82 and DZ-01-1681 (among low amylose %) and the least for DZ-Cr-44 (among high amylose %) are most probably related to this. The pasting time (Pt, min) (cooking time) were ranged 6.1-5.2 with mean 5.6. The lowest Pt was among DZ-01-354, DZ-Cr-44, DZ-01-974 and DZ-01-1285 and the highest was for DZ-Cr-82, DZ-01-1281 and DZ-01-1681 ($p < 0.05$). The varieties Pt was slightly higher than the RVA Pt reported (5.10-3.43 min) for five tef starches[8].

The peak viscosity (PV, BU) had ranged 191.3-126.0 with mean of 158.0. The highest PV was for DZ-01-354 and DZ-01-1285 and the lowest was for DZ-Cr-82. The PV indicates the thickening ability and water holding capacity of the pasted flour and reflects the eating quality of the food products to be made. The PV in wheat was reported be influenced positively by the prime starch level primarily and to a lesser extent negatively by the protein level (i.e., due to competition for water per se on starch gelatinization) in sound wheat[23]. A reduced starch amylose in the starch granule, due to the genetic related decrease in the granule-bound starch synthase enzyme (GBSS: ADP glucose starch glycosyl transferase EC: 2.4.4.21) was correlated to high PV[36], eventhough in some work[24] not unequivocally observed (i.e., high amylose of high PV) for wheat starch pasting. In rice with reduced amylose high PV was reported for varieties of wide amylose range (28.2-6.3%)[28]. In sorghum also high PV was correlated with reduced amylose[6]. In this work, a significant positive correlation ($r = 0.588$, $p< 0.01$) was observed between flour starch amylose and the flour PV. It seems in normal tef (no *amylo*- and *waxy*-) flour starch amylograph pasting, high PV is contributed by other tef starch characters and other flour components, but not by subtle reduced starch granule amylose, since with narrow amylose variation (5.8%) tef is behaving high PV with high amylose. The GPC was negatively correlated with PV ($r = -0.461$, $p< 0.01$), HPV ($r = -0.365$, $p< 0.05$) and BD ($r = -0.360$, $p< 0.05$) similar as reported for wheat by[23].

The minimum viscosity (HPV, BU) recorded during the high temperature (90^{O}C) of 5 min. holding duration had ranged 157.0-115.0 with mean 134.0. The HPV (holding strength) is the minimum apparent viscosity recorded upon continuous shear thinning of the gelatinised system at high temperature for defined duration and reflects the degree of the disintegration of the swollen systems and alignments of amylose and other linear flour components in the direction of the shear. The HPV is positively significantly ($p < 0.01$) correlated with PV ($r = 0.814$) and CPV ($r = 0.772$), whereas the correlation to amylose was positive but not significant. The highest HPV viscosity was observed for DZ-01-354 and DZ-01-1285, which have high PV. The least HPV was observed in DZ-Cr-44 and DZ-Cr-82 ($p < 0.05$). Breakdown viscosity (BD, BU) had ranged 48.0-10.5 with mean of 24.0. The highest shear stabilities (lowest BD) were observed among DZ-01-196, DZ-Cr-82 and DZ-Cr-255 followed by DZ-Cr-37, DZ-01-1281 and DZ-01-1681. The least (highest BD) was for DZ-Cr-44 followed by DZ-01-1285,

Table 3: Pasting properties of 13 tef grain flour varieties

Variety	PT (^{O}C)	Pt (min)	PV (BU)	HPV (BU)	BD (BU)	CPV (BU)	SB (BU)
DZ-01-354	71.0 ± 0.0bc	5.4 ± 0.0a-c	189.0 ± 4.6g	157.0 ± 3.5f	32.0 ± 1.7e	246.3 ± 1.5e	89.3 ± 2.1ab
DZ-01-99	73.7 ± 0.1g	5.7 ± 0.3de	148.0 ± 1.0c	125.7 ± 1.5b	22.3 ± 0.6c	232.7 ± 4.6cd	107.0 ± 3.6c
DZ-01-196	72.6 ± 0.4f	5.4 ± 0.0bc	142.7 ± 2.5bc	129.3 ± 3.5bc	13.1 ± 1.2ab	213.0 ± 4.6ab	83.7 ± 1.2a
DZ-01-787	71.6 ± 0.0de	5.4 ± 0.0bc	165.5 ± 2.1e	136.0 ± 2.6d	29.5 ± 2.1de	222.5 ± 0.7bc	86.5 ± 0.7ab
DZ-Cr-44	67.7 ± 0.3a	5.2 ± 0.1a	163.0 ± 3.5de	115.0 ± 4.0a	48.0 ± 2.0g	203.3 ± 3.8a	88.3 ± 2.5ab
DZ-Cr-82	75.7 ± 0.5J	6.1 ± 0.0f	126.0 ± 2.0a	115.3 ± 1.5a	10.7 ± 2.1a	204.7 ± 17.2a	89.3 ± 15.7ab
DZ-Cr-37	74.6 ± 0.4h	5.9 ± 0.3e	158.7 ± 7.6d	143.0 ± 6.6e	15.7 ± 1.2b	255.3 ± 9.5e	112.3 ± 3.2cd
DZ-Cr-255	73.5 ± 0.6g	5.5 ± 0.0cd	137.5 ± 0.7b	127.0 ± 1.4b	10.5 ± 0.7a	227.0 ± 1.4bc	100.0 ± 0.0bc
DZ-01-974	71.2 ± 0.1cd	5.4 ± 0.0a-c	173.0 ± 2.6f	143.7 ± 1.2e	29.3 ± 1.5de	243.3 ± 2.1de	99.7 ± 1.5bc
DZ-Cr-358	71.8 ± 0.1e	5.4 ± 0.0bc	162.0 ± 3.6de	134.0 ± 2.6cd	28.0 ± 1.7d	225.7 ± 7.6bc	91.7 ± 5.5ab
DZ-01-1281	75.1 ± 0.1i	6.1 ± 0.0f	147.0 ± 3.5c	131.0 ± 4.6b-d	16.0± 1.7b	252.3 ± 11.7e	121.3 ± 15.9de
DZ-01-1285	70.6 ± 0.2b	5.3 ± 0.0ab	191.3 ± 2.9g	152.7 ± 1.2f	38.7 ± 2.5f	284.3 ± 2.5f	131.7 ± 3.5e
DZ-01-1681	75.9 ± 0.2J	6.1 ± 0.0f	146.0 ± 1.7c	130.7 ± 1.2b-d	15.3 ± 0.6b	216.0 ± 2.0ab	85.3 ± 3.1a
Mean (Tef flour)	72.7 ± 2.4	5.6 ± 0.3	158.0 ± 19.1	134.0 ± 12.9	24.0 ± 11.4	233.2 ± 23.7	99.2 ± 16.0
Range (Tef flour)	75.9-67.7	6.1-5.2	191.3-126.0	157.0-115.0	48.0-10.5	284.3-203.3	131.7-83.7
DZ-01-99 starch	70.5 ± 0.4	5.6 ± 0.0	290.0 ± 1.4	250.0 ± 2.8	40.0 ± 1.4	292.0 ±1.4	42.0 ± 1.4
Maize starch	72.5 ± 0.4	6.0 ± 0.1	418.0 ± 2.8	324.0 ± 1.4	94.0 ± 1.4	413.5 ± 2.1	89.5 ± 0.7

*Values within the same column with different letters are significantly different ($p < 0.05$) and are means of at least 3 determinations. Where: PT = pasting temperature, Pt = pasting time (cooking time), PV = peak viscosity, HPV = hot paste viscosity, BD = Break down viscosity, CPV = cold paste viscosity and SB = set back viscosity.

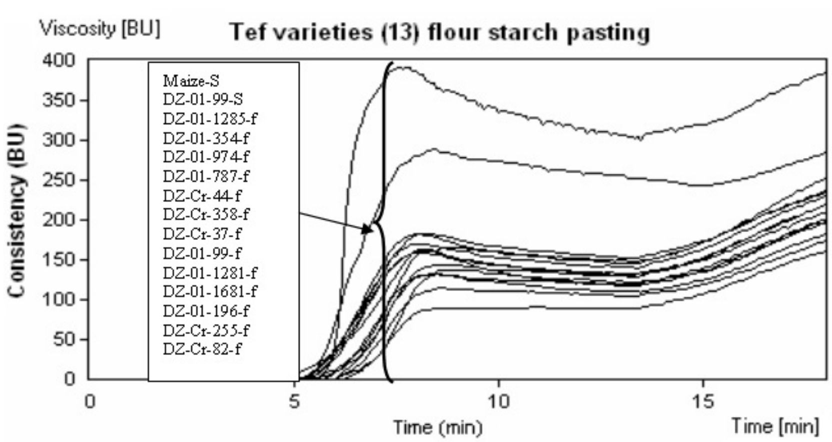

Fig. 1: Amylograph pasting curves for starches (s) (maize and DZ-01-99) and 13 tef flour (f) starch varieties

DZ-01-354, DZ-01-787 and DZ-01-974. The BD measures the differences between PV and HPV achieved during the high temperature (90^{O}C for 5 min) holding duration and shows the relative differences of shear thinning and degree of disintegration of the swollen systems. Tef starch and its flour starch pasting are shear tolerant and thus had a potential for use in foods processed under high shear conditions. The BD was significantly ($p < 0.01$) correlated positively with amylose ($r = 0.667$) and PV ($r = 0.755$) and negatively with TKW ($r = -0.352$, $p < 0.05$), GPC ($r = -0.360$, $p < 0.05$), PT ($r = -0.900$, $p < 0.01$) and Pt ($r = -0.743$, $p < 0.01$).

The cold paste viscosity (CPV, BU) had ranged 284.3-203.3 with mean 233.2. The highest CPV was for DZ-01-1285 and the least was for DZ-01-196, DZ-Cr-44, DZ-Cr-82 and DZ-01-1681. The CPV is significantly ($p < 0.01$) correlated positively with PV ($r = 0.630$), HPV ($r = 0.772$) and SB ($r = 0.860$). The SB (BU) had ranged 131.7-83.7 with mean 99.2. The highest SB was for DZ-01-1281 and DZ-01-1285 and the least was among DZ-01-354, DZ-01-196, DZ-01-787, DZ-Cr-44, DZ-Cr-82, DZ-Cr-358 and DZ-01-1681 ($p < 0.05$). The CPV and SB predict the degree of gelation and the gradual reterogradation tendencies on cooling and storage of the flour starch pasted system.

Table 4: Pearson correlation coefficients among the grain and flour quality factors in tef grain

Property	TKW	GPC	Ash	Fat	Fibre	Amylose	PT	Pt	PV	HPV	BD	CPV	SB
TKW	1.000												
GPC	.008	1.000											
Ash	.116	.376*	1.000										
Fat	-.404*	.110	-.044	1.000									
Fibre	.577**	-.146	-.100	-.099	1.000								
Amylose	-.095	-.099	-.287	.029	-.084	1.000							
PT	.457**	.230	.249	-.129	.457**	-.606**	1.000						
Pt	.370*	.260	.303	-.081	.464**	-.460**	.917**	1.000					
PV	-.136	-.461**	-.398*	-.203	-.101	.588**	-.665**	-.653**	1.000				
HPV	.110	-.365*	-.435**	-.330*	.086	.281	-.188	-.310	.814**	1.000			
BD	-.352*	-.360*	-.175	.033	-.266	.667**	-.900**	-.743**	.755**	.234	1.000		
CPV	-.131	-.294	-.233	.-.287	.013	.195	-.062	-.121	.630**	.772**	.183	1.000	
SB	-.285	-.139	.004	-.157	-.051	.061	.060	.070	.278	.340*	.082	.860**	1.000

Where: TKW is thousand kernel weight; GPC is grain protein content; PT is the pasting temperature; Pt is the pasting time; PV is the peak viscosity; HPV is hot paste viscosity; BD is breakdown viscosity; CPV is cold paste viscosity and SB is setback viscosity. *Significant at $p < 0.05$ and **significant at $p < 0.01$

Tef starch was known to have less thickening ability, shear tolerance and slow setback than commercial normal maize starch[8] on the RVA pasting and similar is also seen in the Brabender amylograph pasting (Table 3 and Figure 1). Tef starches were also known to have slow reterogradation tendencies on the refrigeration and freeze storages and freeze-thaw cycle treatments than the maize starches[10]. The correlation of CPV and SB with amylose in tef flour starch pasting was positive but insignificant, because in part gelation tendency of amylose is suppressed by other flour components. In addition to the known tef starches slow starch reterogradation tendencies, probably such weak SB (gelation tendencies) in the flour is also in part a contributor for tef *injera* good keeping qualities than *injera* made from other cereal flours.

Conclusions: Quality factors in tef grain and flour for *injera* making are not clearly addressed to this date. Traditionally: plump (non-shriveled), clean and non-sprout damaged tef grain milled to optimum level of fine powder are preferred in *injera* making. The grain composition in the 13 tef grain varieties are of typical for tef grain reported elsewhere with no *amylo*- or *waxy*-type starch traits. The slight variations in the pasting characteristics might be used to assess the *injera* making and keeping quality variations and in other tef grain foods. The dependency of SB (gelation tendencies) on amylose in tef flour starch pasting is found weak. It seems tef flour starch pasting is different in this aspect from normal cereals like wheat, rice, sorghum and maize.

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