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**ORIGINAL ARTICLE**

# Effect of extrusion operating conditions on the physical and sensory properties of tef (*Eragrostis tef* [Zucc.] Trotter) flour extrudates

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## ABSTRACT

Effect of extrusion variables including barrel temperature (110, 130 and 150°C), feed moisture content (17, 21 and 26 % wwb) and screw speed (100 and 140 rpm) on the physical and sensory properties of an extruded product was investigated using two tef cultivars (DZ 01-99 and 196, red and white coloured, respectively). Increased barrel temperature, reduced feed moisture content and a higher screw speed showed a significantly ($p < 0.01$) higher radial expansion (2.11 and 2.35), reduced bulk density (0.54 and 0.48 $g/cm^3$) and less compression resistance extrudate (64.16 and 60.83 N) with minimum moisture retention after extrusion respectively, for white and red tef varieties. Water absorbing and water solubility indices more attained the characteristics of a typical gelatinized product at these severe processing conditions. The study showed significant differences ($p<0.05$) in hedonic rating for colour texture and overall acceptance between products as evaluated by the sensory panels. In general, extrusion variables induced significant changes in the product quality attributes evaluated.

***Key words:*** Tef flour, extrusion, puffed product

## INTRODUCTION

Tef (*Eragrostis tef [Zucc.] Trotter*) 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 (Asrat and Frew, 2001). It is as nutritious as major staple cereals like wheat, rice, oats and barley and even better in some aspects, containing more calcium, zinc, iron and potassium and being high in dietary fiber (Seyfu, 1993). It is a rich source of vitamins and is considered to be an excellent source of essential amino acids with higher levels than wheat and barley (Seyfu, 1993). The grain is too small, with average length and width of 1.20 and 0.75 mm respectively (Bultosa, 2004; Zewdu and Solomon, 2007), to separate the germ from the bran hence the germ and the entire seed is consumed. This results in a better nutrition provision and higher fiber content. The whole meal is used for making pancake like bread called *injera.* The flour can also be used to make other food products such as *qitta* (unleavened bread), porridge and home brewed traditional beverages like "*tella*" (local bear) and "*katikalla*"(distilled liquor).Unlike other cereals (wheat, maize, rice and barley) processed at an industrial level, diversified utilization of

tef has been limited which could be attributed to its uniqueness to Ethiopia and an age-old processing carried out at a house hold-level. Extrusion cooking has become one of the
most popular modern processing technologies used extensively by many food processing industries for producing a wide range of products from cereals and starches (Harper, 1981; Chinnaswamy and Hanna, 1988; Raiz, 2001; Mezreb *et al*., 2003, Ibanoglu *et al*., 2005). The quality of products made by extrusion cooking of cereals and starches depend on a large number of variables related to the machine and the raw material used (Baik *et al*., 2004; Ding *et al*., 2005). Studies made on the processing of tef are few and are limited to the biological and biochemical changes taking place during fermentation process (Asrat and Friew, 2001). Utilizing the potential of this crop calls for developing and/or processing different types of products through modern processing technology.

Cognizant of the fact that no work has been done on the development of tef-based manufactured products like breakfast cereals, snack foods, pasta and macaroni in general and that on extrusion cooking of tef flour in particular, this study was undertaken with the objectives of assessing the potential and suitability of tef to be processed as extruded puffed product and to investigate the influence of the main extrusion operating conditions (temperature, moisture content, and screw speed) on selected physical and sensory properties of directly expanded puffed tef product.

## MATERIALS AND METHODS

### Experimental materials

Tef grain was obtained from Debre Zeit Agricultural Research Center (DZARC). Two cultivars namely DZ- 01-196 and DZ-01 99, grown at DZARC in 2005/06 cropping year were used for the study. The selection of tef varieties were based on grain color and yield. The DZ- 01-196 and DZ-01 99 cultivars are from white and red color varieties respectively. Prior to extrusion, cleaned grain tef was milled into flour using small-scale commercial mill. Following grinding, the flour was sifted to pass through 710 μm test sieve, sealed in plastic bags, and stored till extrusion test was conducted. Ground sample flour from each cultivar was analyzed for proximate composition.

### Extrusion tests

Extrusion was performed on a pilot scale co-rotating twin-screw food extruder (model Clextral, BC-21 No 124, Firminy, France). The barrel has 400 mm total length and consists of four modules each 100 mm long fitted with 25 mm diameter screws. The temperatures of the last two modules are controlled by electrical heating and water cooling system. Each zone-temperature was controlled by a Eurotherm controller (Eurotherm Ltd. Worthing, UK). Extrusion was performed at preset temperatures of zone 3 and zone 4 of the extruder barrel sections. The barrel temperature was fixed in zone 3 at 70°C. The temperature of zone 4, which was located just before the die, was an independent variable in the study and varied at 110, 130 and 150°C. Twin screw volumetric feeder (type KMV- KT20) delivered the raw material into the extruder inlet. While operating, water at ambient temperature was injected into the extruder via an inlet port by a positive displacement pump (DKM-Clextral, France). The moisture content of the material was adjusted by varying the water injection rate of the pump to give a moisture content of 26, 21 and 17% in the mixes for a constant material feed rate of 9 kg/hr. Screw speed was set at 100 and 140 rpm. The selected moisture, temperature and speed levels were chosen from pre test experiments. The end of the extruder was caped with a die plate, which held a die having four circular openings of 2 mm diameter.

Samples were subjected to extrusion test at all combinations of the operating conditions. During extrusion samples were extruded as straight rope (rod) for a time interval of ten seconds so as approximately about 100 cm long extrudate emerge from the die. Extruded samples were collected when the extrusion process parameters reached steady state, i.e. when there were no visible drift in torque and die pressure (Garber *et al.*, 1997). The extruded products were placed on a table and allowed to cool for 30 minutes at room temperature (Ibanoglu, *et al.*, 2005) for the measurement of weight, length and diameter. Samples were collected and sealed in plastic bags after equilibration for 24 hr at ambient condition. Sealed samples were stored at room temperature and physicochemical determinations and sensory quality evaluation were done in four weeks after extrusion.

**Experimental designs and statistical analysis**

A full factorial experimental design was used to study the influence of three extrusion-operating conditions on product quality attributes. Thus, there were 18 treatment combinations: 3 (feed moisture) × 3 (barrel temperature) × 2 (screw speed) replicated three times for each grain tef cultivars. The analysis of variance (ANOVA) was carried out to investigate the effect of operating conditions on final product quality using the Statistical Analysis System (SAS) for windows V.801 (SAS Institute Inc., 1999). Mean separation was performed using Student Newman Keuls Test (SNK) for multiple comparison of means.

**Extrudate moisture content**

Moisture content of extruded product was determined immediately after extrusion following AOAC (1995), method 925-09.

**Radial expansion, specific length and bulk density**

Length was measured by a pocket size steel tape of 1mm accuracy. The diameter of the extrudates was measured by a vernier caliper (СДЕЛАНО, сссp, Russia) having 0.05 mm accuracy. Weight was measured by a digital balance (ADAM, AFP1200, South Africa) of 0.01g sensitivity. A mean value of length, weight and diameter from 4, 4 and 10 measurements respectively was recorded for each experimental run. The expansion ratio (diametric) is defined as the ratio of the diameter of the extrudate to the diameter of the die hole (Mason Hoseney, 1986). The specific length of the extrudate is defined as the length (cm) of the extrudate per unit mass (g). The bulk density of the extrudates was calculated as (Mason Hoseney, 1986):

$$\rho = 4w \big/ [\pi d^2 \times L]$$

where $\rho$ = bulk density (g/cm$^3$), d = diameter of extrudate (cm), L= length of extrudate (cm) and w = weight of extrudate (g).

**Extrudate hardness**

Sample of extrudates, short cylinders of 1cm length were individually placed on the sample platform of a hardness tester (KIYA 174886, Seisakusho Ltd., Tokyo, Japan) and compressed radialy with a flat die of 4 mm diameter. The breaking strength in kg of each extrudate was recorded and the average of 10 samples was used for calculation. Moisture content of samples was determined following AOAC (1995) method 925-09.

**Water absorbing and water solubility indices**

Water absorption index of the flour and extruded product were determined according to Anderson et al. (1969). Sample (about 1.25 g) was placed in about 20 mL centrifuge tube and suspended in 15 mL distilled water. The sample was incubated into shaking water bath at about 25°C for 30 minutes and was centrifuged at 3000 g for 5 minutes. Mass of the sample was determined before and after decantation of the clear supernatant of centrifugation. The WAI was calculated as grams of adsorbed water per gram of dry sample mass (1.25 g). The clear supernatant of the centrifugation was transferred into pre-dried (105°C) and weighed glass beaker (about 50 mL) for the estimation of the water solubility index (WSI). The supernatant preserved from WAI measurement was evaporated at 105°C for overnight. The WSI was calculated as a ratio of dry residue to the original mass (about 1.25 g) used to estimate WAI. The result was expressed as percentage.

**Sensory analysis**

A 26 member judges (15 males and 11 females) selected from Melkassa Agricultural Research Center staff members assessed the sensory qualities of extruded products. In order to reduce the number of samples to be provided to the judges, a preliminary product selection was performed. Out of 36 products obtained from two tef varieties and 18 processing conditions, 12 products were pre selected for sensory evaluation and selection results were given as acceptable/not acceptable. Selection was made on the basis of bulk density, extrudate hardness and overall product appearance. The sensory attributes: visual color, texture (crispiness/hardness) flavor and overall acceptability were evaluated using a nine point hedonic scale rated from 1(extremely dislike), 5 (neither like nor dislike) to 9 (extremely like). Coded product samples, about 8 to 10 cm lengths, from each selected product were arranged in a random order on white plates and served to the sensory judges. The test was conducted for three days in 7 panel sessions each consisting of four judges. Just before each test session, orientation was given to the judges on the procedure of sensory evaluation.

## RESULTS AND DISCUSSION

**Composition of tef flour**

The chemical composition of the two tef cultivars used in the study is presented in Table 1. The DZ-01-196 cultivar has a slightly higher protein content compared with DZ-01-99. Both cultivars exhibited comparable ash and crude fat content. Crude protein content for both cultivars was close to those reported in previous study (Fufa, 1998). Compared to other cereals, tef has higher protein content than maize (8.3%), sorghum (7.1%), barley (9.0%), millet (7.2%) and almost equivalent to wheat (10.3%) (Asrat and Frew, 2001). The fat content appeared to be lower than maize (4.6%) but higher than wheat, barley and millet and equivalent to sorghum (2.8%) whereas the ash content is lower than millet and higher than others (Asrat and Frew, 2001). The amylose to amylopectine ratio is a genetic characteristic. Tef starch was found to have amylose content of 28.8 and 28.6 % for the white and red varieties, respectively (Bultosa *et al*., 2002) indicating normal starch composition. In extrusion of cereal flour and starch-based products, the qualities of the raw material such as the composition of starch, protein, lipid and fiber dictate product quality attributes, among others the expansion and the functional properties (Mercier and Feillet, 1975; Chinnaswamy and Hanna, 1988).

**Water absorption and water solubility indices**

Gelatinization, which leads to transformation of raw starches to a cooked digestible material, is one of the important effects that extrusion has on starch component of foods. As extruded product characteristics, WAI and WSI are very important parameters in representing the degree of gelatinization (cooking). The WAI and WSI of extrudates from both cultivars significantly ($p<0.05$) affected by barrel temperature, feed moisture content and screw speed (Table 3). Extrudates from red tef generally absorbed water over five times their weight and 4 to 5 times in the case of white tef. As barrel temperature increased in the temperature range of 110 to 130°C, WAI of extrudates from red tef showed initial increase from 5.29 to 5.76 then fall to 5.25 with increased barrel temperature to 150 °C. For white tef extrudates WAI increased consistently with the increase in temperature within the investigated range. Initial increase and subsequent decrease in WAI were also reported for maize grits (Oellet *et al.*, 1990). The initial increase in WAI was attributed to higher proportion of gelatinized starch granules and maximum WAI indicated complete gelatinization and the subsequent decrease is due to further macromolecular degradation, which increases the solubility of starch. Absence of maximum and subsequent decrease in WAI in white tef extrudates could be due to incomplete gelatinization in the range of operating conditions used and hence it might require additional thermal energy or mechanical shear by increasing barrel temperature, reducing feed moisture or increased screw speed.

Water solubility index of extrudates from both tef varieties were dependent on barrel temperature and feed moisture content. WSI increased significantly ($p<0.05$) from 0.024 to 0.028 and 0.026 to 0.033 for white and red tef extrudates, respectively as barrel temperature increased from 110 to 150°C. However, WSI increased from 0.0238 to 0.0279 for white tef and 0.023 to 0.0316 for red tef as the moisture content reduced from 26 to 17%. These trends were consistent with the results reported for millet and cowpea (Almeida *et al.*, 1993), flint and sweet corn grit (Gujeral *et al.*, 2001), rice based extrudates (Ding *et al.*, 2005) and wheat based extrudates (Ding *et al.*, 2006). Changes in WSI as screw speed increased from 100 to 140 rpm were not statistically significant ($p>0.05$). Probably the narrow range between the two screw speed levels was not big enough so as to bring substantial difference in the WSI. Increased WAI with increase in screw speed were reported in previous studies (Lo *et al.*, 1998; Gujeral *et al.*, 2001; Mezreb *et al.*, 2003). The water solubility index indicates the extent of molecular degradation (Ollet *et al.*, 1990). The increase in WSI therefore shows macromolecular degradation with the intensity of extrusion condition. Large amount of soluble materials are released at high extrusion temperature, high screw speed and low feed moisture content. Increased screw speed induces a sharp increase of mechanical energy resulting in a harsh mechanical disruption of starch molecules (Lo *et al.*, 1998).

**Table 1.** Chemical composition of tef flour used in extrusion experiments

| Component | *g/100 g | |
|---|---|---|
| | Red tef | White tef |
| Moisture (%db) | 12.57 ± 0.43 | 12.11± 0.12 |
| Crude protein (N×6.25) | 10.69 ± 0.19 | 11.36 ± 0.49 |
| Crude fat (%db) | 2.5 ± 0.64 | 2.84 ± 0.35 |
| Ash (%) | 2.52 ± 0.12 | 2.49 ± 0.29 |

* mean ± SD, n = 3

**Radial expansion and specific length**

The radial expansion of extruded products from red and white tef flour were significantly ($p < 0.05$) affected by the combination of feed moisture content, barrel temperature, and screw speed (Table 2). Samples extruded at 130 °C barrel temperature at 17% feed moisture content and at 100 rpm screw speed (treatment 12) had the greatest radial expansion ratio of 2.44 and 2.14 for red and white tef respectively, compared to the rest of the conditions. Extrusion using high barrel temperature (150 °C) at the same feed moisture and screw speed levels resulted in extrudates with significantly higher ($p < 0.05$) expansion ratio as compared to those processed at barrel temperatures of 130 and 110 °C. Low feed moisture at the same barrel temperature and screw speed also showed a significantly higher ($p < 0.01$) radial expansion of extrudates for both types of tef flours (Table 2). Previous studies also reported increased radial expansion with increased barrel temperature and reduced feed moisture content for corn grits and corn starch (Mercier and Feillet, 1975), rice flour (Ding *et al.*, 2005), wheat flour (Ding *et al.*, 2006) and cassava (Chang and Ei-Dash, 2003). As the barrel temperature increased the viscosity of the feed material decreased resulting in better expansion (Mercier and Feillet, 1975; Lo, *et al.*, 1998; Ding *et al.*, 2005).

**Table 2.** Main effect of extrusion variables on WAI and WSI of tef extrudates

| Variable | n | *Red tef | | *White tef | |
|---|---|---|---|---|---|
| | | WAI(g/g) | WSI(g/100g) | WAI(g/g) | WSI(g/100g) |
| BT (°C) | | | | | |
| 110 | 18 | 5.295 b | 0.026 c | 4.349 c | 0.024 b |
| 130 | 18 | 5.762 a | 0.029 b | 4.919 b | 0.026 b |
| 150 | 18 | 5.258 b | 0.033 a | 5.258 a | 0.028 a |
| $SNK_{0.05}$ | 2(3) | 0.245(0.29) | 0.0023 | 0.18(0.22) | 0.002 |
| $MC_f$ (%wwb) | | | | | |
| 17 | 18 | 5.145 b | 0.0316 a | 4.553 c | 0.0279 a |
| 21 | 18 | 5.388 a | 0.0298 a | 4.798 b | 0.0263 a |
| 26 | 18 | 5.573 a | 0.0266 b | 5.175 a | 0.0238 b |
| $SNK_{0.05}$ | 2(3) | 0.245(0.29) | 0.002 | 0.18(0.22) | 0.0022 |
| SS (rpm) | | | | | |
| 100 | 27 | 5.268 b | 0.0295 a | 4.668 b | 0.0261 a |
| 140 | 27 | 5.469 a | 0.0291 a | 5.016 a | 0.0261 a |
| $SNK_{0.05}$ | 2 | 0.2 | 0.0019 | 0.154 | 0.0018 |
| Mean | 54 | 5.37 | 0.029 | 4.84 | 0.0261 |
| CV | | 6.75 | 11.66 | 5.75 | 12.34 |

Values followed by the different letters with in a column indicate significant difference BT = barrel temperature (°C); $MC_f$ = feed moisture content (%); SS = screw speed (rpm) ($p<0.05$), * mean; n = number of observations; SNK = Student Newman Keuls

High moisture content reduces the melt viscosity, providing less resistance for the extruder screw rotation thus decreasing the torque and the die pressure (Li *et al.*, 2004). For most treatments an increase in screw speed from 100 to 140 rpm significantly ($p < 0.05$) increased the radial expansion. Similar results were observed in extruding corn starch (Chinnaswamy and Hanna, 1990), corn grits (Gujral *et al.*, 2001) and wheat and corn (Mezreb *et al.*, 2003) which could be attributed to increased specific mechanical energy

(SME), decreased apparent viscosity and more even distribution of moisture at higher screw speed conditions. In contrast to this finding increasing screw speed increased axial expansion at the expense of radial puffing, which is attributed to less resistance at the die due to lower die pressure observed at high screw speed (Lo *et al*., 1998). A radial expansion of 1.79 to 3.75 were reported for maize grits extruded by twin screw extruder operated under feed moisture content of 13 to 17%, product temperature 150 to 160 °C, and material feed rate of 47 to 60 kg/hr (Ilo *et al*., 1996).

The radial expansion of tef extruded at barrel temperature of 130 to 150°C (with the exception at 26 % feed moisture for 140 and 100 rpm screw speed for red and white tef, respectively) fall within the range reported above for maize grits but close to the lower margin. Specific length (cm/g) of extruded product measures the axial expansion of the extrudate and related to the expansion volume. Extruding when barrel temperature was 110 and 150 °C at 26 % feed moisture and 100 rpm screw speed resulted in products with a higher specific length than the rest of the conditions. Using barrel temperature of 130 °C at 17 % feed moisture and 140 rpm screw speed showed a lower specific length but favored radial expansion at the expense of axial expansion (Table 2). The higher specific length of extrudates at 110 °C barrel temperature and 100 rpm screw speed (treatment 1 and 3) appeared with minimum radial expansion. Extruding at 150 °C barrel temperature and 17% feed moisture showed a relatively higher radial as well as higher axial expansion, thus a maximum volumetric expansion. The more the extrudates expand in either the axial and radial direction, the less dense they become indicating a higher proportion of starch gelatinization (Hsieh *et al*., 1993). In general, when barrel temperature was 110 °C at feed moisture content of 26 to 21%, an increase in screw speed from 100 to 140 rpm significantly ($p < 0.05$) reduced the specific length but not for higher extrusion temperatures and lower feed moisture contents.

**Fresh extrudate moisture content**

The moisture content of fresh extrudate was significantly affected ($p<0.05$) by feed moisture content followed by barrel temperature whereas screw speed has no a significant effect. The mean extrudate moisture content was less than the feed moisture content for both cultivars under all processing conditions only in the order of 2-3%. This agrees with the findings of Camire *et al*. (1991) who reported the influence of moisture content of the material before extrusion depends on the moisture content of the extruded samples from mixtures of corn meal and glandless cotton seed. This could be due to insufficient vaporization occurring at high moisture (Harris *et al*., 1988). Extrusion at 150°C barrel temperature gave extruded products, which showed higher expansion and retained the lowest moisture after puffing for the same feed moisture content. Similar results were reported in extruding wheat flour (Andersson and Hedlund, 1991). High moisture contents were associated with less expanded extrudates and required additional energy input to remove the water (Camire, *et al*., 1991).

**Bulk density**

Bulk density was significantly ($p<0.05$) influenced by extrusion variables used and their interaction. The results in Table 2 indicate that barrel temperature exhibited a predominant effect followed by feed moisture in reducing the bulk density evidenced by about 50% and 30% relative decrease respectively in bulk density for the same other two variables. However, screw speed appeared to have slight effect on the bulk density. Tef flour extruded at barrel temperature of 150 °C, 17% feed moisture were significantly ($p<0.05$) less dense than extruded under the rest of the conditions. Density was reported to decrease with the increase in the extrusion temperature due to starch gelatinization (Mercier and Fiellet, 1975; Sacchetti *et al.*, 2004). Increased gelatinization increases the volume of extruded product, consequently bulk density decreases as observed in this work. At high temperature the vapor pressure of the free moisture is also greater which would cause an increased rate of moisture flashing and puffing up on exit from the die (Harris, *et al*., 1988). This could result in a decreased bulk density as well.

The bulk density values of tef flour are not as low as those of highly expanded cereal extrudates, for which the low moisture and high barrel temperature extrusion conditions lead to high mechanical energy dissipation and consequently high expansion. The lowest bulk density in this work was 482 $kg/m^3$ (treatment 17) and 516 $kg/m^3$ (treatment 18) for white and red tef extrudates, respectively. A bulk density of 90 to 320 $kg/m^3$ were recorded for maize grits extruded by twin screw extruder operated at a feed moisture content ranging from 13 to 17% (wwb), product temperature from 150 to 160°C and feed rate from 47 to 60 kg/hr (Ilo *et al*., 1996). Commercial corn products generally have a bulk density between 50 and 300 $kg/m^3$ (Harper, 1981). Extruded mixtures of corn meal and glandless cottonseeds showed a bulk density of 28.5-108.9 $kg/m^3$ (Camire *et al*., 1991). The high bulk density for tef extrudate could be due to the relatively high moisture content observed in sample products and a lower expansion due to the relatively higher levels of fiber and protein contents.

**Hardness**

The force required to compress a food material indicates the relative softness or hardness to fracture and related to the crispness and crunchiness human perception. The interaction effects of processing conditions on the hardness of tef extrudate are shown in Table 2. For similar moisture content and screw speed levels, high barrel temperature resulted in a significantly reduced hardness ($p<0.05$) of the extruded products from both tef varieties. Extrudates processed at 110°C showed very much limited expansion causing its hardness to exceed the measuring range of the hardness tester. The increased expansion characteristics at higher barrel temperature might be due to consistent decrease in density of extrudates. Similar trends with increased temperature were reported for corn meal (Mercier and Fiellet, 1975; Lo *et al*., 1998). A decreased breaking strength of extrudates was also associated with high expansion index and low bulk density (Gambush *et al*., 1999). Feed moisture content also significantly ($p<0.05$) affected the hardness of the final product. In general, an increase in barrel temperature from 110 to 150°C and decrease in feed moisture content from 26 to 17 % at 140 rpm screw speed decreased compression force from over 200 to 64.16 N and to 60.83 N for white and red tef extrudates, respectively (Table 2). Gambush *et al*. (1999) reported extrudate hardness of 51.2 and 93.5 N for corn, 35.7 and 90.11 N for wheat and 150 N and above for potato starch extruded at 16 and 25% feed moistures, respectively, which is comparable to the hardness of tef flour extruded at 150 and 130°C.

**Sensory evaluation of extruded tef flour**

The mean sensory scores for these products are summarized in Table 4. The sensory scores for color, flavor, and texture indicate that all products have a mean value greater than 5, indicating that the products are well liked by the judges. Scores for color, texture and overall acceptance revealed that significant ($p<0.05$) differences exist between the products. All products processed at barrel temperature of 130°C had a relatively lower overall acceptance score compared to those extruded at 150°C barrel temperature. Flavor score for the products was not significantly ($p>0.05$) different. Clear differences in color were detected between the products from the two varieties with a highest score for white tef. Extrudates processed at 130°C from white tef scored the maximum for color. Processing conditions of 150°C and 17% moisture content showed highest score in texture while extrudates processed at 130°C from both cultivars obtained the least score. Texture scores were corresponding to the increase in compression force and bulk density shown in Table 2 where the increased barrel temperature and decreased feed moisture were found to promote lower bulk density and minimum compression force.

**Table 3.** Effect of combinations of operating conditions on extrudate quality attributes

| Processing condition | | | | *Red tef extrudate | | | | *White tef extrudate | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tt** | **BT** | $MC_f$ | SS | RE | SL | BD | H | RE | SL | BD | H |
| 1 | 110 | 26 | 100 | 1.23 l | 3.05 dc | 1.725 a | >200 | 1.14 l | 3.84 a | 1.59 b | >200 |
| 2 | 110 | 26 | 140 | 1.31 k | 2.65 gh | 1.740 a | >200 | 1.30 j | 2.79 h | 1.69 a | >200 |
| 3 | 110 | 21 | 100 | 1.30 k | 3.16 bc | 1.47 b | >200 | 1.21 k | 3.82 a | 1.43 c | >200 |
| 4 | 110 | 21 | 140 | 1.39j | 2.75 fgh | 1.49 b | >200 | 1.44 i | 3.58 b | 1.32 d | >200 |
| 5 | 110 | 17 | 100 | 1.43 j | 3.00 cde | 1.29 d | >200 | 1.34 j | 3.36 bcd | 1.07 f | >200 |
| 6 | 110 | 17 | 140 | 1.51 i | 2.51 h | 1.38 c | >200 | 1.61 g | 3.08 defg | 1.00 g | >200 |
| 7 | 130 | 26 | 100 | 1.55 i | 2.68 fgh | 1.24 c | 114.5 a | 1.55 h | 2.92 fgh | 1.13 e | 140.67 a |
| 8 | 130 | 26 | 140 | 2.01 g | 2.28 i | 0.86 e | 90.33 ab | 1.77 e | 3.18 ed | 0.80 h | 118.16 b |
| 9 | 130 | 21 | 100 | 2.07 efg | 2.16 i | 0.86 e | 92.16 ab | 1.86 d | 3.05efgh | 0.75 hi | 115.16 b |
| 10 | 130 | 21 | 140 | 2.03 gf | 2.78 fg | 0.69 f | 88.33 b | 1.96 c | 2.85 gh | 0.73 i | 106.16bc |
| 11 | 130 | 17 | 100 | 2.10 ef | 2.62 gh | 0.68 f | 95.0 ab | 2.04 b | 3.09defg | 0.62 j | 97.16 bcd |
| 12 | 130 | 17 | 140 | 2.44 a | 2.17 i | 0.61 f | 91.16 ab | 2.14 a | 2.83 gh | 0.61 j | 81.83 cde |
| 13 | 150 | 26 | 100 | 2.07 efg | 2.58 gh | 0.72 f | 92.50 ab | 1.70 f | 3.46 bc | 0.79 h | 85.15 cde |
| 14 | 150 | 26 | 140 | 1.68 h | 3.53 a | 0.79 e | 96.66 ab | 1.76 e | 3.51 bc | 0.73 i | 77.0 de |
| 15 | 150 | 21 | 100 | 2.12 de | 2.82 fge | 0.62 f | 85.33 cb | 2.01 b | 3.27 cde | 0.60 j | 84.0 cde |
| 16 | 150 | 21 | 140 | 2.18 d | 2.62 gh | 0.64 f | 85.0 cb | 2.03 b | 2.99 fgh | 0.64 j | 72.16 ed |
| 17 | 150 | 17 | 100 | 2.24 c | 3.29 b | 0.48 g | 67.83 dc | 2.01 b | 3.28 cde | 0.59 j | 65.30 e |
| 18 | 150 | 17 | 140 | 2.35 b | 2.91 fde | 0.49 g | 60.83 d | 2.11 a | 3.29 cde | 0.54 k | 64.16 e |

* Mean of three replications; Values followed by the different letters with in a column indicate significant difference ($p<0.05$); Tt = treatment number; BT = barrel temperature (°C); $MC_f$ = feed moisture content (%); SS = screw speed (rpm); RE = radial expansion, SL = specific length (cm/g), BD = bulk density ($g/cm^3$) and H = hardness (N)

**Table 4.** Sensory evaluation of extruded tef flour products

| Processing condition | | | Cultivars | *Panelist mean score | | | |
|---|---|---|---|---|---|---|---|
| BT | $MC_f$ | SS | | Color | Flavor | Texture | Overall |
| 130 | 17 | 100 | 26 red | 5.65 ± 1.54c | 6.15 ± 1.31a | 5.35 ± 1.25b | 4.81ab |
| 130 | 17 | 140 | 26 red | 5.96 ± 1.26bc | 6.69 ± 1.87a | 5.46 ± 1.4 9b | 6.65a |
| 150 | 17 | 100 | 26 red | 6.16 ± 2.33abc | 7.11 ± 2.36a | 6.08 ± 1.72ab | 7.08a |
| 150 | 17 | 140 | 26 red | 5.38 ± 1.43c | 7.03 ± 1.45a | 6.00 ± 1.71ab | 6.50ab |
| 150 | 21 | 100 | 26 red | 5.23 ± 1.70c | 6.57 ± 1.57a | 6.00 ± 1.19ab | 5.42cd |
| 150 | 21 | 140 | 26 red | 5.36 ± 2.42c | 6.76 ± 2.11a | 6.00 ± 1.72ab | 5.64bc |
| 130 | 17 | 100 | 26 white | 7.07 ± 0.96ab | 6.07 ± 0.05a | 5.62 ± 1.44b | 5.65cb |
| 130 | 17 | 140 | 26 white | 6.29 ± 0.94abc | 6.16 ± 0.09a | 5.25 ± 1.27b | 4.60d |
| 150 | 17 | 100 | 26 white | 7.48 ± 0.92a | 7.24 ± 0.18a | 5.96 ± 1.76ab | 7.28a |
| 150 | 17 | 140 | 26 white | 6.30 ± 2.41abc | 6.76 ± 1.39a | 6.96 ± 1.75a | 7.08a |
| 150 | 21 | 100 | 26 white | 7.53 ± 1.44a | 6.65 ± 1.60a | 6.00 ± 1.36ab | 6.88a |
| 150 | 21 | 140 | 26 white | 7.52 ± 2.42a | 6.68 ± 1.82a | 6.00 ± 1.39ab | 6.92a |
| $SNK_{0.05}$ | | | | 0.96-1.6 | 0.77-1.29 | 0.88-1.48 | 0.72-1.21 |
| CV% | | | | 27.4 | 20.95 | 27.18 | 21.1 |

SNK = Student Newman Keuls; Values followed by different letters with in a column indicate significant difference ($p<0.05$). * = Mean ± SD, n = number of judges, BT = barrel temperature (°C), $MC_f$ = feed moisture content (wwb %), SS = screw speed (rpm)

## CONCLUSION

Under the conditions studied extrusion at 150°C barrel temperature, 17 % feed moisture content and 140 rpm screw speed produced a better quality extruded product with 2.11 and 2.35 radial expansion, 0.54 and 0.48 g/cm$^3$ bulk density, 64.16 and 60.83 N hardness (compression resistance) respectively, for white and red tef varieties. With 110°C barrel temperature extruded products were less puffed, more dense, very hard and had uncooked pasta like appearance with high moisture content after puffing. Similarly the functional properties like WAI and WSI appeared to attain the characteristics of a typical gelatinized product at increased barrel temperature and decreased feed moisture content. The extrudates exhibited higher water solubility and water absorbing index as compared to raw tef flour and those processed at mild conditions. Most product quality attributes were less influenced by screw speed variation as compared to barrel temperature and feed moisture. Generally high screw speed favored radial expansion, low bulk density, low hardness and increased gelatinization characteristics for some extrusion conditions. The three extrusion variables namely barrel temperature, feed moisture content and screw speed induced significant changes in the product quality attributes evaluated. This study represents the first investigation using tef flour to determine some physichochemical changes in relation to extrusion operating conditions and therefore ascertained the potential of tef for producing extrusion cooked food products. Promising results were obtained for tef-based product development and process optimization studies.

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