Effects of Sorghum Cultivar on Injera Quality

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ABSTRACT

Cereal Chem. 81(3):314–321

Injera is an Ethiopian flat bread made from cereals, with tef preferred for the best quality *injera.* Because sorghum is less expensive in Ethiopia, there is great interest in improving the quality of sorghum *injera*. Effects of cultivar on *injera* quality were studied using 12 Ethiopian sorghum cultivars of varying kernel characteristics. White tef with good *injera* making quality was included as a reference. *Injera* quality was evaluated using two techniques: descriptive sensory analysis of fresh *injera* and instrumental texture analysis of *injera* stored over a storage period of 48 hr using a three-point bending rig. Principal component analysis (PCA) of sensory data associated fresh *injera* from sorghum cultivars 3443-2-op, 76TI #23, and PGRC/E #69349 of varying endosperm texture, with positive *injera* texture attributes of softness, rollability, and fluffiness. Across the two seasons, texture analysis showed *injera* prepared from AW and CR:35:5, both with soft endosperm, required the least force to bend after 48 hr of storage. Bending force was negatively correlated with softness ($r = -0.63$, $P < 0.05$) and positively with grittiness ($r = 0.75$, $P < 0.01$) after 48 hr of storage. Sorghum cultivar has an influence on both *injera* making and keeping qualities.

Injera is a leavened, flat round Ethiopian traditional bread made from cereals such as tef and sorghum (Gebrekidan and GebreHiwot 1982). Its surface has essentially evenly spaced gas holes, that make up a honeycomb-like structure formed due to the production of gas during fermentation and baking. The bottom surface of *injera* is smooth and shiny. A good *injera* is soft, fluffy and able to be rolled without cracking. It should retain these textural properties after two to three days of storage, which is traditionally done in a straw basket. A slight sourness is a characteristic taste of *injera.* Because *injera* is a leavened bread made from nongluten containing flour, it has great potential for commercial production internationally.

Injera prepared from flour of tef [*Eragrostis tef* (Zucc.) Trotter], a tiny, millet like grain, is the most preferred. The annual production of tef in Ethiopia is about 1.32 million metric tons (Central Statistical Authority 1998). Of note is the fact that tef commands a higher market price than other cereals in Ethiopia (Seyfu 1993). Sorghum (*Sorghum bicolor* (L.) Moench) is the second most preferred cereal for injera preparation in Ethiopia (Gebrekidan and GebreHiwot 1982) with an annual grain production of 1.34 million metric tons (FAO 2001). Preparing *injera* from sorghum has considerable economic benefits over tef, as sorghum commands a much lower price. However, the problem is that sorghum *injera* rapidly becomes firm and friable upon storage.

Gebrekidan and GebreHiwot (1982) reported that sorghum cultivar differences existed for *injera* making quality and staling. Yetneberk and Adnew (1985) developed a standard procedure for sorghum *injera* preparation and used it to evaluate the *injera* making qualities of different sorghum cultivars obtained from the Ethiopian Sorghum Improvement Program. They confirmed the existence of sorghum cultivar differences for *injera* making quality. It has also been found that the use of composite flour of sorghum and tef improved *injera* texture compared with 100% sorghum (Gebrekidan and GebreHiwot 1982; Yetneberk and Haile 1992). Zegeye (1997) conducted a consumer preference sensory test of *injera* from different cereals and reported that sorghum was accepted as a substitute for tef in *injera* preparation.

The above studies indicate that sorghum cultivar does have an influence on *injera* making and keeping qualities. Thus sorghum cultivars with improved *injera* making quality could probably be selected on the basis of positive *injera* quality attributes. However, previous researchers (Gebrekidan and GebreHiwot 1982; Yetneberk and Haile 1992; Zegeye 1997) used consumer sensory methods to evaluate sorghum *injera* making qualities. The use of descriptive sensory analysis and instrumental textural analysis to quantitatively evaluate *injera* quality has not been reported. Descriptive sensory analysis detects, identifies, describes, and quantifies attribute differences between products and gives information on how raw material and process variables affect sensory characteristics (Stone and Sidel 1985).

The objective of the present study was to determine the influence of sorghum cultivar on *injera* making and keeping quality using descriptive sensory analysis and texture analysis with a view to objectively evaluate sorghum cultivars for selection in sorghum breeding. A wide range of Ethiopian lowland sorghums was used and compared with a white tef cultivar of known good *injera* making quality.

MATERIALS AND METHODS

Materials

Twelve sorghum cultivars (IS-777, A ligider Wodifereja [AW], PGRC/E #69441, Seredo, CR:35:5, 3443-2-op, SK-82-022, 76TI #23, Gambella 1107, PGRC/E #69349, [(SC-423xCS-3541)-2-1xRS/R-20-8614-2] [SC-423], [(SC-108-3xCS-3541)-19-1xRS/R-20-8614-2)] [SC-108]) grown in both the 1999 and 2000 crop years at the Melkassa Agricultural Research Center, Nazareth, Ethiopia, were used.

These cultivars had different endosperm texture and pericarp color. Seven were white tannin-free, one red tannin-free, and four tannin types as indicated by presence of pigmented testa in the latter (Table I). The cultivars are adapted for cultivation in the lowland (high temperature, erratic rainfall) areas of Ethiopia. A white tef cultivar DZ-01-196 with excellent *injera* making quality, grown in 1999 and 2000 at the Debre Zeit Research Center, Ethiopia, was included for comparison. All sorghum grains were decorticated to ≈80% extraction rate using an abrasive rice pearler (Miag, Braunschweig, Germany) milled to flour using a hammer mill (3100, Falling Number, Huddinge, Sweden) fitted with a 500-μm screen. Tef was not dehulled before milling.

Kernel Characterization

Sorghum grains were characterized visually for pericarp and endosperm color by comparing with color plates (Rooney and Miller 1982). Glume color was determined by examining the inside of the glume after removing the kernel as described by Rooney and Miller (1982). Pericarp thickness was subjectively rated as thin, intermediate, and thick by scraping through the pericarp with

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Publication no. C-2004-0310-03R.

a sharp razor blade. Endosperm texture, the relative proportion of vitreous to floury endosperm, was determined by cutting 10 kernels in halves longitudinally and evaluating using a rating scale of 1 (vitreous) to 5 (floury) as described by Rooney and Miller (1982). Grain hardness was measured by using a tangential abrasive dehulling device (TADD) according to Reichert et al (1982), with extraction rate calculated as percent weight recovered (high recovery indicates harder grain) after abrasion of 20 g of grain for 2 min using 60-grit sandpaper (Norton type R284 metalite). The presence of a pigmented testa was determined using the Chlorox bleach test method described by Waniska et al (1992).

Injera Preparation

The flow diagram of the standardized *injera* making procedure is presented in Fig. 1. The procedure involved milling decorticated sorghum or whole tef grain into a flour, preparation of a dough, and fermentation of the dough after adding starter culture (a batter from a previous batch) and fermenting at room temperature for ≈48 hr. The organisms involved in tef dough fermentation are reported to be gram negative rods, lactic acid bacteria, and yeasts growing in succession (Gashe et al 1982). After fermentation, ≈25% of the fermented dough was thinned with 30 mL of water and cooked in 200 mL of boiling water for 1 min. The objective of gelatinization (cooking) was primarily to bring about cohesiveness of the dough and secondly to provide easily fermentable carbohydrate to leaven the *injera*. The gelatinized batter was cooled to ≈45°C at room temperature and added back to the fermenting dough. After thorough mixing, 100 mL of water was added and the batter was fermented at room temperature for 2–3 hr. Additional water (20 mL) was added to fermented tef dough to bring to batter consistency. Adding back the warm gelatinized starch into the fermented dough promotes the growth of mesophilic microorganisms by raising the fermentation temperature to ≈30°C. About 500 g of the fermented batter was poured in a circular manner on a 50-cm diameter hot clay griddle, covered, and baked for ≈2 min.

Descriptive Sensory Analysis

A panel was trained based on the method described by Einstein (1991). The selected panelists were tested for their ability to detect sweet, sour, bitter, and salty tastes (Jellinek 1985). The selected panel consisted of 10 people as recommended by Stone and Sidel (1985). They were female and male, aged between 20 and 35 years, who work at Melkassa Agricultural Research Center.

Nineteen *injera* quality descriptors were generated and selected by the trained panel: whiteness of top surface, whiteness of bottom surface, redness of top surface, redness of bottom surface, shininess of top surface, eye size, eye evenness and distribution, *injera* softness, stickiness, fluffiness, rollability, grittiness in the mouth, sourness, sweetness, bitterness, sour aftertaste, sweet aftertaste, and bitter aftertaste. A score sheet was prepared using the selected descriptors. Each attribute was evaluated using a 10-point numerical

TABLE I
Pericarp and Glume Color, Pericarp Thickness, Endosperm Color, Pigmented Testa, Endosperm Texture, and Hardness of Sorghums and a Tef Cultivar Grown for Two Seasons

Growing Season and	Sorghum Cultivars						
Physical Variable	IS-777	AW	PGRC/E #69441	Seredo	CR:35:5	3443-2-op	SK-82-022
Both seasons							
Pricarp color	Red	Red	Red	Light red	White	White	White
Glume color	Purple	Purple	Purple	Purple	Tan	Tan	Purple
Pericarp thickness	Thick	Thick	Thick	Thick	Thick	Intermediate	Thick
Endosperm color	White	White	White	White	White	White	White
Pigmented testa[a]	Yes	No	Yes	Yes	Yes	No	No
1999							
Endosperm texture[b]	3	5	3	4	4	3	3
Hardness (%)	71.2cd (2.9)[c]	56.5a (1.0)	76.8d–f (2.8)	66bc (4.9)	62.2ab (4.4)	71.7cd (7.0)	80.3fg (2.4)
2000							
Endosperm texture	4	4	3	4	4	3	3
Hardness (%)	73.6bc (3.0)	76.2 b–d(5.1)	83gh (4.8)	67.1a (2.0)	72.0ab (2.2)	78.2e–g (3.6)	80fg (4.5)

[a] Yes = pigmented testa present, No = pigmented testa absent.
[b] Subjectively rated on a scale of 1 to 5 (1 = vitreous, 5 = floury).
[c] Values followed by the same letter in the same row are not significantly different ($P < 0.05$). Values in parentheses are standard deviations of three replicates.

TABLE I (continued)
Pericarp and Glume Color, Pericarp Thickness, Endosperm Color, Pigmented Testa, Endosperm Texture, and Hardness of Sorghums and a Tef Cultivar Grown for Two Seasons

Growing Season and	Sorghum Cultivars					Tef
Physical Variable	76TI #23	Gambella 1107	PGRC/E #69349	SC-423	SC-108	DZ-01-196
Both seasons						
Pricarp color	White	White	White	White	White	White
Glume color	Tan	Tan	Tan	Tan	Tan	Tan
Pericarp thickness	Intermediate	Thick	Intermediate	Thin	Thin	V. thin
Endosperm color	White	White	White	White	White	nd[d]
Pigmented testa[a]	No	No	No	No	No	No
1999						
Endosperm texture[b]	3	3	2	4	2	nd
Hardness (%)	73.3de (3.5)[c]	73.5de (0.9)	78.8e–g (3.1)	63.8b (5.0)	84.5g (1.8)	nd
2000						
Endosperm texture	3	2	2	3	2	nd
Hardness (%)	73.3b–d (3.8)	87.2hi (2.3)	86.3hi (1.0)	83.3gh (1.6)	89.7i (0.6)	nd

[a] Yes = pigmented testa present, No = pigmented testa absent.
[b] Subjectively rated on a scale of 1 to 5 (1 = vitreous, 5 = floury).
[c] Values followed by the same letter in the same row are not significantly different ($P < 0.05$). Values in parentheses are standard deviations of three replicates.
[d] Not determined.

scale (0–9) anchored on both sides with verbal descriptions (i.e., 0 = not white, 9 = very white) to allow the panel to score the intensity on a framed common scale.

The actual product evaluations were performed following good sensory practices according to Lawless and Heymann (1999). Rolled pieces of *injera* (3 cm wide) were presented to the panelists on a tray at ambient temperature (≈25°C) within 2 hr after baking.

A glass of drinking water was provided to the panelists for rinsing between samples. A maximum of five *injera* samples were served at each session.

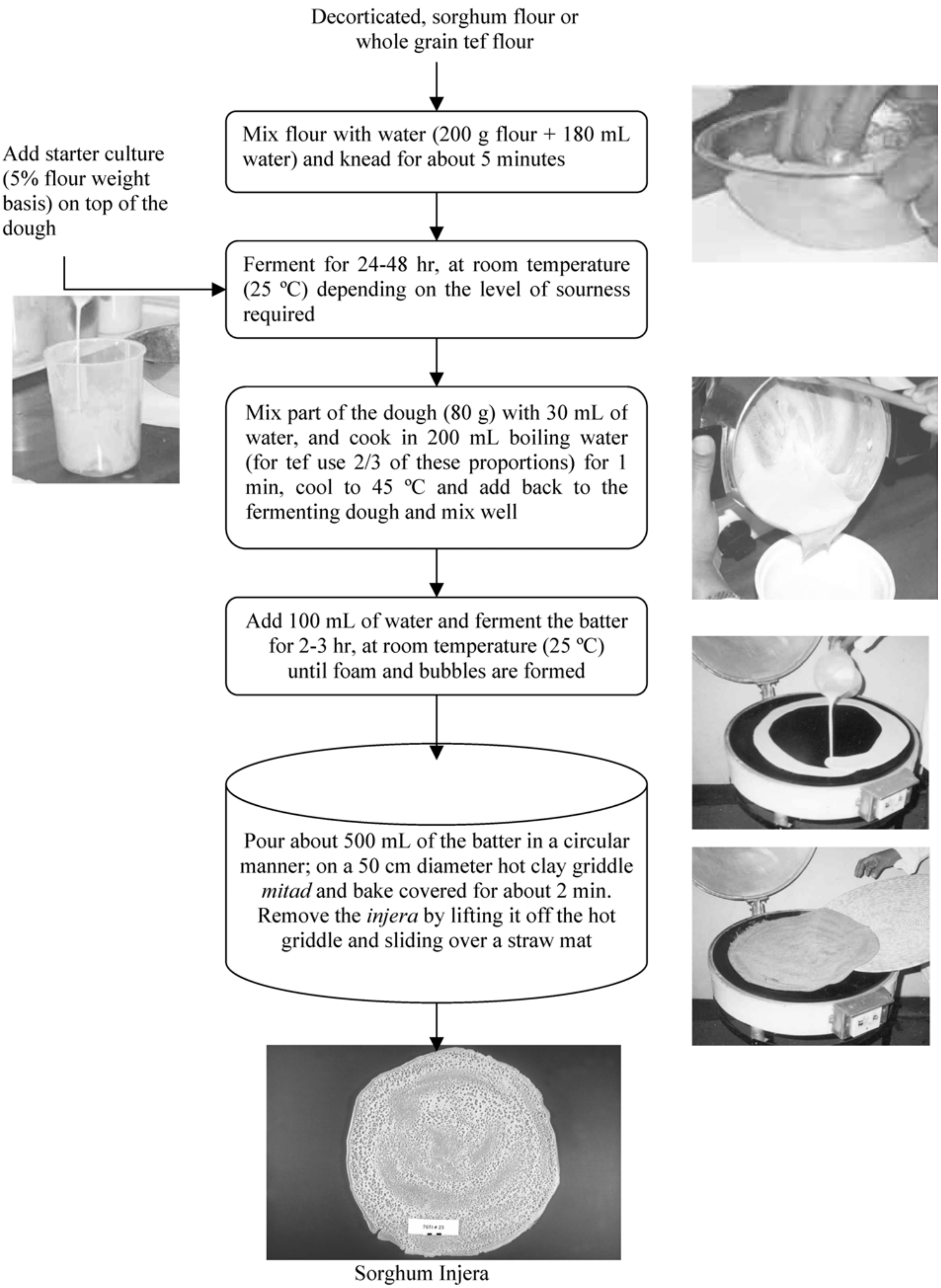

Fig. 1. Flow diagram of standardized *injera* making procedure.

Texture Analysis

Texture analysis of *injera* made from tef and cultivars of sorghum grown for two seasons was performed using a TA-XT2 texture analyser (Stable Microsystems, Godalming, UK). After baking, *injera* samples were allowed to cool for ≈30 min at room temperature (≈25°C). Each *injera* was cut into three equal-sized pieces. Each piece was placed in a separate polythene bag for 1, 24, and 48 hr of storage and the open end of each bag was folded. Bags were stored at room temperature in the dark. For texture analysis, *injera* samples were cut into strips of 9 cm × 4 cm. Five strips per treatment were measured for maximum bending force using a three-point bending rig attachment at a cross-speed of 0.4 mm/sec for a distance of 10 mm.

Data Analysis

The instrumental texture data were analysed using multifactor analysis of variance and multiple range analysis. Principal component analysis (PCA) of the sensory attributes was conducted using a covariance matrix with cultivar means in rows and attributes in columns.

RESULTS AND DISCUSSION

Kernel Characterization

Pericarp colors of the sorghum cultivars ranged from white to red (Table I) and were similar for both growing seasons, confirming that pericarp color is genetically controlled (Rooney and Miller 1982). Tef also varies in pericarp color from white to red (National Research Council 1996). White tef is, however, the most preferred grain for *injera* production. The glume color of the sorghum cultivars varied from tan to purple. Glume colors have the tendency to stain the sorghum kernel due to leaching of polyphenolic pigments into the pericarp (Rooney and Miller 1982), which might in turn affect the color of the food product. The pericarp thickness of the sorghum cultivars ranged from thin to thick; tef pericarp as observed by Parker et al (1989) was thin and membranous. In the eastern part of Ethiopia, sorghum consumers use traditional wooden mortar and pestle to remove the pericarp. An inverse relationship of pericarp thickness with the time required for mortar and pestle decortication was reported by Scheuring et al (1983). Because sorghum pericarp thickness affects milling property (Rooney and Miller 1982), cultivars with thicker pericarp are preferred for traditional mortar and pestle decortication. Endosperm color of all the sorghum cultivars was white.

Four sorghum cultivars, IS-777, PGRC/E #69441, Seredo, and CR:35:5, had a pigmented testa (Table I). The tef cultivar did not have a pigmented testa. The pigments responsible for testa color are polymeric polyphenols known as tannins (Butler 1990). Tannins cause dark color and astringent taste in foods prepared from whole sorghum (Earp et al 1983). Yetneberk and Haile (1992) also reported that *injera* prepared from whole sorghum with pigmented testa had red color, astringent taste, and poor eye quality, which made it unacceptable to consumers. However, decorticating the sorghum grain for 5 min with a TADD or compositing the flour with tef at a 1:1 ratio improved the *injera* quality.

Endosperm texture of two sorghum cultivars, PGRC/E #69349 and SC-108, was relatively vitreous, whereas AW, CR:35:5, and Seredo were essentially floury. The floury endosperm area has loosely packed endosperm cells (Rooney and Miller 1982). For the 1999 growing season, grain hardness expressed as extraction rate (%) varied from 56.5% (AW) to 84.5% (SC-108). For the 2000 growing season, grain hardness increased and varied from 67.1% (Seredo) to 89.7% (SC-108). It appears that cultivars with a high proportion of floury endosperm generally had a lower extraction rate compared with the cultivars with more vitreous endosperm. Lawton and Faubion (1989) also reported that sorghums with softer endosperm had higher rates of loss than did harder sorghums. Sorghum grain hardness is related to the distribution density of protein bodies and matrix in the endosperm (Shull et al 1990). Hard grains had higher milling yields after abrasive dehulling (Mwasaru et al 1988). For sorghum, decortication removes the pericarp and improves the color and quality of *injera* (Yetneberk and Haile 1992). SC-108, a more vitreous sorghum cultivar, had a high extraction rate (89.7%) after abrasive decortication. This suggests that vitreous sorghum cultivars are suitable for mechanical decortication. Because of its small size, tef grain does not lend itself to mechanical decortication and is not decorticated to make *injera.* Because tef *injera* is preferred, the bran of tef does not cause obvious acceptability problems.

PCA of Sensory Attributes

The product of a PCA is a data map illustrating the various relationships among multiple dependent variables and samples (Lawless and Heymann 1999). Principal components (PC) are orthogonal directions of maximum variance in the original data. The first two PC described 70% of the total variance in sensory attributes of *injera* made from sorghum and tef from the 1999 season (Fig. 2). The abscissa, which corresponds to PC1 (Destefanis et al

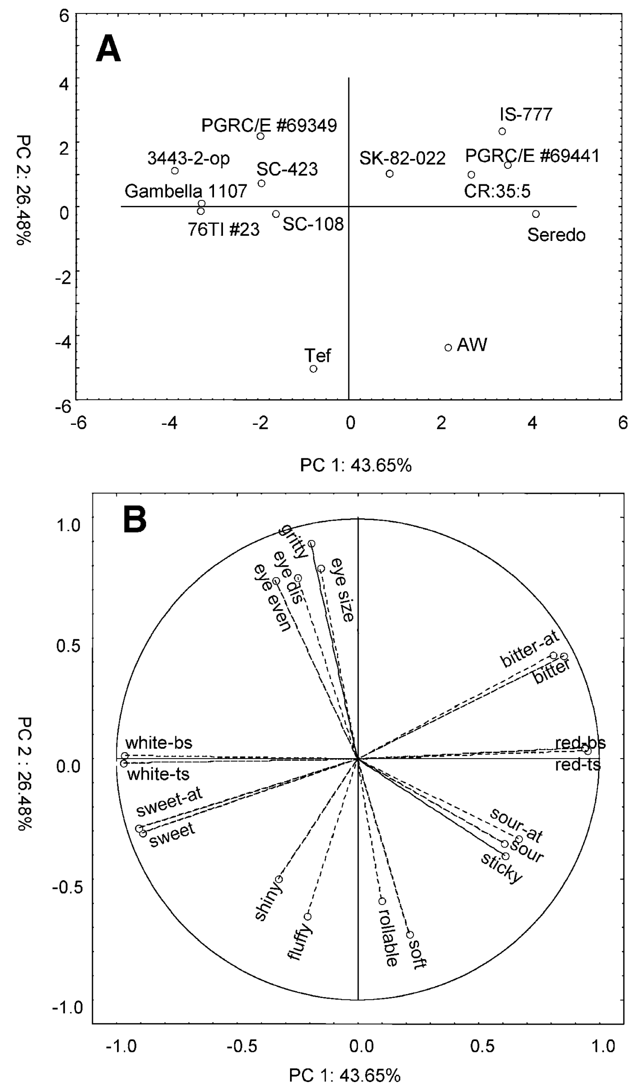

Fig. 2. Principal component analysis of *injera* from 12 sorghums and a tef cultivar grown in 1999. Plot of the first two principal component scores of the cultivars (**A**). Plot of the first two principal component loading vectors of sensory attributes (**B**). White-ts = whiteness of top surface; white-bs = whiteness of bottom surface; red-ts = redness of top surface; red-bs = redness of bottom surface; eye dis = eye distribution; eye even = eye evenness; sour-at = sour aftertaste; sweet-at = sweet aftertaste; bitter-at = bitter aftertaste.

2000), explained 44% of the total variance. Cultivars that were clustered together on the left were the white cultivars, PGRC/E #69349, 3443-2-op, SC-423, Gambella 1107, SC-108, and 76TI #23 (Fig. 2A). The attributes that described *injera* from these white pericarp sorghum cultivars were grittiness, even eye size and distribution, white top and bottom surfaces, sweet taste and aftertaste (Fig. 2B). On the right plane of PC1 were the tannin-containing sorghum cultivars (IS-777, PGRC/E #69441, CR:35:5, and Seredo), which are generally characterized as having bitter taste and aftertaste, red top surface and bottom surface, sour taste and aftertaste, and stickiness. SK-82-022, a white sorghum cultivar with purple glume color gave a faint red colored *injera*, possibly imparted by leaching of the glume color through the pericarp into the peripheral endosperm.

The ordinate of the PCA corresponds to PC2 (Destefanis et al 2000). The PC2 of the 1999 season explained an additional 26% of the total variance. PC2 separated cultivars mainly on the grounds of *injera* texture characteristics and appearance of eyes. Cultivars in the upper part of the plot were associated with the *injera* of more gritty texture but evenly distributed, larger eyes compared with the lower part of the plot (Fig. 2A). The cultivars at the bottom part of the plot, including AW, a red pericarp sorghum cultivar with floury endosperm, were characterized by soft and rollable *injera*, while *injera* from tef was characterized by a fluffy texture with a more shiny top surface.

For the 2000 growing season, the PC1 and PC2 described less of the total variance (59%), compared with the 1999 growing season (70%). PC3 accounted for an additional 15%, so that 75% of the total variance in the 2000 data could be explained (Figs. 3 and 4). PC1, which described 40% of the variance of the 2000 season, showed a trend similar to that of the 1999 data. *Injera* from the white pericarp sorghums and tef were characterized as being sweeter and whiter, while *injeras* from the tannin sorghums were associated with a more bitter taste and red top and bottom surfaces (Fig. 3A). *Injera* from the red tannin-free sorghum (AW) produced red *injera*, and the white sorghum cultivar with purple glume color (SK-82-022) produced a faint red *injera* as noted in the previous season.

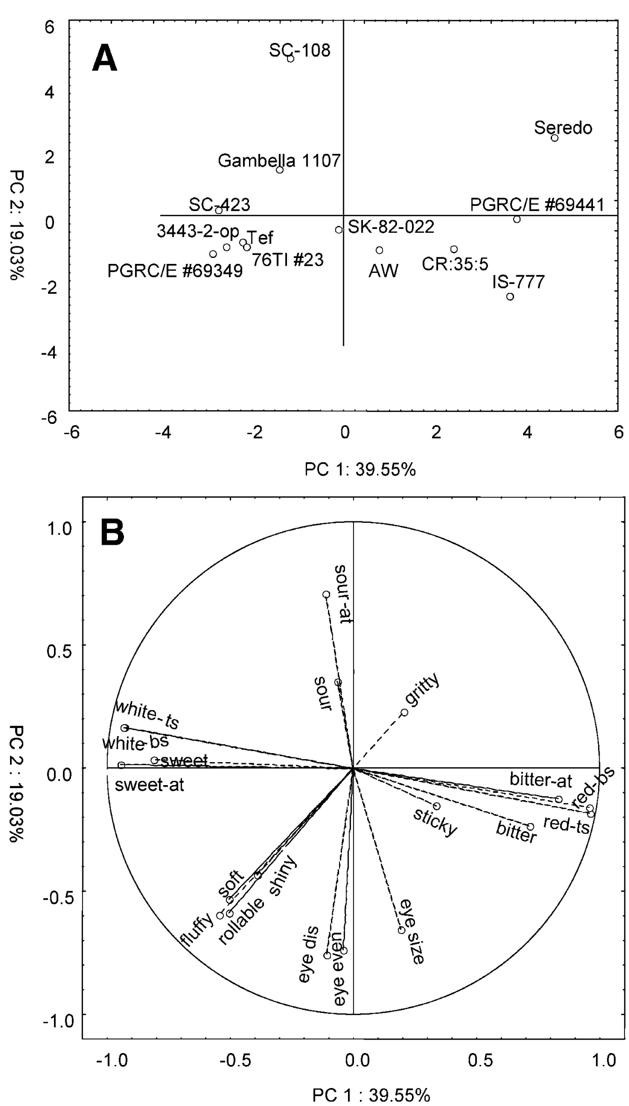

Fig. 3. Principal component analysis of *injera* from 12 sorghums and a tef cultivar grown in 2000. Plot of the first two principal component scores of the cultivars (**A**). Plot of the first two principal component loading vectors of sensory attributes (**B**). White-ts = whiteness of top surface; white-bs = whiteness of bottom surface; red-ts = redness of top surface; red-bs = redness of bottom surface; eye dis = eye distribution; eye even = eye evenness; sour-at = sour aftertaste; sweet-at = sweet aftertaste; bitter-at = bitter aftertaste.

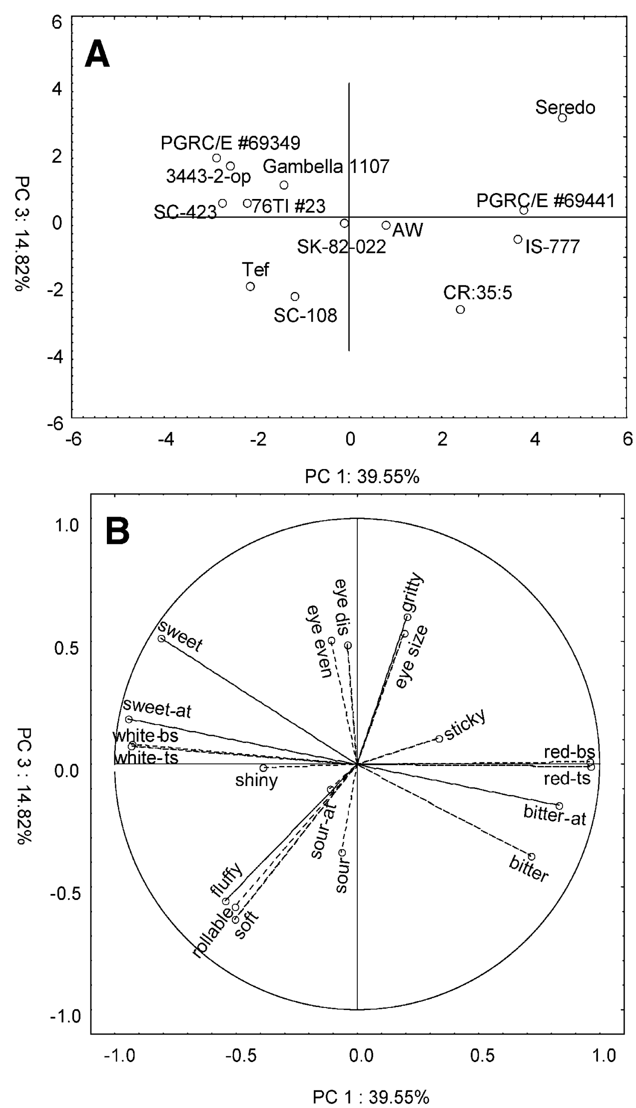

Fig. 4. Principal component analysis of *injera* from 12 sorghums and a tef cultivar grown in 2000. Plot of the first and third principal component scores of the cultivars (**A**). Plot of the first and third principal component loading vectors of sensory attributes (**B**). White-ts = whiteness of top surface; white-bs = whiteness of bottom surface; red-ts = redness of top surface; red-bs = redness of bottom surface; eye dis = eye distribution; eye even = eye evenness; sour-at = sour aftertaste; sweet-at = sweet aftertaste; bitter-at = bitter aftertaste.

In the upper plot of PC2 of the 2000 season (Fig. 3A), a white pericarp sorghum cultivar (SC-108) was characterized by a more sour aftertaste compared with other sorghum cultivars. The lactic acid fermentation of this cultivar could have been rapid. In the lower part of the plot, tef was grouped among the white sorghum cultivars (76TI #23, 3443-2-op, and PGRC/E #69349). The attributes associated with these cultivars were sweet taste, positive textural attributes (fluffy, rollable, and soft), and shiny surface with more evenly distributed eyes. The endosperm texture of these cultivars varied from intermediate to relatively vitreous (Table I).

PC3 of the 2000 season further explained differences in the texture (softness, rollability, fluffiness, and grittiness), eye appearance, and sweetness of the *injera* (Fig. 4). White pericarp sorghum cultivars (PGRC/E #69349, 3443-op, Gambella 1107, SC-423, and 76TI #23) were characterized by evenly distributed eyes, sweet taste, and white top and bottom surfaces. Tef and a white sorghum cultivar with relatively vitreous endosperm (SC-108) produced soft, rollable, and fluffy *injera*. Although seasonal variation in cultivar association was observed, both seasons showed similar trends in terms of grouping cultivars with similar *injera* attributes as perceived by the trained sensory panel.

Interrelationships of Sensory Attributes

According to Destefanis et al (2000), variables close together in the loading plot are positively correlated, while variables lying opposite to each other are negatively correlated. As expected, whiteness and redness of top and bottom surfaces of the *injera* were negatively correlated (Figs. 2B, 3B, and 4B). Softness was very closely associated with rollability (Figs. 2B, 3B, and 4B). This agrees with the observed tendency of soft *injera* to roll easily. Both characteristics are considered important eating qualities of *injera*. Good *injera* is soft and rollable to wrap and hold the sauce (*wot*) during consumption (Gebrekidan and GebreHiwot 1982). Bitter taste and aftertaste were negatively correlated with sweet taste and aftertaste (Figs. 2B, 3B, and 4B). The consumption of tannin-rich foods and beverages is associated with astringency or dryness and roughness felt in the mouth (Bacon and Rhodes 2000). It appears as if this sensation was perceived by the panel as bitter.

Instrumental Texture Measurement

The maximum force required to bend fresh *injera* and *injera* stored for 24 and 48 hr are presented in Table II. *Injera* from tef required the least force in all cases, while *injera* from the sorghum cultivars increased in the force required to bend over 48 hr of storage. The force required to bend sorghum *injera* varied between cultivars for both fresh and stored injera and across seasons. For the 1999 growing season, fresh *injera* from cultivars PGRC/E #69441, SK-82-02, and CR:35:5 required the least force and were similar to *injera* from tef, which had the most bendable *injera*. Fresh *injera* from cultivars SC-423, Seredo, 76TI #23, and 3443-2-op required the highest force to bend. After a storage period of 48 hr, *injera* from sorghum cultivars AW and SK-82-022 required the least force, whereas 76TI #23 and 3443-2-op required the most. Cultivars with low staling properties were tannin-free but varied in pericarp color and endosperm texture. AW had red pericarp color and floury endosperm, while SK-82-022 had white pericarp color and an intermediate endosperm texture. Cultivars with high staling properties were white and tannin-free with intermediate endosperm texture.

For season 2000, fresh *injera* from sorghum cultivars (76TI #23, SK-82-02, CR:35:5, AW, and PGRC/E #69441) required the least force to bend, while SC-423 and PGRC/E #69349 required the most. After two days of storage, CR:35:5 and AW required the least force, whereas SC-423 and PGRC/E #69349 required the most. CR:35:5 was a tannin-containing sorghum with floury endosperm. Both the high staling cultivars had white pericarp color with intermediate endosperm texture and were tannin-free. Sorghum endosperm texture data, expressed as corneousness (Murty et al 1982), was related to *injera* shelf life results reported by Gebre-

TABLE II
Maximum Force (N) Required to Bend Injera Stored at 25°C Over a Period of Two Days from Sorghums and a Tef Cultivar Grown for Two Seasons

Growing Season and Storage Time	Sorghum Cultivars					
	IS-777	AW	PGRC/E #69441	Seredo	CR:35:5	3443-2-op
1999						
1 hr	0.18b–d (0.03)[a]	0.19b–d (0.06)	0.14ab (0.03)	0.26gh (0.05)	0.17a–d (0.06)	0.24e–h (0.05)
24 hr	0.25d–f (0.05)	0.18bc (0.03)	0.23c–e (0.06)	0.21b–d (0.06)	0.27ef (0.03)	0.29f (0.05)
48 hr	0.26b–d (0.01)	0.19ab (0.06)	0.26cd (0.07)	0.33d (0.1)	0.33d (0.06)	0.47e (0.19)
2000						
1 hr	0.21bc (0.03)	0.19b (0.04)	0.20b (0.06)	0.24cd (0.03)	0.19b (0.05)	0.28df (0.06)
24 hr	0.31de (0.06)	0.23bc (0.04)	0.37f (0.06)	0.26cd (0.04)	0.19b (0.06)	0.47g (0.11)
48 hr	0.42ef (0.05)	0.28c (0.04)	0.52g (0.09)	0.33cd (0.07)	0.22b (0.03)	0.58h (0.11)

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$). Values in parentheses are standard deviations of two injera baked on separate days (5 determinations per injera).

TABLE II (continued)
Maximum Force (N) Required to Bend Injera Stored at 25°C Over a Period of Two Days from Sorghums and a Tef Cultivar Grown for Two Seasons

Growing Season and Storage Time	Sorghum Cultivars						Tef
	SK-82-022	DZ-01-196	Gambella 1107	PGRC/E #69349	SC-423	SC-108	DZ-01-196
1999							
1 hr	0.16a–c (0.15)	0.24f–h (0.08)	0.21d–f (0.05)	0.19c–e (0.08)	0.27h (0.08)	0.21d–g (0.08)	0.12a (0.01)
24 hr	0.15ab (0.02)	0.36g (0.17)	0.27ef (0.06)	0.25d–f (0.04)	0.29f (0.05)	0.20b–d (0.03)	0.11a (0.02)
48 hr	0.22a–c (0.07)	0.42e (0.09)	0.27cd (0.07)	0.32d (0.09)	0.32d (0.03)	0.27cd (0.01)	0.15a (0.06)
2000							
1 hr	0.19b (0.03)	0.18ab (0.03)	0.29f (0.04)	0.37g (0.05)	0.43h (0.09)	0.26de (0.05)	0.14a (0.05)
24 hr	0.26cd (0.03)	0.36ef (0.09)	0.32ef (0.08)	0.54h (0.02)	0.70i (0.03)	0.33ef (0.05)	0.13a (0.05)
48 hr	0.33cd (0.05)	0.45f (0.08)	0.47fg (0.06)	0.62hi (0.07)	0.66i (0.07)	0.37de (0.04)	0.15a (0.03)

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$). Values in parentheses are standard deviations of two injera baked on separate days (5 determinations per injera).

kidan and GebreHiwot (1982). There was no consistent trend between endosperm texture and staling property. This agrees with the present finding.

When means of sensory textural scores and instrumental measurements across seasons were compared, bending force was negatively correlated with softness ($r = -0.63$, $P < 0.05$) and positively with grittiness ($r = 0.75$, $P < 0.01$) after 48 hr of storage. This relationship indicates that soft *injera* requires less force to bend. This was clearly demonstrated by the fact that tef *injera*, which is considered soft, had the lowest bending force throughout the 48 hr of storage. The relative softness of tef *injera* could be related to starch granule size. Tef starch has smaller granule size (2–6 µm) (Umeta and Parker 1996) compared with sorghum starch granule size (≈20 µm) (Hoseney 1994). It is also possible that cell walls and aleurone components of the tef could positively affect the texture of *injera*. Conversely, *injera* perceived as being gritty (a negative attribute) by the panel required the most force to bend. These relationships show that bending force could be used as an indication of the quality of fresh and stored *injera*.

Across seasons, cultivars AW and CR:35:5 staled least, while cultivars PGRC/E #69349, SC-423 and 3443-2-op staled most. The cultivars with low staling properties had floury endosperm. The cultivars with high staling properties were white with intermediate endosperm and were tannin-free sorghums. AW, with low staling properties across seasons was also picked up by the sensory panel as soft and rollable (positive attributes) for the 1999 growing season (Fig. 2). Conversely, for the same season, PGRC/E #69349 with high staling properties across seasons was perceived as gritty by the sensory panel (Fig. 2).

In the course of the storage trial, it was noted that for both seasons after a storage period of only one day, *injera* from PGRC/E #69349, SC-423, 76TI #23, Gambella 1107, and 3443-2-op, all with relatively high staling properties, showed a moist bottom surface. Water was probably released (syneresis) out of the *injera* matrix due to reassociation (retrogradation) of starch components, causing increased firmness as reported by Lineback and Rasper (1988) with regards to rigidity of wheat bread crumb. Staling is due, at least in part, to the gradual transition of amorphous starch to a partially crystalline, retrograded state (Whistler and BeMiller 1999). Martin and Hoseney (1991) suggested bread firming is also a result of cross-links between starch granule remnants and protein fibrils. During baking of *injera*, starch granules completely gelatinize and fuse into a continuous amorphous matrix (Parker et al 1989). This amorphous matrix probably transforms to a retrograded state upon storage.

CONCLUSIONS

Sorghum cultivar affects *injera* making quality. AW (floury endosperm), 3443-2-op and 76TI #23 (intermediate), and PGRC/E #69349 (with more vitreous endosperm) were generally associated with soft, rollable and fluffy positive attributes of *injera* as perceived by the sensory panel. *Injera* from AW and CR:35:5 (both floury endosperm) required least force to bend after 48 hr of storage across seasons. Further work on the physicochemical properties of flours of these sorghum cultivars should be conducted and correlated with *injera* quality. This should lead to identification of the specific flour quality parameters that are related to good sorghum *injera* quality.

ACKNOWLEDGMENTS

The Agricultural Research and Training Project (ARTP) of the Ethiopian Agricultural Research Organization (EARO) supported this research. Senayit Yetneberk gratefully acknowledges the partial financial assistance from the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program.

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[Received July 8, 2003. Accepted October 30, 2003.]