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Rheological and textural properties of tef [*Eragrostis tef* (Zucc.) Trotter] grain flour gels

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ABSTRACT

Interest in tef [*Eragrostis tef* (Zucc.)Trotter] grain in food applications has increased in recent years because of its nutritional merits and the absence of gluten. With the objective of evaluating the suitability of tef for making gel type food products, gel viscoelastic properties of three varieties of tef (one brown and two white) at different concentrations (6, 8, 10, 12 & 14% w/w) were evaluated at 25 °C and 90 °C. The texture and color evolution for 16% (w/w) gels were evaluated. Proximate compositions of the flours were quantified. Rice, refined and whole wheat flours were analyzed as reference. The minimum flour concentration required for gel formation from the three tef varieties was 6–8%, similar to wheat flour. All tef flour suspensions pre-heated to 95 °C led to gels with a solid-like behavior ($G' > G''$), both at 25 °C and 90 °C, with higher consistency than wheat gels at the same concentration. The dependence of viscoelastic moduli with concentration fulfilled the power law. The Avrami model was successfully fitted to the textural evolution of tef gels. Important differences were observed among tef and rice and wheat flours, probably contributed by their differences in protein, starch, lipid and fiber constituents. Gelling properties characterized suggest that tef flours would be suitable ingredients in gel food formulations.

1. Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is originated from Ethiopia where it shows major diversity. It is the major staple food grain in the country and also well utilized in the region of North-Eastern Africa (Curtis et al., 2008). The whole grain is ground to flour for making *injera* (fermented flatbread), sweet unleavened bread, local beverage porridges and soup (Bultosa and Taylor, 2004).

Tef grain products are nutritionally well packed because they are always consumed as whole grain rich in carbohydrate and fiber (USDA, 2007), with more iron, calcium and zinc than other cereal grains, including wheat, barley and sorghum (Abebe et al., 2007). The grain proteins offer an excellent balance among the essential amino acids (Yu et al., 2006). Tef has recently been receiving global attention particularly as a "healthy food" due to the absence of gluten and gluten-like proteins, making it suitable for celiac disease patients (Dekking et al., 2005), and also due to other dietary advantages such as slow-release of carbohydrate constituents useful for diabetic patients.

Tef flour has been reported to produce high-quality leavened flatbread that stales much slower than if made from other cereals used to produce gluten-free baked goods and traditional flatbreads (Taylor and Emmambux, 2008; Yetneberk et al., 2005). However, as the majority of the gluten free cereals, western type bakery products from tef have different structure, flavor and sensory properties (Mohammed et al., 2009). This effect is more pronounced as the percentage of tef increases. In view of addressing these problems, effects of different enzymes such as xylanase, lipase, amylase, glucose oxidase and proteases (Alaunyte et al., 2011; Renzetti and Arendt, 2009), and microbial transglutaminase (Renzetti et al., 2008) have been studied. However, tef flour-enriched leavened products seem to still have a sensibly decreased quality in giving wheat bread type baked product. Nevertheless, works have shown a high water absorption capacity of tef flour and a slow retrogradation of the starch, which could have positive impact on the shelf life of cereal based products (Bultosa, 2007; Bultosa et al., 2008).

During processing, manufacture, and consumption of foods, gels are formed and the gelled systems are subjected to large deformations that may cause the food either to deform irreversibly or to fail in fracture (Tabilo-Munizaga and Barbosa-Cànovas, 2005). Hence, in order to develop new foods such as gel-like products from tef and/or to incorporate it in existing formulations for modifying

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Abbreviations

a	Exponent from fitting power law to G′ data from a frequency sweep
a*	Chromatic color coordinate
b	Exponent from fitting power law to G″ data from a frequency sweep
b*	Chromatic color coordinate
c	Exponent from fitting power law to tan δ data from a frequency sweep
C*	Chroma of the color
G'_1	Elastic modulus at a frequency of 1 Hz obtained from fitting power law to G′ data from a frequency sweep
G''_1	Viscous modulus at a frequency of 1 Hz obtained from fitting power law to G″ data from a frequency seep.
h	Hue of the color
L*	Luminosity color coordinate
LVR	Linear Viscoelastic Region
m	Elastic modulus, G'_1, at a gel concentration of 1% obtained from fitting power law to G'_1 versus gel concentration data
n	Exponent from fitting power law to G'_1 versus gel concentration data
$(\tan\delta)_1$	Loss tangent at a frequency of 1 Hz obtained from fitting power low to tan δ data from a frequency sweep
p	Viscous modulus, G''_1, at a gel concentration of 1% obtained from fitting power law to G''_1 versus gel concentration data
q	Exponent from fitting power law to G''_1 versus gel concentration data
τ_{max}	Maximum shear stress in the LVR
ω	Oscillation frequency

their functional and nutritional quality, an in depth study on gel properties is necessary. However, studies on tef undertaken so far were more concentrated on nutritional attributes (Hager et al., 2012), baking quality (Bultosa, 2007; Mohammed et al., 2009) and physico-chemical or functional characterization of starch extracted from the flour (Bultosa and Taylor, 2004; Bultosa et al., 2008). This study was therefore conducted to characterize tef whole flour gelation capacities and to evaluate viscoelastic, textural and color properties of the gels.

2. Materials and methods

2.1. Material

Three tef varieties DZ-01-99 (brown tef), DZ-Cr-37 (white tef) and DZ-Cr-387 (Qouncho, white tef) were obtained from the Debre Zeit Agricultural Research Center of the Ethiopian Institute of Agricultural Research (EIAR). Rice, whole wheat and refined wheat flours were supplied by Emilio Esteban SA (Valladolid, Spain).

2.2. Preparation of tef flours

Grain tef varieties were manually cleaned by siftings and winnowing before milling. A Cyclotech Sample mill (Foss Tecator, Häganäs Sweden) fitted with a 0.5 mm opening screen size was utilized for milling.

2.3. Flour proximate composition

Moisture, ash, fat and protein contents of the flours were determined using methods 44–19, 08–01, 30–25 and 46–11A of AACC (AACC, 2000) respectively. Total carbohydrates were determined by difference to 100% (FAO/WHO, 2003). Starch content was determined by the Fraser et al. (1956) method and amylose and amylopectin with the Megazyme assay kit (Megazyme Bray, Ireland). All the assays were conducted in duplicate.

2.4. Oscillation measurements

Dynamic oscillatory rheometry of the gels were carried out with a RheoStress 1 rheometer (Thermo Haake, Karlsruhe, Germany) with parallel plate geometry (60 mm diameter) of serrated surface and with 2 mm gap at 90 and 25 °C. Suspensions of different concentrations (6, 8, 10, 12 and 14%, w/w, of flour with 28.5 g total weight) were prepared by using the Rapid Visco Analyzer (RVA) (RVA-4 Newport Scientific Pty Limited, Warriewood, Australia). The suspensions were stirred with a constant rotating paddle at 160 rpm, heated from 50 to 95 °C at a rate of 6 °C/min and held at 95 °C for 15 min. Hot paste from the RVA was quickly transferred to the parallel plates for 90 °C measurement while the remaining portion was kept sealed and used for the 25 °C measurement undertaken after 25 min. The excess of suspension was removed and to prevent drying at the edge, vaseline oil was applied to cover the exposed sample surfaces. Before the measurement, the suspension was allowed to rest for 700 s to allow relaxation. Frequency sweeps were carried out in the previously established linear viscoelastic zone, from 10 to 0.1 Hz. Stress sweeps were conducted from 0.1 to 1000 Pa at 1 Hz of frequency. The limit of the linear viscoelastic region (LVR), τ_{max}, was located by the decrease of G′ modulus above 10%, that coincided with the sudden increase of tan δ. The RheoWin 4 software (Thermo Haake, Karlsruhe, Germany) was used for data analysis. Each gel was prepared twice and measured in duplicate. Frequency sweep data were fitted to the power law model as in previous works (Ronda et al., 2011):

$$G'(\omega) = G'_1 \cdot \omega^{a} \quad (1)$$

$$G''(\omega) = G''_1 \cdot \omega^{b} \quad (2)$$

$$\tan\delta(\omega) = \frac{G''(\omega)}{G'(\omega)} = \left(\frac{G''}{G'}\right)_1 \cdot \omega^{c} = (\tan\delta)_1 \cdot \omega^{c} \quad (3)$$

The coefficients G'_1, G''_1, and $(\tan\delta)_1$, stand for the elastic modulus, viscous modulus and the loss tangent at a frequency of 1 Hz. Fittings were done in the frequency range (1–10 Hz), where a linear double logarithm curve was systematically obtained. The *a*, *b* and *c* exponents quantify the degree dependence of these moduli and the loss tangent with the oscillation frequency, ω expressed in Hz.

2.5. Gel texture evolution

The texture properties firmness, adhesiveness, springiness, cohesiveness, and resilience and gumminess of flour gels were evaluated using a TA-XT2 Texture Analyser (Stable Microsystems, Surrey, UK) equipped with the software Texture Expert. Gels were prepared from 16% (w/w) suspensions of flours (28.5 g total weight) by using the RVA (RVA-4 Newport Scientific Pty Limited, Warriewood, Australia). This was the minimum concentration that led to self-standing gels in all flours tested except rice, where it was impossible to get it even at concentrations as high as 20%. The