Hydration kinetics of teff grain

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Abstract: Hydration kinetics of teff [Eragrostis teff (Zucc.) Trotter] grain was studied during soaking in water at the temperatures of 20℃, 30℃, 40℃ and 50℃ for 10 - 160 min. The weight gain during soaking of the grains was used to calculate the moisture content (% db) and the data was fit to Peleg's model. Peleg's model adequately predicted the water uptake of the teff grain under the experimental conditions investigated (r^2 = 0.97 – 0.99). The Peleg rate constant, k_1, and capacity constant, k_2, decreased from 0.714 to 0.272 min $\%^{-1}$ and 0.043 to 0.025$\%^{-1}$, respectively, with the increasing temperature from 20℃ to 50℃. Arrhenius type equation described the temperature dependence of k_1 and k_2 with r^2 values of 0.91 and 0.98, respectively, and activation energy of 24.59 kJ mol^{-1}. The strong correlation coefficient value of 0.97 - 0.99 indicated that Peleg's model could be used to characterize the hydration kinetics of teff grain under the experimental conditions considered.

Keywords: teff, Peleg's model, hydration, Ethiopia

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1 Introduction

Teff [*Eragrostis teff* (Zucc.)] is a millet-like, tiny, and prolate spheroid grain (Zewdu and Solomon, 2007) with length ranging from 0.9 to 1.7 mm and width from 0.7 to 1 mm (Bultosa and Taylor, 2004). The proximate composition (db) of teff is reported to be 9.4% – 13.3% protein, 73.0% carbohydrate 1.98% – 3.5% crude fiber, 2.0% – 3.1% fat and 2.7% – 3.0% ash (Bultosa and Taylor, 2004). Teff is considered to have an excellent amino acid composition, with lysine levels higher than wheat or barley, as well as very high calcium, phosphorous, iron, copper, aluminium, barium, and thiamine (Mengesha, 1966). Teff is also gluten-free, and is gaining popularity as an alternative grain for persons with gluten sensitivity (Bultosa, 2007).

According to the national estimates of the Central Statistics Authority (CSA, 2012), teff [*Eragrostis teff* (Zucc.) Trotter] accounts for about 16% of the gross grain production of all the cereals cultivated in Ethiopia covering about 2.7 million hectares of land in December, 2011. Because teff is predominantly grown in Ethiopia as a cereal crop, and its cultivation as a cereal grown for food is little known elsewhere in the world, its primary processing is mainly limited to indigenous processing to make *injera*, pancake-like fluffy soft bread, which is a staple food for most Ethiopians (Bultosa, 2007; Ketema, 1997; Mohammed *et al.,* 2009; Zewdu and Solomon, 2007). The grain is also used to make local alcoholic drinks, called *tella* and *katikala* (Bultosa, 2007; Ketema, 1997).

Due to its importance in most Ethiopians nutrition and its intensive production in the country, recently there is a growing interest on teff research to explore its potential for nutrition and economic merits such as starch production (Bultosa and Taylor, 2004), extrusion (Sirawdink and Ramaswamy, 2011; Kebede et al., 2010; Solomon, 2007), a composite with sorghum for *injera* making (Yetneberk et al., 2005) and as a composite with wheat for bread (Mohammed et al., 2009). Teff grain being starch rich cereal (Bultosa, 2007; Bultosa and Taylor, 2004), could also be potentially used for malting.

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Gebremariam *et al.* (2012) reviewed teff grain as a raw material for malting, brewing, and manufacturing of gluten-free foods and beverages. In the malting process, carefully selected grains are soaked in water until saturation before germination (Kashiri et al., 2010). Germination also increases nutrient digestibility and mineral bioavailability (Ejigui et al., 2005; Finney 1982; Kumar and Chauhan, 1993; Mugendi et al., 2010; Rusydi and Azrina, 2012) which is important for food formulation and product development. Besides barley, other cereals such as sorghum (Beta et al. 1995; Ijasan et al., 2011), pearl millet (Pelembe et al., 2004) and rice (Adebowale et al., 2010; Kongkaew et al., 2012) have been researched for malting with positive findings.

Optimizing the hydration conditions in order to control and predict the process is vital since hydration governs the subsequent operations and quality of the final product (Cheevitsopon and Noomhorm, 2011; Solomon, 2007). Water absorption depends on soaking time and temperature (Kashiri et al., 2010; Maskan 2002; Resio *et* al., 2006; Solomon, 2007; Solomon, 2009). Water hydration kinetics has been studied for several cereals including wheat (Maskan 2002; Kornarzynski et al., 2002), rice (Cheevitsopon and Noomhorm, 2011), sorghum (Kashiri et al., 2010) and amaranth (Resio et al., 2006), but information on the hydration kinetics of teff grain is lacking in the literature. Considering the potential of teff grain for malting and hence product diversification, this research was initiated to study the hydration characteristics of teff grain during soaking in water.

2 Materials and methods

2.1 Sample preparation

Teff grain sample, DZ-01-2423 variety, harvested in 2011/2012 production year, was collected from Adet Agricultural Research Center, Ethiopia. The sample was cleaned for foreign matter and broken kernels. Grains with defected shape and cracks were also removed.

2.2 Determination of physicochemical properties

Thirty randomly selected grains were used to measure length and width using electronic digital calliper with an accuracy of 0.01 mm. Thousand grain weight was determined by counting one thousand grains manually and weight was taken using digital electronic balance of 0.1 mg accuracy (AAA250L, Adam Equipment Co. Ltd, UK). Bulk density and true density were determined according to Zewdu and Solomon (2007). The bulk density was determined by pouring the grains in volumetric measuring cylinder of known volume up to the top, and by removing excess grain with rolling a cylindrical glass rod on the rim of the measuring cylinder container without compacting the grain. The mass of the grains filled in the cylinder divided by the volume of the cylinder gave the bulk density. True density was determined as the ratio of sample mass to the true volume of the grains using toluene displacement.

The porosity, ε, was determined from the bulk density (ρ_b) and true density (ρ_t) using the following formula (Zewdu and Solomon, 2007):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{1}$$

where, ρ_b and ρ_t are in kilogram per cubic meter.

The chemical composition of the teff grains (initial moisture content, crude protein, crude fat and ash) was determined according to AOAC (2000).

2.3 Water uptake study

Water uptake study was conducted according to Resio et al. (2006). Ten grams of samples were soaked in screw-tap flasks containing 150 mL of distilled water. The soaking temperatures considered were 20℃, 30℃, 40℃ and 50℃ for 120 min. This temperature lies on the ranges of temperatures used to study the hydration kinetics of cereals such as wheat (Maskan, 2002), amaranth (Resio et al., 2006), sorghum (Kashiri et al., 2010) and rice (Cheevitsopon and Noomhorm, 2011), and includes usual soaking temperatures for germination. Before performing hydration experiments, the flasks with distilled water were placed in thermostatically controlled oven (WH-71, Electric heated thermostatic dry box, China) fixed at the required soaking temperature (20 - 50℃) for several hours to reach thermal equilibrium (Kashiri et al., 2010; Solomon 2007; Resio et al., 2006). The grains were also separately conditioned to the respective experimental temperatures before soaking.

Then, the grains were poured into the screw-tap flasks containing distilled water.

These were placed in a constant temperature stirred water bath controlled within ±0.5℃ of the testing temperature (CU 420, Electric heat constant temperature water box, China). At regular intervals ranging between 10 and 40 min, the flasks were withdrawn from the bath. The grains were superficially dried by blotting with tissue paper four to five times (Solomon, 2007; Solomon, 2009) and weighed using electronic balance of 0.1 mg sensitivity (AAA250L, Adam Equipment Co. Ltd, UK).

2.4 Data analysis

Descriptive statistics were used to calculate the mean and standard deviation of the data of physicochemical properties of teff grain.

The difference between the weight measured at a given time and the initial weight during hydration was taken as weight gain due to water absorption (Cheevitsopon and Noomhorm, 2011; Kashiri et al., 2010; Resio et al., 2006; Solomon, 2007; Solomon, 2009). The weight gain was added to the initial water content to determine the instantaneous water content of the samples and was converted to moisture content (% db) (Solomon, 2007; Solomon, 2009).

Peleg (1988) showed that moisture sorption curves for food products could be described using a simplified two-parameter empirical model called Peleg's equation as is shown in Equation (2). This model has been successfully used to predict hydration kinetics of cereals and legumes (Kashiri et al., 2010; Maskan, 2002; Resio et al., 2006; Solomon, 2007; Solomon, 2009).

$$M(t) = M(0) + \frac{t}{k_1 + k_2 t} \tag{2}$$

where, $M(t)$ is the moisture content at time t, % db; $M(0)$ is the initial moisture content, % db; t is the soaking duration, min ; k_1 is Peleg's rate constant, min $\%^{-1}$, and k_2 is Peleg's capacity constant, $\%^{-1}$. This equation was fitted to the water absorption data to describe the hydration characteristic at each temperature considered. For the equation fitting, the curvilinear portion of the hydration data was used in the analysis because beyond this region ($M[t]$– $M[0]$) is approximately constant. This region is considered according to the literature (Resio et al., 2006; Solomon, 2007; Solomon, 2009).

At sufficiently prolonged period of time ($t \to \infty$), $M(t)$ approaches saturation or equilibrium condition and Equation (2) could be simplified to Equation (3). This shows that k_2 is inversely related to water absorption capacity or equilibrium moisture content, M_e (Peleg, 1988):

$$M_e = M(0) + \frac{1}{k_2} \tag{3}$$

The instantaneous moisture absorption rate is given by Equation (4) (Peleg 1988):

$$\frac{dM(t)}{dt} = \frac{k_1}{(k_1 + k_2 t)^2} \tag{4}$$

At the very beginning of the hydration process ($t \to 0$), the rate of water absorption, W, can be evaluated as follows indicating that k_1 is related to the initial water absorption rate (Peleg, 1988).

$$W = \left.\frac{DM(t)}{dt}\right|_{t=0} = \frac{1}{k_1}$$

3 Results

3.1 Physicochemical properties

Physicochemical properties of the teff grains used in this study are given in Table 1.

Table 1 Average chemical composition and physical properties of teff grain

Parameter	Mean ±SD*
Moisture content/% db	11.83±0.07
Protein (N×6.25)/%	10.73±0.06
Ash/%	2.93±0.08
Fat/%	3.07±0.03
Carbohydrate**/%	71.44±0.09
Thousand grain weight (TGW)/g	0.33±0.01
Length/mm	1.08±0.107
Width/mm	0.63±0.109

Note: * Standard deviation; ** Calculated by difference.

3.2 Hydration phenomena

The moisture content (db) of teff grains calculated at four soaking temperatures during the hydration process is given in Figure 1. As expected, the rate of water absorption was the highest at the early stages of hydration followed by decreasing rate until it approaches saturation. This trend was similar for all the temperatures considered implying that the water absorption rate approached equilibrium condition.

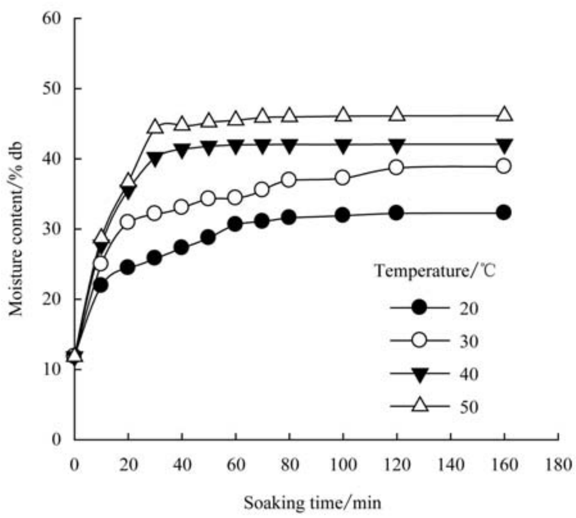

Figure 1 Water absorption curves of teff grain during soaki at different temperatures

3.3 Modelling the hydration kinetics

Nonlinear regression was employed to determine the constants k_1 and k_2 of Peleg's model (Equation (2)) using SPSS version 16. The values of Peleg's rate constant, k_1 and capacity constant, k_2 for all the soaking temperatures and the corresponding correlation coefficients are given in Table 2. Peleg's equation adequately represented the hydration characteristics of teff grain (r^2=0.97-0.99). The values of k_1 showed decreasing trend with increasing temperature, indicating increasing rate of water absorption. One way analysis of variance showed that k_1 and its reciprocal, the rate of water absorption (W), are both significantly (p<0.05) affected by temperature. The rate of water absorption varied from 1.4 up to 3.68 for the temperature change of 20℃ to 30℃. It is also important worth mentioning that, the water absorption rate of teff grain at 50℃ was three fold of the water absorption rate at 20℃.

Table 2 Peleg's constants at different temperatures and corresponding correlation coefficients

Soaking temperature/℃	k_1/min %$^{-1}$	k_2×10^{-2} /%$^{-1}$	r^2
20	0.714 ± 0.097	4.3 ± 0.0020	0.978
30	0.387 ± 0.034	3.63 ± 0.001	0.992
40	0.3187 ± 0.054	2.80 ± 0.0010	0.977
50	0.2717 ± 0.046	2.5 ± 0.0013	0.970

Note: Values in parenthesis are standard errors.

Table 2 shows that k_2 decreased from 0.043%$^{-1}$ to 0.025%$^{-1}$ while soaking temperature increased from 20℃ to 50℃. This was because of increase in water absorption capacity of the teff grain with temperature. This could also be explained by the increase in equilibrium moisture content (M_e) of the teff grain with increasing temperature (Table 3, Figure 1). The trend of achieving equilibrium moisture content was similar for all the temperatures but the grains soaked at higher temperatures achieved equilibrium condition faster than grains soaked at lower temperatures (Figure 1).

Table 3 Values for equilibrium moisture content and initial water absorption

Soaking temperature/℃	M_e /% db	W (kg water min^{-1})
20	33.494 ± 1.460	1.4006
30	39.532 ± 0.399	2.584
40	47.469 ± 0.070	3.1381
50	51.755 ± 0.070	3.681

The temperature dependence of k_1 has been described by Arrhenius type relationship (Maskan, 2002; Solomon, 2009):

$$\frac{1}{k_1} = k_0 \exp\left(\frac{-E}{RT}\right) \tag{6}$$

where, E is activation energy, kJ mol^{-1} K; R is universal gas constant, 8.318 kJ kmol^{-1} K; T is absolute temperature, K, and k_0 is frequency factor, % min^{-1}. The activation energy was found by linear regression of natural logarithm of k_1 versus 1/T and was found to be 24.59 kJ mol^{-1} with r^2 value of 0.91.

The relationship between temperature and k_2 was also adequately described using Arrhenius type equation as is shown in Equation (6). The constants C_p and D_p were found to be 9.6×10^{-5} % and 1789.364%°K, respectively with r^2 value of 0.98.

$$\ln(k_2) = \ln C_P + \left(D_P.\frac{1}{T}\right) \tag{7}$$

4 Discussion

The length and width of the grains was similar to earlier report of length and width of 0.51 - 1.3 mm and 0.1 - 0.67 mm respectively, for 13 teff varieties grown in Ethiopia (Bultosa, 2007). In another study, Zewdu and Solomon (2007) reported the average length and width of teff grains was 1.01 and 0.59 mm, respectively, at a moisture content of 5.6% (wb). The slightly higher values of length and width of the grains in this study could be because of the higher moisture content of the grains (11.83% db). Length and width of teff grain increases with moisture content (Zewdu and Solomon, 2007). Thousand grain weight (TGW) of the teff grains was 0.33 ± 0.01 g. Earlier studies reported TGW of 0.241 - 0.285 g for 13 teff varieties with the moisture content of 9.3% - 11.22% (db) (Bultosa, 2007), 0.257 g at a moisture content of 5.6% (wb) (Zewdu and Solomon, 2007) and 0.3 g without considering moisture content (Yetneberk et al., 2005). Since TGW increases with moisture content (Zewdu and Solomon, 2007), the higher TGW of the teff grains in this study could be due to the higher initial moisture content of the grains (11.83% db) and relatively higher dimensions of the grains. The bulk density, true density and porosity of the grains were 835.82 ± 21.6 kg m^{-3}, 1358.45 ± 30 kg m^{-3} and 38.47%, respectively. These values are comparable to earlier study where the bulk density, true density and porosity of teff grains were reported to be 840 kg m^{-3}, 1207 kg m^{-3} and 38.31%, respectively, at a moisture content of 5.6% (wb) (Zewdu and Solomon, 2007).

The proximate composition of teff grain (Table 1) was in agreement with earlier report for 13 teff varieties (Bultosa, 2007). Bultosa and Taylor (2004) and Kebede *et al.* (2010) also reported similar results.

Hydration

The rate of water absorption depends on the difference between the water content at saturation and at a given time, which is the driving force. As hydration proceeds, the water content increases, decreasing the driving force and consequently the absorption rate. The process ceases when the seeds attain the equilibrium moisture content (Resio et al., 2005; Solomon, 2009).

Figure 1 also shows that higher soaking temperature resulted in higher water absorption rate as compared to low temperature at all the stages of the hydration process. This phenomenon could be linked to high rate of water diffusion at higher temperature (Solomon, 2009). Similar trends have been reported for wheat (Maskan, 2002), rice (Cheevitsopon and Noomhorm, 2011), sorghum (Kashiri, 2010), amaranth (Resio et al., 2006), and roasted lupin (Solomon, 2009).

Maskan (2002) got similar results at soaking temperature of 70℃ for wheat and suggested that it was because of high temperature inducing softening. The decrease in k_1 and the associated increase in rate of water absorption is in agreement with the literature (Maskan, 2002; Resio et al., 2006; Kashiri, 2010; Solomon, 2007; Solomon, 2009).

The activation energy of teff grain was similar with *Dovme*, 24.29 kJ mole^{-1} (Maskan, 2002) and sorghum, 24.21 kJ mole^{-1} (Kashiri et al., 2010) but higher than wheat, 11.98 kJ mole^{-1} (Maskan, 2002) and lower than rice, 30.46 kJ mole^{-1} (Cheevitsopon and Noomhorm, 2011).

Both increasing and decreasing trends of k_2 with temperature exist in the literature. Decreasing trend of k_2 with increasing temperature was reported for wheat (Maskan, 2002); Amarenth (Resio et al., 2006) and sorghum (Kashiri et al., 2010). In other studies, increasing trend of k_2 with temperature is also reported for lupin (Solomon, 2007) and roasted lupin (Solomon, 2009).

5 Conclusion

Soaking temperature drastically affected the water absorption of teff grains. Both rate constant, k_1 and capacity constant k_2 were significantly reduced with increasing temperature from 20℃ to 50℃. The temperature dependence of k_1 and k_2 were adequately described by Arrhenius type relationship. Peleg's model adequately described the water absorption characteristics of teff grain. Therefore, this model could be used by teff grain processors to determine the amount of water absorbed during soaking at specific temperature for a known period of time.

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