HYDRATION BEHAVIOUR OF SORGHUM [Sorghum bicolor (Linn.) Moench] GRAINS AS INFLUENCED BY TRADITIONAL AND MODIFIED SOAKING METHODS

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ABSTRACT

The hydration behaviour of sorghum [*Sorghum bicolor* (Linn.) Moench] grains using traditional and modified soaking techniques was investigated. Three sorghum varieties (SAMSORG-14, SAMSORG-41 and SAMSORG-42) were used for the study; three traditional soaking techniques (SWG-72, PBW-24 and IBG5-24) were involved; while the equilibrium moisture content (EMC) for each variety was obtained experimentally. The hydration behaviour of sorghum grains was found to be influenced by variety, soaking method and time. The Peleg's model for predicting water absorption behaviour of grains was not appropriate for the traditional/modified soaking methods due to the non-constant nature of temperature of soaking. The Peleg's model was not accurate when used to predict the EMC of the traditionally-soaked sorghum grains. Generalized equations were derived for each traditional/modified soaking method with respect to individual sorghum variety. These equations would be of great relevance in the prediction of total moisture content in the grains at any time of soaking but the assumption is that such soaking duration must be less or equal to the time for EMC attainment with respect to the variety involved.

Keywords: Sorghum, Hydration, EMC, Soaking method, Peleg's model.

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INTRODUCTION

Sorghum [Sorghum bicolor (Linn.) Moench] belongs to a group of small seeded cereal used for food or feed, and is sometimes referred to as miscellaneous cereal or coarse grain (Kent and Evers, 1994). It is a large variable grain with many cultivars widely grown in the diverse areas of Africa and Asia (Dicko *et al*., 2006). The grain sorghum is particularly important in the semi-arid tropics (SAT) where it provides appropriate calorie needs, through staple diets, for millions of people in the region (Belton and Taylor, 2004). An important characteristic peculiar to sorghum cultivation is its unique ability to tolerate and survive under harsh climatic conditions of continuous or intermittent drought and temporary logging (Kent and Evers, 1994). Globally, grain sorghum has become an increasingly major food crop in Africa and India, and an important livestock feed in the Americas, Europe and Japan (Doggett, 1988). In many parts of Africa, grain sorghum plays an important role in the attainment of food security for a lot of households while it is also being used as an article for income generation (Anglani, 1998). Several food products are obtainable from grain sorghum, particularly from Africa, and these include *ogi*, *kunu*, *eko* and *tuwo* (Obilana, 1982); malted and fermented beverages such as *mahewu* (Bvochora *et al*., 1999); porridge, *couscous* and *dolo* (Dicko *et al*., 2006); *injera* and *ugali* (Banigo *et al*., 1974); among others.

One particular unit operation peculiar to the utilization of grain sorghum for most food production is the soaking of the grains. The soaking step normally causes the grains to be highly hydrated so that the hard kernel can become softened thereby making subsequent operations such as grinding or cooking easier (Addo *et al*., 2006). Soaking can also lead to the breakdown of several components, within the grains, into simpler compounds which are capable of causing alterations in the texture, flavour, aroma and taste of the final products (Parveen and Hafiz, 2003). In Nigeria and other West African countries, the traditional soaking method for cereal grains in the course of 'ogi' production essentially involves soaking of the grains for up to 72 h at ambient temperature (25-35^{o}C) after which the softened grains are wet-milled. A modification to the traditional grain soaking method, however, was suggested by Nago et al. (1998) which involved initial mild boiling of the grains at 95-100^{o}C for 10 min followed by actual soaking for 12-48 h at ambient temperature (25-35^{o}C) and wet-milling.

Several research works have been carried out on the hydration behaviour of cereal grains and leguminous seeds such as rice, maize, sorghum, wheat, foxtail millet, cowpea, bambara nut and kidney beans (Peleg, 1988; Abu-Ghannam and McKenna, 1997; Taiwo *et al*., 1998; Jideani and Mpotokwana, 2009; Kashiri *et al*., 2010; Vasudeva *et al*., 2010). Similarly, several mathematical models have also been developed for describing the hydration kinetics of food materials and these include Peleg model, Henderson and Pabis model, Exponential model, Page model, Two-term exponential model and Modified Page model (Becker, 1960; Hsu, 1983a,b; YiZang *et al*., 1984; Singh and Kulshrestha, 1987; Peleg, 1988; Kashaninejad *et al*., 2007). It has, however, been observed that most of these models, apart from Peleg's model, are based on Fick's law of diffusion which is considered rather complex and involves numerous functions and parameters that are not convenient for use in computations under most practical situations (Maskan, 2002). The Peleg's model, on the other hand, is essentially a two-parameter, non-exponential empirical equation, known as Peleg's equation, and was proposed to model water absorption behaviours of food materials (Peleg, 1988). The principal features of this equation lie in its simplicity when compared to other equations, it is applicable to the curvilinear segment of the sorption curve (Vasudeva *et al*., 2010) and most of its applications were carried out at constant soaking temperatures (Peleg, 1988; Abu-Ghannam and McKenna, 1997; Taiwo *et al*., 1998; Shittu *et al*., 2004; Jideani and Mpotokwana, 2009; Vasudeva *et al*., 2010).

The significance of establishing hydration kinetics for individual food material, destined to undergo soaking unit-operation in the course of its processing, is to know how such material will be affected by processing variables such as temperature (Verma and Prasad, 1999) and also how to predict the soaking time under given conditions. Therefore, the quantitative data normally generated during hydration experiments are useful for practical applications in the areas of optimising and characterizing the soaking conditions, designing of food processing equipment and predicting the water absorption as a function of time and temperature (Bhattacharya, 1995; Abu-Ghannam and McKenna, 1997; Taiwo *et al*., 1998; Addo and Bart-Plange, 2009).

Therefore, the principal focus of this present study is to develop appropriate regression equations for the hydration behaviour of sorghum grains under each condition of these traditional soaking methods as well as to examine the applicability of Peleg equation to the hydration behaviour of the grains with respect to each of these traditional methods in spite of non-constant nature of the soaking temperatures.

MATERIALS AND METHODS

Materials

Three sorghum varieties (SAMSORG-14, SAMSORG-41 and SAMSORG-42) were used for this study. They were obtained from the Institute of Agricultural Research (IAR), Samaru, Zaria, Nigeria.

Methods

Sample Preparation

The grain sorghum from each variety was subjected to preliminary cleaning through the removal of foreign materials and broken kernels. More uniform kernels were also obtained from each variety through screening after which the moisture content of the grains was determined (AOAC, 2000). This was carried out, in triplicate, by air draught oven at 103±2^{o}C until a constant weight was obtained.

Grain Soaking Procedures

The soaking of sorghum grains was carried out using both traditional and modified methods:

Soaking of grains in distilled water for 72 h at ambient temperature (SGW-72 Method): Approximately 50 g of sorghum grains, from respective variety, was soaked in 500 ml of distilled water at ambient temperature (29±2^{o}C). The soaking was done for a total period of 72 h during which samples were being taken out for moisture content assessment on hourly basis for 12 h. The grain sample taken out was first eliminated of its excess water using adsorbent paper after which it was weighed and moisture content determined, in triplicate, by air draught oven at 103±2^{o}C until a constant weight was obtained.

Pouring of boiled distilled water on the grains and allowing it to cool down for 24 h at ambient temperature (PBW-24 Method): Half a litre (500 ml) of boiled distilled water was poured onto 50 g of sorghum grains, from respective variety, in a plastic bowl for the grains to be fully submerged. Both the soaking grains and the hot distilled water were left in that position for 24 h during which they cooled down gradually to assume ambient temperature (29±2^{o}C) after few hours. The grain samples were being taken out for moisture content assessment on hourly basis for 12 h and this involved an initial elimination of excess water on the sample using adsorbent paper after which it was weighed and moisture content determined, in triplicate, by air draught oven at 103±2^{o}C until a constant weight was obtained.

Initial boiling of sorghum grains for 5 min followed by cooling at ambient temperature for 24 h (IBG5-24 Method): Approximately 600 ml of distilled water was initially brought to boiling in a stainless steel bowl to which 50 g of sorghum grains were added. Both were then allowed to boil for further 5 min after which they were brought down from cooking fire and then left in that position for 24 h during which they cooled down gradually to assume ambient temperature (29±2^{o}C) after few hours. The grain samples were being taken out for moisture content assessment on hourly basis for 12 h similar to the procedure explained above.

Determination of Equilibrium Moisture Content

The equilibrium moisture content (EMC) for each sorghum variety with respect to individual traditional soaking method was established by monitoring the water absorption process beyond 12 h. Though our actual data collection was terminated on the 12th hour of soaking yet the monitoring continued for 13 – 36 h during which the EMC was established at a point when there was no longer an increase in the amount of water absorbed by the sorghum grains.

Derivation of Regression Equations for the Soaking Methods

A step-wise regression procedure was performed respectively on all data generated from the soaking runs, using Microsoft Excel software (version Windows 7), on the three varieties of grain sorghum investigated with respect to the three different traditional soaking methods. The total moisture content in the grains (%, dry basis) was plotted against the soaking time (h) to obtain the respective equation that best describes the hydration characteristics of each sorghum variety. The goodness of fit between the experimental and predicted total moisture content in the grains was determined using the coefficient of determination (R^2).

Assessment of the Applicability of Peleg's Equation to the Hydration Behaviour of the Grains Using the Traditional Soaking Methods

The relevance of Peleg's equation to the hydration behaviour of the sorghum grains subjected to the traditional soaking methods was evaluated. According to the equation (Peleg, 1988);

$$M_t = M_o + t/(k_1 + k_2 t) \text{ .... Eq. (1)}$$

where;

M_t = Moisture content at time t on dry basis;

M_o = Initial moisture content on dry basis;

t= time (h);

k_1=the Peleg's rate constant ($h^{-1}\ \%^{-1}$); and

K_2 = the Peleg's capacity constant ($\%^{-1}$).

Re-arranging Eq. (1), we have:

$$M_t - M_o = t/(k_1 + k_2 t)$$

Therefore,

$$t/(M_t - M_o) = k_1 + k_2 t \text{ -------- Eq. (2)}$$

Hence, by plotting '$t/(M_t - M_o)$' versus 't' in hour, we have a straight line with k_1 as the ordinate intercept and k_2 the gradient line; whereby the graphical characteristics of these constants (k_1 and k_2) could be evaluated.

It has also been observed that if time goes to infinity, the equilibrium moisture content (M_e, dry basis) of the soaking grains can be calculated from the following expression (Quicazan *et al.*, 2012):

$$M_e = M_o + (1/k_2) \text{ .... Eq. (3)}$$

RESULTS

Water Absorption Behaviour of Sorghum Grains under Different Traditional Soaking Methods

The water absorption behaviours of sorghum grains under different traditional soaking methods are presented in Tables 1-3. The use of SGW-72 traditional soaking method (Table1) revealed different degrees of hydration rate being exhibited by sorghum grain varieties. In the first hour of soaking, SAMSORG-14, SAMSORG-41 and SAMSORG-42 increased from their initial total moisture content by 5.86, 4.06 and 9.56%, respectively. The equilibrium moisture content (EMC) and the corresponding period of attainment for SAMSORG-14, SAMSORG-41, SAMSORG-42, using SGW-72 soaking method, were 45.04% (30 h), 46.88% (32 h) and 47.56% (31 h), respectively.

The use of PBW-24 traditional soaking method showed rapid water penetration rate into the grains in the first hour of soaking (Table 2). The increase in the initial moisture content of the grains by 12.18, 5.53 and 12.0% for SAMSORG-14, SAMSORG-41, and SAMSORG-42 respectively, was observed. The equilibrium moisture content (EMC) attained by all the sorghum varieties were respectively higher in PBW-24 soaking method than that of SGW-72; while the periods of attainment were also respectively shorter. The EMC and time of attainment for SAMSORG-14, SAMSORG-41 and SAMSORG-42 were 50.89% (18 h), 50.12% (20 h) and 49.44% (16 h), respectively with PBW-24 soaking method.

In IBG5-24 traditional soaking method, the first hour of sorghum soaking witnessed rapid increase in the initial moisture content of the grains by 20.65, 11.20 and 18.72% for SAMSORG-14, SAMSORG-41 and SAMSORG-42, respectively (Table 3). These initial increases in moisture content were highest when compared to those of SGW-72 and PBW-24 soaking methods. The EMC and the time of attainment for SAMSORG-14, SAMSORG-41

Table 1: Percentage of total moisture content (dry weight) in sorghum grains during traditional soaking period (SGW-72 method)

Sorghum variety	Total moisture content in sorghum grains on hourly basis (%, dry weight)													
	0 (Initial moisture content of grain)	1	2	3	4	5	6	7	8	9	10	11	12	Equilibrium moisture content (EMC) and time of attainment
SAMSORG-14	8.53	14.39	19.62	23.59	26.87	28.91	30.78	32.81	34.36	36.67	37.41	38.52	39.49	45.04 (30 h)
SAMSORG-41	9.78	13.84	17.85	20.78	23.66	26.81	28.24	30.36	32.47	34.52	35.66	37.01	38.44	46.88 (32 h)
SAMSORG-42	9.41	18.97	24.35	27.84	29.91	31.43	33.46	35.02	36.68	38.24	39.81	40.59	42.04	47.56 (31 h)

Table 2: Percentage of total moisture content (dry weight) in sorghum grains during traditional soaking period (PBW-24 method)

Sorghum variety	Total moisture content in sorghum grains on hourly basis (%, dry weight)													
	0 (Initial moisture content of grain)	1	2	3	4	5	6	7	8	9	10	11	12	Equilibrium moisture content (EMC) and time of attainment
SAMSORG-14	8.53	20.71	26.55	31.27	35.94	40.57	42.61	43.87	45.99	46.87	47.79	48.54	49.04	50.89 (18 h)
SAMSORG-41	9.78	15.31	19.44	23.17	27.38	31.21	34.86	37.74	40.66	43.21	45.76	47.04	48.88	50.12 (20 h)
SAMSORG-42	9.41	21.41	25.68	30.41	34.79	37.46	40.98	42.81	44.21	46.62	47.53	48.02	48.21	49.44 (16 h)

Table 3: Percentage of total moisture content (dry weight) in sorghum grains during traditional soaking period (IBG5-24 method)

Sorghum variety	Total moisture content in sorghum grains on hourly basis (%, dry weight)												
	0 (Initial moisture content of grain)	1	2	3	4	5	6	7	8	9	10	11	12	Equilibrium moisture content (EMC) and time of attainment
SAMSORG-14	8.53	29.18	32.34	37.58	41.34	43.53	45.64	47.15	48.23	49.17	49.89	50.22	50.31	51.11 (15 h)
SAMSORG-41	9.78	20.98	25.44	29.87	33.22	37.18	40.26	43.04	45.68	47.18	48.62	50.39	51.79	52.68 (18 h)
SAMSORG-42	9.41	28.13	32.08	35.87	38.58	40.34	42.96	44.54	46.54	47.42	48.65	49.66	49.75	50.12 (14 h)

and SAMSORG-42, when IBG5-24 method was used, were 51.11% (15 h), 52.68% (18 h) and 50.12% (14 h), respectively.

Assessment of Suitability of Peleg's Model to Sorghum Hydration Using Traditional Soaking Methods

Figures 1-3 show the plots of experimental data and predicted data using Peleg's equation with respect to the three traditional soaking methods under consideration. From the linear regression curve, the coefficient of determination (R^2) was respectively obtained which varied between 0.9876 and 0.9964 (SGW-72 method), 0.9915 and 0.9958 (PBW-24 method), and 0.9817 and 0.9974 (IBG5-24 method). However, the accuracy of the equation was also evaluated by using the values of Peleg's constants (K_1 and K_2) generated from the linear regression curves to predict the equilibrium moisture content (EMC) for the hydrated grains through the traditional soaking methods. Table 4 summarizes the prediction of the EMC using Peleg's model equation. It was found that the actual equilibrium moisture content (experimental) of the grains did not tally with the calculated ones from Peleg's model. The calculated EMC's from the model were virtually far higher than the experimental values.

Derivation of Appropriate Regression Equations for Hydrated Sorghum Grains Using Traditional Soaking Methods

The regression curves of hydration behaviour of sorghum grains subjected to traditional soaking techniques under consideration are presented in Figures 4-6. The relationships between the total moisture content in the grain (%) and the soaking time (h) were all polynomial (non-linear) while the coefficient of determination (R^2) fell between 0.9994 and 0.9998 (SGW-72 method), 0.9985 and 0.9998 (PBW-24 method), and 0.9948 and 0.9997 (IBG5-24 method). Therefore, the generalized equations for predicting the total moisture

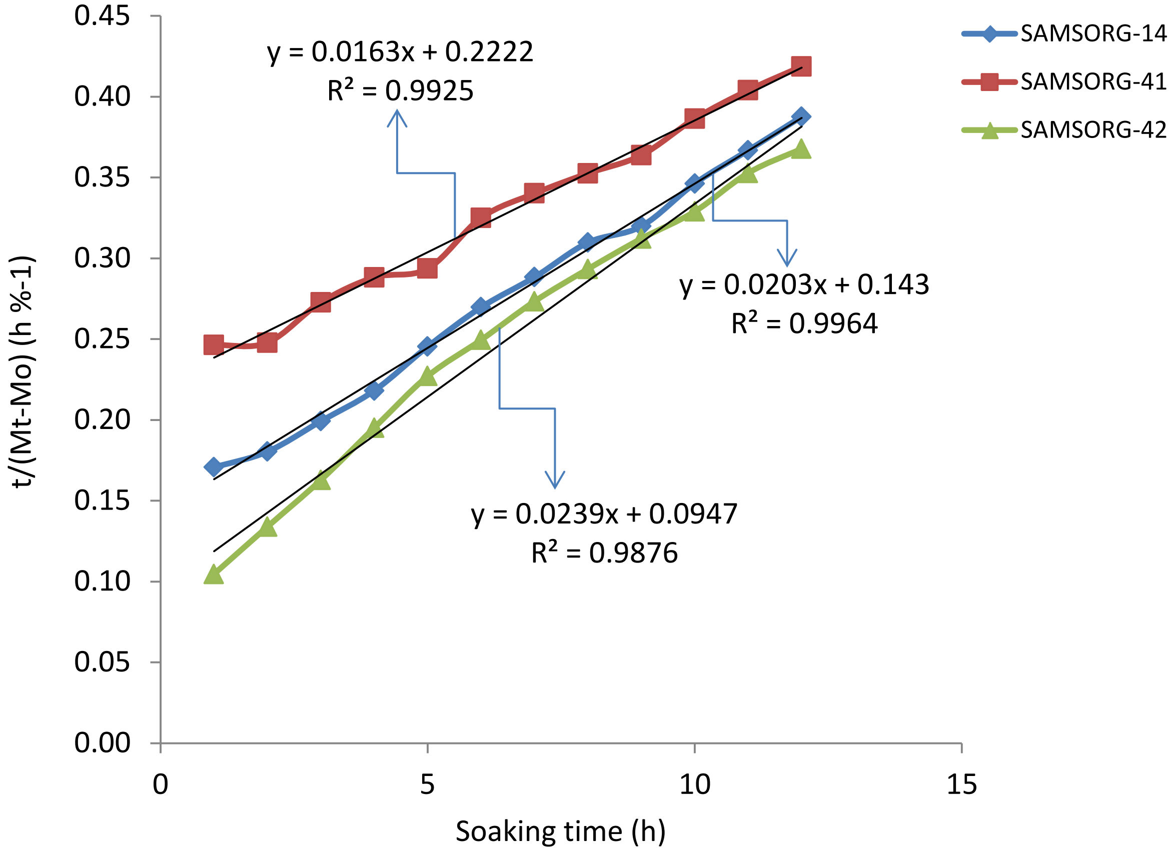

Figure 1: Application of Peleg's model to sorghum hydration using SGW-72 traditional soaking technique.

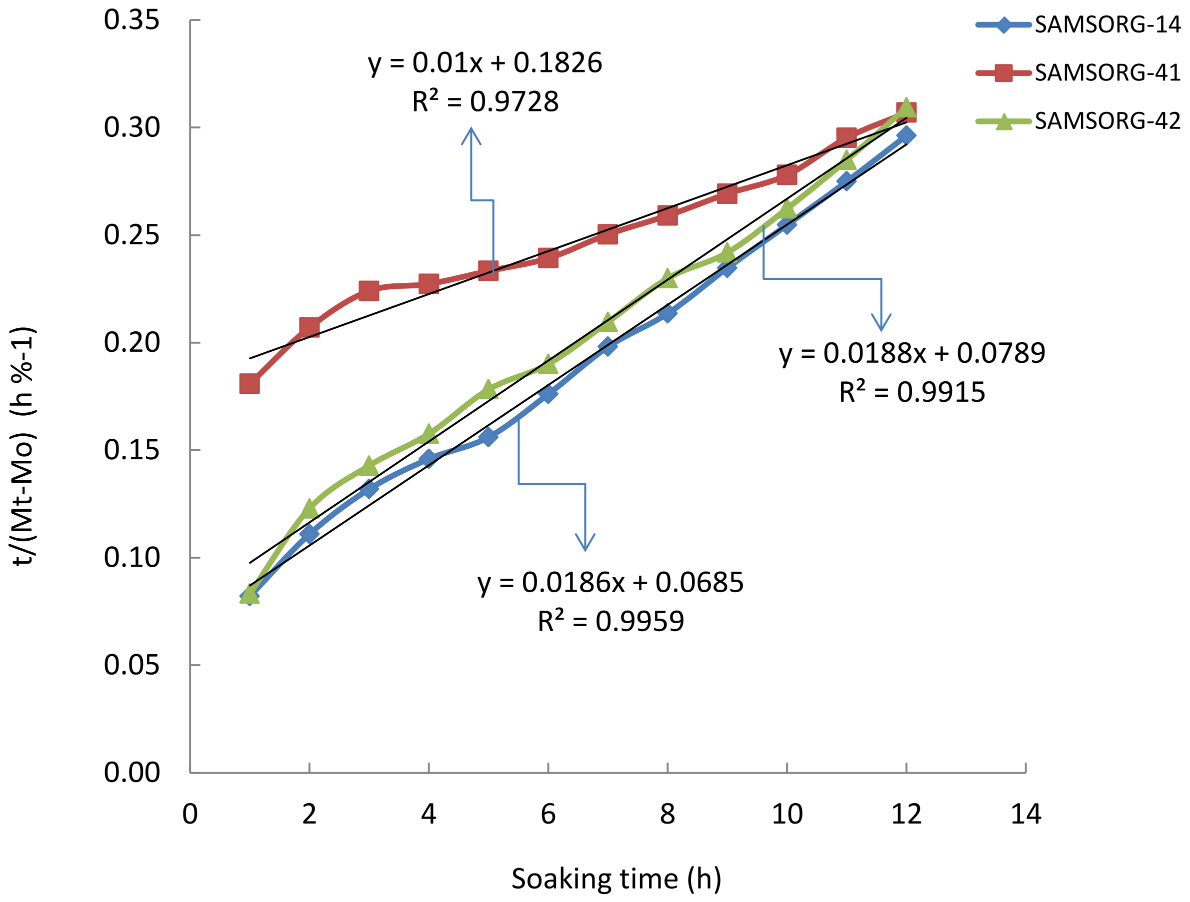

Figure 2: Application of Peleg's model to sorghum hydration using PBW-24 traditional soaking technique.

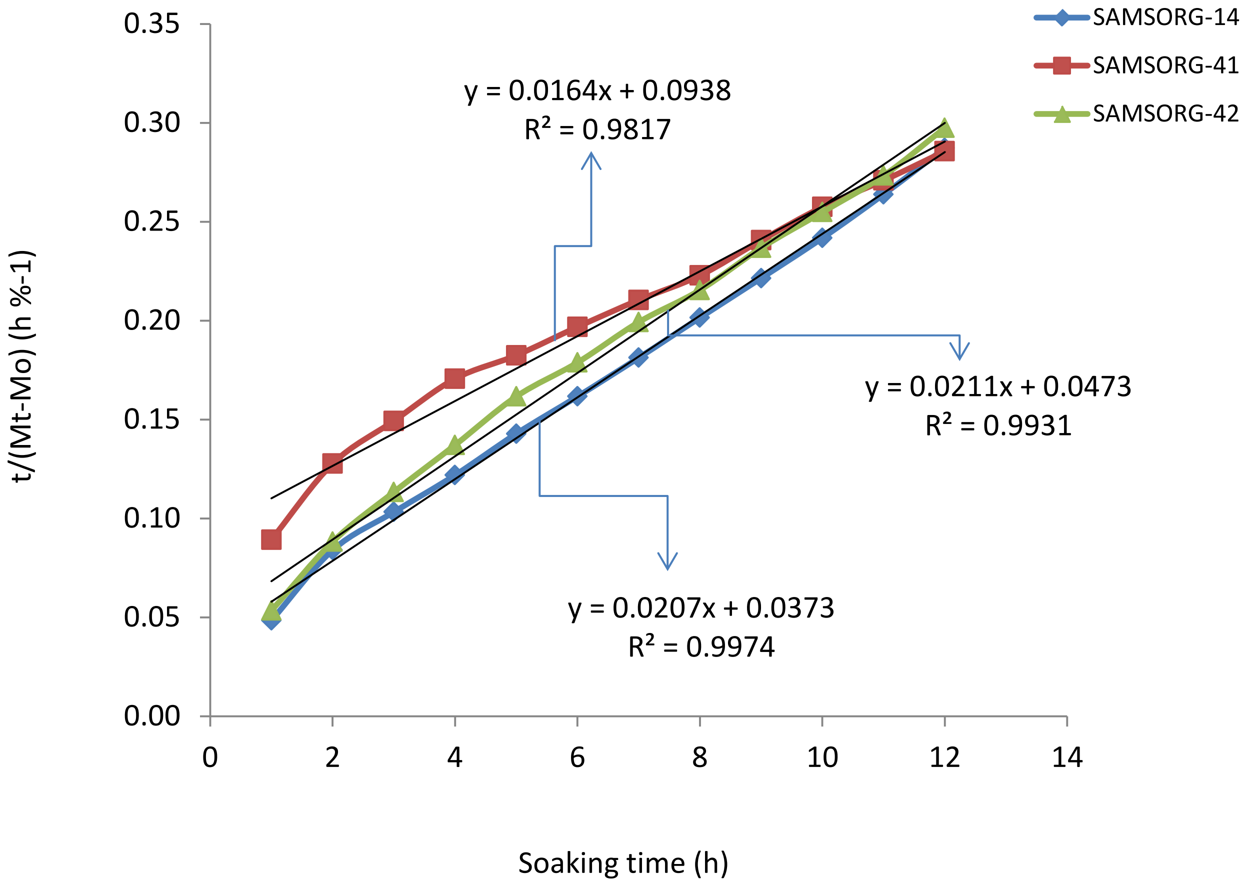

Figure 3: Application of Peleg's model to sorghum hydration using IBG5-24 traditional soaking technique.

Table 4: Accuracy assessment of Peleg's model for the prediction of equilibrium moisture content (M_e) of traditionally-soaked sorghum grains

Sorghum variety	M_o (%)	k_2 ($\%^{-1}$)	$1/k_2$ (%)	$M_e = M_o + (1/k_2)$ (%)	Actual equilibrium moisture content (experimental) (%)
SWG-72 Soaking Method:					
SAMSORG-14	8.53	0.0203	49.26	57.79	45.04
SAMSORG-41	9.78	0.0163	61.35	71.13	46.88
SAMSORG-42	9.41	0.0239	41.84	51.25	47.56
PBW-24 Soaking Method:					
SAMSORG-14	8.53	0.0188	53.19	61.72	50.89
SAMSORG-41	9.78	0.01	100.00	109.78	50.12
SAMSORG-42	9.41	0.0186	53.76	63.17	49.44
IBG5-24 Soaking Method:					
SAMSORG-14	8.53	0.0207	48.31	56.84	51.11
SAMSORG-41	9.78	0.0164	60.98	70.76	52.68
SAMSORG-42	9.41	0.0211	47.39	56.80	50.12

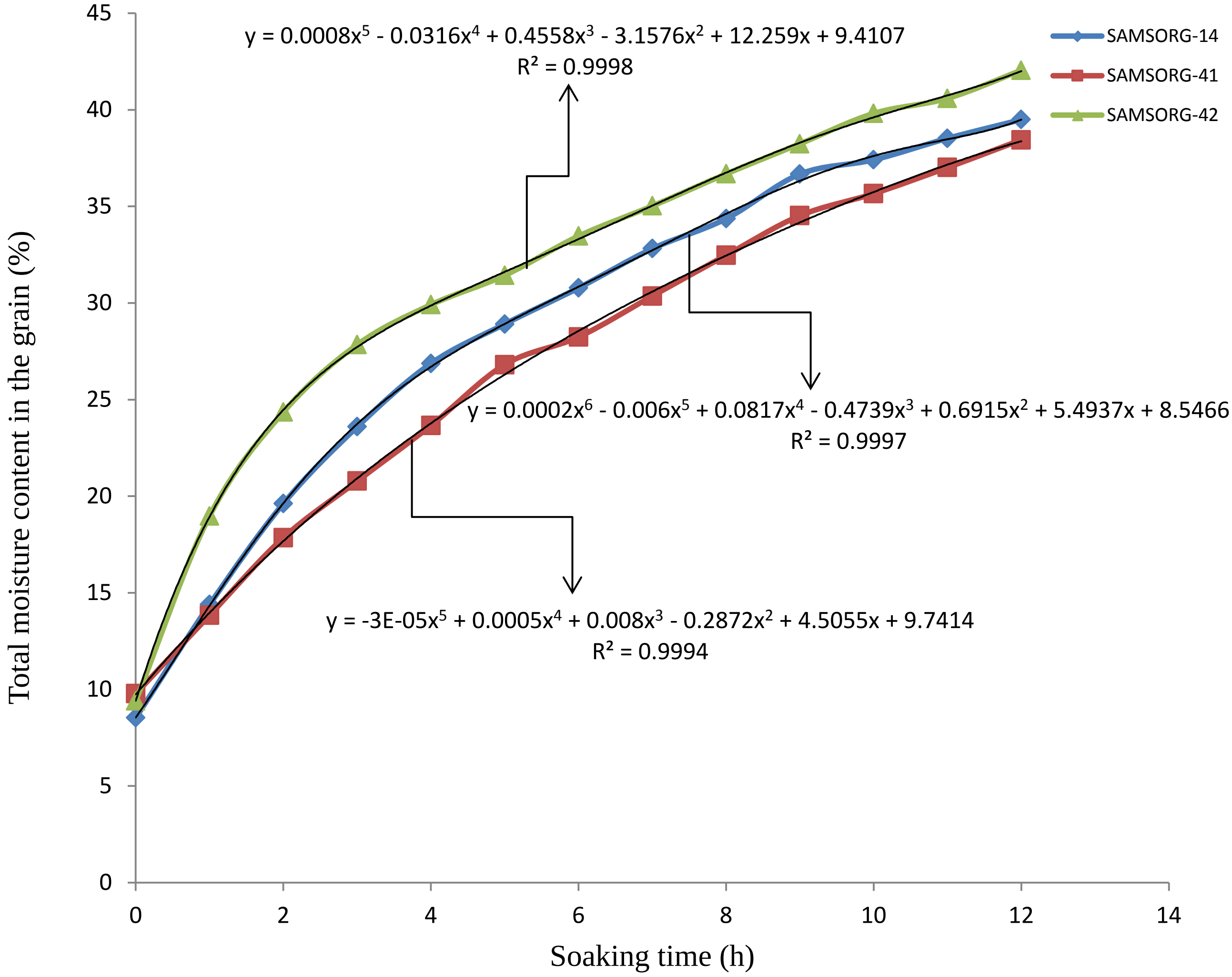

Figure 4: Regression curves of hydration behaviour of sorghum grains subjected to SGW-72 traditional soaking technique.

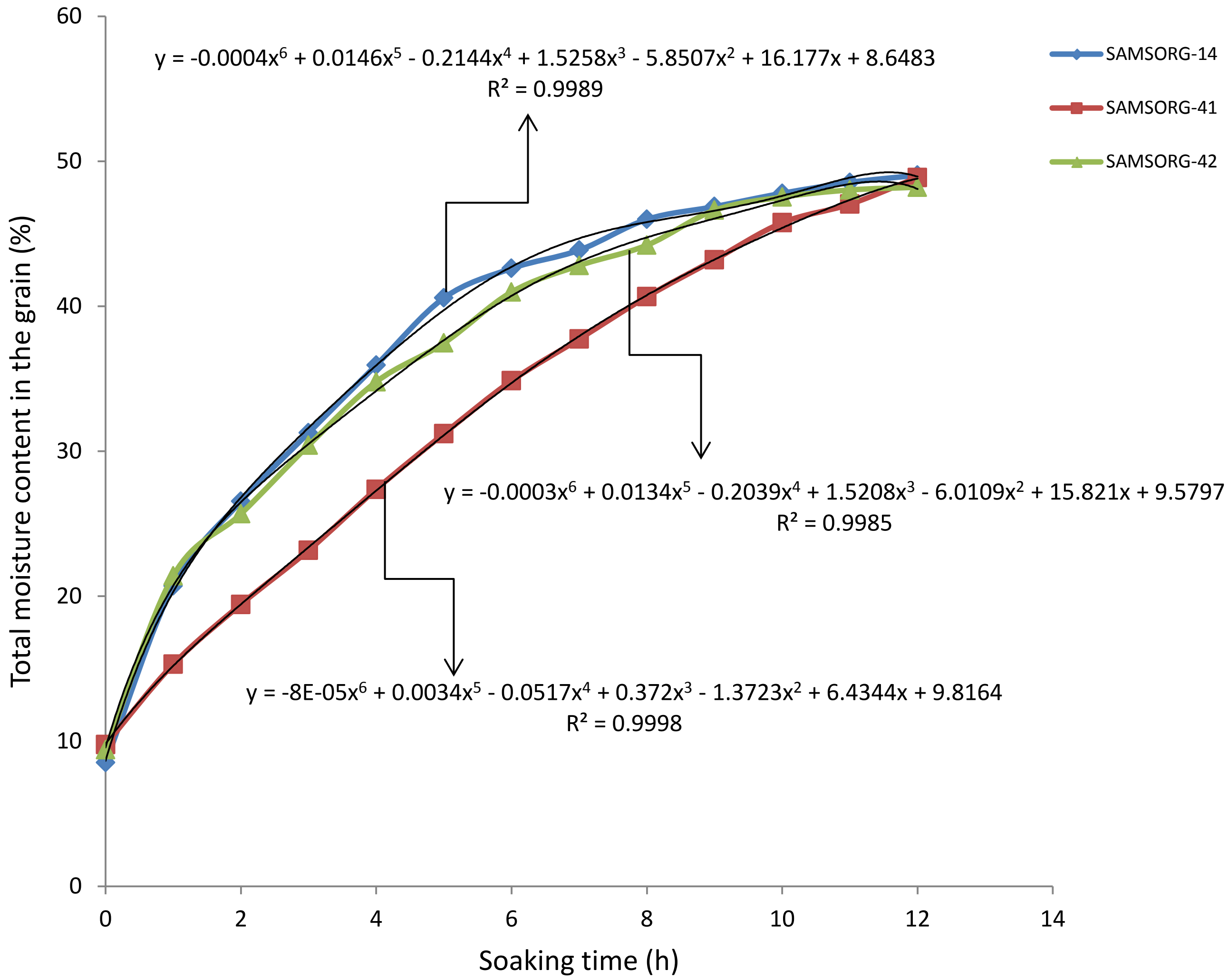

Figure 5: Regression curves of hydration behaviour of sorghum grains subjected to PBW-24 traditional soaking technique.

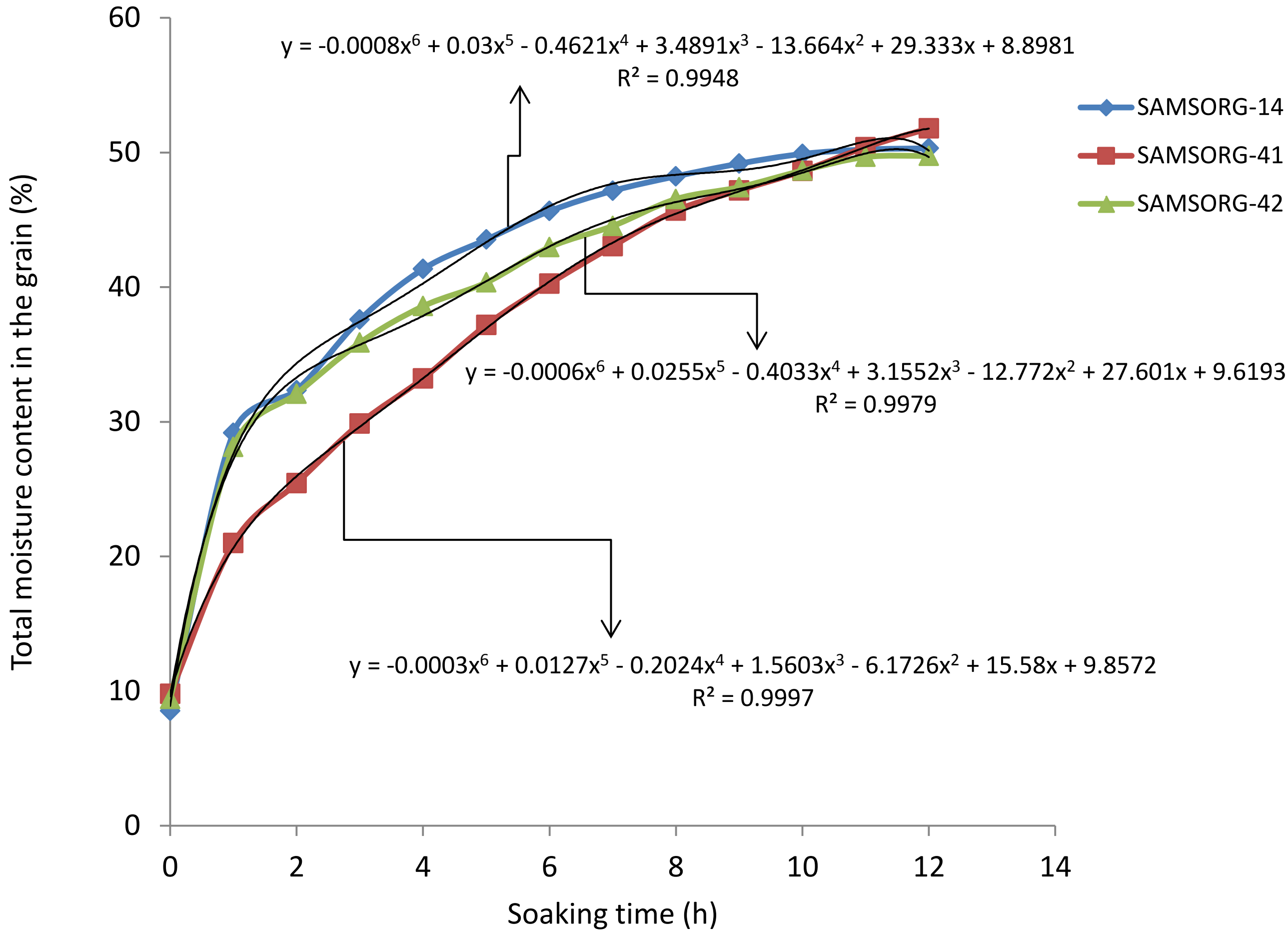

Figure 6: Regression curves of hydration behaviour of sorghum grains subjected to IBG5-24 traditional soaking technique.

content in the sorghum grains in the course of absorption at any time as per traditional soaking techniques are summarized in Table 5. The revelation from the summary is that a particular sorghum variety would exhibit varying hydration behaviours with respect to soaking technique adopted. From the Table, SAMSORG-14 would have the following generalized equations with respect to the traditional soaking techniques used:

SGW -72 method:

$Mt = 0.0002t^6 - 0.006t^5 + 0.0817t^4 - 0.4739t^3 + 0.6915t^2 + 5.4937t + M_o$……………...Eq. (4)

PBW- 24 method:

$M_t = -0.0004t^6 + 0.0146t^5 - 0.2144t^4 + 1.5258t^3 - 5.8507t^2 + 16.177t + M_o$…………….Eq. (5)

IBG5- 24 method:

$M_t = -0.0008t^6 + 0.03t^5 - 0.4621t^4 + 3.4891t^3 - 13.664t^2 + 29.333t + M_o$………………..Eq. (6)

For SAMSORG-41, the generalized equations with respect to the traditional soaking techniques will be as follows:

SGW -72 method:

$Mt = -0.00003t^5 + 0.0005t^4 + 0.008t^3 - 0.2872t^2 + 4.5055t + M_o$ …………….……..Eq. (7)

PBW- 24 method:

$M_t = -0.00008t^6 + 0.0034t^5 - 0.0517t^4 + 0.372t^3 - 1.3723t^2 + 6.4344t + M_o$………………..Eq. (8)

IBG5- 24 method:

$M_t = -0.0003t^6 + 0.0127t^5 - 0.2024t^4 + 1.5603t^3 - 6.1726t^2 + 15.58t + M_o$………………..Eq. (9)

Table 5: Summary of generalized equations that best describe the hydration behaviour of sorghum grains as per traditional soaking techniques

Sorghum variety	Equation that best describes the hydration behaviour as per traditional soaking technique	Coefficient of determination (R^2)
SWG-72 Soaking Method:		
SAMSORG-14	$Mt = 0.0002t^6 - 0.006t^5 + 0.0817t^4 - 0.4739t^3 + 0.6915t^2 + 5.4937t + M_o$	$R^2 = 0.9997$
SAMSORG-41	$Mt = -0.00003t^5 + 0.0005t^4 + 0.008t^3 - 0.2872t^2 + 4.5055t + M_o$	$R^2 = 0.9994$
SAMSORG-42	$Mt = 0.0008t^5 - 0.0316t^4 + 0.4558t^3 - 3.1576t^2 + 12.259t + M_o$	$R^2 = 0.9998$
PBW-24 Soaking Method:		
SAMSORG-14	$M_t = -0.0004t^6 + 0.0146t^5 - 0.2144t^4 + 1.5258t^3 - 5.8507t^2 + 16.177t + M_o$	$R^2 = 0.9989$
SAMSORG-41	$M_t = -0.00008t^6 + 0.0034t^5 - 0.0517t^4 + 0.372t^3 - 1.3723t^2 + 6.4344t + M_o$	$R^2 = 0.9998$
SAMSORG-42	$M_t = -0.0003t^6 + 0.0134t^5 - 0.2039t^4 + 1.5208t^3 - 6.0109t^2 + 15.821t + M_o$	$R^2 = 0.9985$
IBG5-24 Soaking Method:		
SAMSORG-14	$M_t = -0.0008t^6 + 0.03t^5 - 0.4621t^4 + 3.4891t^3 - 13.664t^2 + 29.333t + M_o$	$R^2 = 0.9948$
SAMSORG-41	$M_t = -0.0003t^6 + 0.0127t^5 - 0.2024t^4 + 1.5603t^3 - 6.1726t^2 + 15.58t + M_o$	$R^2 = 0.9997$
SAMSORG-42	$M_t = -0.0006t^6 + 0.0255t^5 - 0.4033t^4 + 3.1552t^3 - 12.772t^2 + 27.601t + M_o$	$R^2 = 0.9979$

M_t = Total moisture content in the grains at time ‘t’(%, dry basis).
t= Soaking time (h).
M_o = Initial moisture content in the grain (%, dry basis)

For SAMSORG-42, the generalized equations with respect to the traditional soaking techniques will also be as follows:

SGW -72 method:

$Mt = 0.0008t^5 - 0.0316t^4 + 0.4558t^3 - 3.1576t^2 + 12.259t + M_o$……………………..……...Eq. (10)

PBW- 24 method:

$M_t = -0.0003t^6 + 0.0134t^5 - 0.2039t^4 + 1.5208t^3 - 6.0109t^2 + 15.821t + M_o$……..…..Eq.(11)

IBG5- 24 method:

$M_t = -0.0006t^6 + 0.0255t^5 - 0.4033t^4 + 3.1552t^3 - 12.772t^2 + 27.601t + M_o$………..Eq. (12)

DISCUSSION

The water absorption behaviour of sorghum grains as observed with SGW-72 traditional soaking method (Table 1) implies that different sorghum grain varieties have diverse capacities for initial water penetration into the grains most probably due to the relative resistance being offered by the grain pericarp (Sayar *et al*., 2001). The varying degrees in grain resistance to water imbibition may also be linked to variation in the respective genetic make-up of the varieties (Tuinstra *et al*., 1997). As the soaking process continued, water penetration rate into the grains steadily decreased which may be attributed to the accumulation of water in the free capillary and intermicellar spaces of the grains (Abu-Ghannam and Mckenna, 1997). This, in turn, may lead to different sorghum varieties having variation in equilibrium moisture content (EMC) and the period of its attainment.

The initial rapid water penetration rate as observed in PBW-24 soaking method (Table 2) may be attributed to the elevated temperature of the soaking water. It had earlier been observed that at high temperature of soaking water, grain could exhibit typical sorption behaviour with exponential increase in water diffusivity thereby leading to higher hydration rate (Kashaninejad *et al*., 2009). Sample SAMSORG-41 seemed to exhibit highest resistance to water penetration into the grain as it had the lowest increase in the initial moisture content in the first hour of soaking. The higher EMC values as observed also in PBW-24 soaking method may imply greater swelling of the grains. An earlier study had observed that soaking of grains/seeds at elevated temperature could lead to increased rate of water imbibition and decreased time required for maximum absorption (Taiwo *et al*., 1998).

The 5-minute initial boiling of the grains, in the case of IBG5-24 traditional soaking method, may be implicated in the rapid increase in the initial moisture content of the grains (Table 3). This severe elevated temperature, most probably, generated a higher driving force for increased water diffusivity in the grains. The high temperature seemed to have contributed to the softening of the grain pericarp thereby causing rapid reduction in its resistance to water penetration. This is also a clear demonstration that severe elevated temperature of soaking water could lead to increased rate of water diffusivity, decreased time for EMC attainment and possible greater swelling of the grains via increased water accumulation.

In the case of the assessment of suitability of Peleg's model to sorghum hydration using traditional soaking methods, the linear regression curves obtained having high R^2-values indicates that the Peleg's equation might be valid for the traditional soaking methods (Figures 1-3). However, the validity of the equation should not be misconstrued for accuracy as the calculated EMC's from the model were virtually higher than the experimental values (Table 4) which implies that the model could not be used in predicting the EMC of the hydrated grains. This observation, however, may be attributed to the fact that the use of Peleg's equation in modeling the water absorption behaviour of grains normally dictates that the soaking temperature be kept at a constant level as Peleg's constants (K_1 and K_2) are function of temperature (Ramos *et al*., 2016). The traditional soaking methods under consideration were not carried out at a constant temperature level, hence the non-accuracy of the model.

The derivation of appropriate regression equations for the hydrated sorghum grains (Figure 4-6), using traditional soaking methods, revealed polynomial relationships while the high values of R^2 indicated the validity of the polynomial equations generated. The implication of generalized equations derived is that they could be influenced by the sorghum variety, soaking technique adopted and the soaking duration. However, the assumption to these generalized equations is that the soaking duration must be lower than or equal to that for EMC attainment with respect to the variety involved.

CONCLUSION

There were variations in the hydration behaviour of sorghum grains when subjected to traditional soaking techniques. Other influencing factors were grain variety and soaking duration. The equilibrium moisture content (EMC) for the grains was attained faster with soaking methods involving elevated temperature of soaking water. The Peleg's model for predicting water absorption behaviour of grains was not applicable when traditional soaking methods were involved due to non-constant nature of temperature of soaking. The Peleg's model was not accurate when used to predict the EMC of the traditionally-soaked sorghum grains. The generalized equations with respect to the soaking methods and grain varieties would be of great help to predict the total moisture content in the grains at any time but below or equal the time for EMC attainment for individual sorghum variety.

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