jpht

Journal of Postharvest Technology
2017, **05**(4): 51-61
http://www.jpht.info

RESEARCH ARTICLE

Applicability of Peleg's equation in predicting water absorption during the soaking of Ofada and Nerica (L1) rice

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Received: 11.08.2017 Accepted: 16.09.2017

ABSTRACT

Water absorption kinetics of *Ofada* and *Nerica* (L1) paddy grains were investigated by soaking in water at different temperatures in a thermostatically controlled water bath at soaking times ranging from 40 to 180 min. Soaking temperatures were obtained from the gelatinization temperature measured with a Rapid Visco Analyzer (RVA) prior to soaking. Data obtained were fitted to the Peleg Model to determine Peleg's constants using a non-linear regression model. Complete gelatinization occurred at 54 °C and 65 °C for Ofada and Nerica respectively. Soaking temperature selected ranged from 40 to 70°C. The coefficients of determination (R^2) for the regression ranged from 0.90 to 0.99 and 0.89 to 0.98 for Ofada and Nerica rice respectively, indicating a good fit to the experimental data. Temperature, time and rice type had significant effect ($p < 0.05$) on water absorption. Peleg's rate constant, (K_1) varied proportionally with temperature for both grains while capacity constant (K_2) was not significantly affected by increased temperature for Ofada but decreased with increased temperature for Nerica paddy. Activation Energy, Ea of 0.42 kJ/mol and 1.78 kJ/mol were obtained for Ofada and Nerica respectively. The soaking parameters obtained can be use to optimize and characterize soaking conditions and predict water absorption as a function of time and temperature.

Keywords: Absorption, Nerica, Ofada, Paddy, Soaking

Citation: Adesina B.S., Olayanju, T.M.A., Dairo, O.U., Bolaji, B.O. and Sobukola, O.P. 2017. Applicability of peleg's equation in predicting water absorption during the soaking of Ofada and Nerica (L1) rice. *Journal of Postharvest Technology*, 5(4): 51-61.

INTRODUCTION

Rice (*Oryza sativa*) is one of the most important cereals of the world. It is produced locally in most part of Nigeria, namely, Abakaliki, Bida, Abeokuta, Mokwa, where it is used mainly for human consumption. Rice is the sixth major crop in cultivable area after sorghum, millet, cowpea and yam in Nigeria. It is well known for its hygroscopic behaviour. Rice has been such an important grain worldwide, with its processing being one of the most important events that have had the greatest impact on most people.

Soaking of paddy is the most time consuming operation in the parboiling process (Igathinathane et al., 2005). Long duration cold water soaking leads to microbial growth and off-flavour development (Ojiha and Michael, 2006). Hot water soaking at high temperature requires high energy inputs and produces unsatisfactory coloration with its consequent effect on consumer acceptability (Luh and Mickus, 1991). Understanding water absorption in grains therefore during soaking is of

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ISSN: 2348-4330

practical importance, since it affects subsequent processing operations and the quality of the final product (Turhan et al., 2001). Sequel to this there is need for the determination of the optimum hydrothermal treatments needed to be given to paddy during parboiling.

Soaking is an important operation during the processing of some foods as in rice parboiling (Engels et al., 1986). Researchers have already demonstrated that increasing the temperature of the soaking medium is an effective way to accelerate water uptake by various seeds as it shortens the soaking time (Sopade and Obekpa, 1990; and Abu Ghannam and McKenna, 1997). There have been extensive studies (Hsu, 1983; Zhang et al., 1984; King and Aston, 1985; Engels et al., 1986; 1986, 1988; Tagawa et al., 2003) to assess the rate of water intake by food materials. Several researchers conducted soaking tests of grains and found that Becker's model fits best for the experimental data (Verma and Prasad, 1999). Understanding water absorption in grain during soaking is of practical importance since it affects subsequent processing operation, the quality of the product and the cooking time (Takada et al., 1990). Hence, modelling moisture transfer in grains and legumes during soaking has attracted considerable attention. The water absorption kinetics of the dry legumes during soaking has been describe either by a two parameter empirical Peleg model or by analytical expression derived from Fick's law of diffusion (Tang et al., 1994).

The empirical model is simple to apply and has been shown to successfully describe the water absorption behaviours of various legumes and grains (Hung et al., 1993). Peleg (1988) proposed an empirical equation to model water absorption characteristic of food materials. It has been applied to various food materials by other researchers (Sopade and Okonmah, 1993) and was found suitable. The Peleg's empirical equation is commonly used for modelling water absorption in various grain and food during soaking.

This model is referred to as Peleg's model as given by Equation 1. It relates instantaneous moisture with the initial moisture contents and the soaking time as shown.

$$M_t = M_o \pm \frac{t}{k_1 + k_2 t} \qquad \textbf{(1)}$$

Where:

M_o = the initial moisture content (% dry basis)

M_t = moisture content at a known time (t) (% dry basis)

k_1 = peleg's rate constant (h//% dry basis)

k_2 = peleg's capacity constant ($\%^{-1}$) .

t = soaking time (h),

Linearization of equation (1) gives Equation (2)

$$\frac{t}{m_t - m_0} = k_1 + k_2 t \qquad \textbf{(2)}$$

A plot of $\frac{t}{m_t - m_o}$ against time t, gives a straight line with k_1 as the ordinate intercept and k_2, the gradient of the line. Such a plot allows the characteristics of Peleg's constants to be determined. Although not derived from any physical laws or diffusion theories, its applications for various food materials e.g. milk powder, rice and various legumes have been demonstrated (Sopade et al., 1994). According to Sopade et al. (1994) k_1 was inversely related to temperature and its reciprocal defines the initial hydration rate. The constant k_2 is a characteristic sorption parameters of the food materials being examined. Peleg's equation is applicable to the curve linear segment of the sorption curve and the reciprocal of k_2 can be used to predict the equilibrium moisture content.

Hsu et al. (1983) and Maskan (2002) reported the influence of temperature on moisture diffusivity into soybean and found it to follow Arrhenius relation. The Arrhenius equation is a simple, but remarkably accurate, formula for the temperature dependence of the reaction rate constant, and therefore, rate of a chemical reaction. The Arrhenius equation gives "the dependence of the rate constant k of chemical reactions on the temperature T (in absolute temperature, such as Kelvin or degree Rankine) and activation energy E_a". This is given by Equation 3.

$$k = Ae^{-Ea/RT} \tag{3}$$

Where:

A = pre – exponential factor (h^{-1})

R = Universal Gas Constant (kJ/mol K^{-1})

T = Absolute Temperature (K)

E_a = Activation Energy (kJ/mol)

K = Rate Constant

The activation energy is the minimum energy needed for the moisture transfer to initiate and proceed. Taking the natural logarithm of the Arrhenius equation gives Equation 4.

$$\ln(k) = -\frac{E_a}{R}\frac{1}{T} + \ln(A) \tag{4}$$

Sopade et al. (1992) and Dyah et al. (2008) indicated that k_1 could be compared to a diffusion coefficient and the Arrherius equation could be used to describe the temperature dependence of the reciprocal of Peleg's constant k_1. So, when a reaction has a rate constant that obeys the Arrhenius equation, a plot of $\ln(1/k_1)$ versus T^{-1} gives a straight line, whose slope and intercept can be used to determine E_a and A.

MATERIALS AND METHODS

Seeds and seeds preparation

Two types of paddy grains (Ofada, and Nerica L-1) were obtained from the Ogun State Agricultural Development Programme (OGADEP). The seeds were cleaned by removing foreign matters, damaged and immature seeds. The samples were stored separately in a sealed polythene bag at room temperature (25 ± 2 °C) until use (Juliano, 1985).

Gelatinization temperature determination

The pasting characteristics of the paddy grains were determined with a Rapid Visco- Analyzer (RVA). Pasting or gelatinization temperature among others was obtained from the pasting profile with the aid of thermo-cline for windows software connected to a computer.

Initial moisture content determination

The initial moisture content of the grains was determined using the ASAE (1983) standard. The value of the moisture content was computed using Equation 5, which is converted to dry basis for the purpose of this study.

$$\%MCwb = \frac{W_w}{W_w + W_d} \times 100 \qquad (5)$$

Where:

MC_{db} = moisture content dry basis (%)

MC_{wb} = moisture content wet basis (%)

W_w = weight of water (g)

W_d = weight of dry matter (g)

Water absorption procedure of paddy grains

The hot water soaking of the paddy rice was carried out in a thermo-statically controlled hot water bath. One hundred grammes of the cleaned paddy samples each of Ofada and Nerica were weighed into three perforated cans. The paddy grains were placed in the perforated cans that were kept inside the water bath (Plate 1). The range of hot water temperatures chosen for the soaking study was based on the observed gelatinization temperature of rice starch so that the range covered one level above and two levels below the gelatinization point (Igathinnathane and Chattopadhyay, 1997). The water bath was set at a required temperature for each sample of paddy grains and at ambient temperature (25 ± 2 °C) as control experiment.

Samples in triplicate were drawn at required intervals of time (40, 60, 80, 100, 120 140, 160, 180 minutes). The hydrated seeds were blotted free of excess surface moisture with paper tissue as described by Desphande et al. (1994) and the weight determined using a digital balance. The increase in weight was taken as the amount of water absorbed. All samples were studied in triplicate and the average results noted as percent moisture on dry basis (% dry basis). The proportion of water absorbed was calculated as true water absorption (WA_t, % d.b.). WA_t is associated with the water absorbed by the insoluble residue. The formula reported by McWatters et al. (2002) was used (Equation 6).

$$\mathbf{WA_t} = \frac{[(M_1 + H_2O) - M_1]}{M_1} \times 100 \qquad (6)$$

Where:

WA_t = true water absorption

M_1 = Initial Mass (g)

RESULTS AND DISCUSSION

The determination of the gelatinization temperature is necessary for hot water soaking (Igathinathane et al., 2005). From the pasting temperature determination carried out, it was observed that a complete gelatinization occurred at 54 °C and 65 °C for Ofada and Nerica respectively. Hot water soaking was conducted around the observed gelatinization temperature. The range selected was two levels below and one level above the observed gelatinization temperature (Igathinathane et al., 2005). The ranges selected for this study were 40, 50, and 60 °C for Ofada, and 50, 60 and 70 °C for Nerica. The water absorption was high during the initial hours of soaking with moisture increasing to about 28% dry basis from the initial moisture content of 12.06 % dry basis for Ofada and to about 32 % moisture content dry basis from the initial moisture content of 11.62 dry basis for Nerica (Table 1).

Table 1. Mean proportion of water absorbed (% d.b.)

	Time (min)								
Paddy	**Temp (°C)**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**
	40	20.65	23.53	25.67	26.87	28.54	29.30	30.17	30.96
Ofada	50	18.89	21.26	25.52	27.28	28.30	26.28	26.71	30.42
	60	19.44	25.36	27.13	27.52	27.92	29.86	31.57	32.18
	50	39.78	43.98	55.82	55.55	57.50	55.31	59.75	62.08
Nerica	60	20.03	23.41	23.31	28.01	28.09	28.02	31.89	32.17
	70	23.18	27.94	28.78	32.17	31.91	34.45	34.77	34.75

The shapes of the curves of water absorption profiles for the grains are typical of water absorption in some grains (Abu-Ghannam and McKenna, 1997a; Sopade et al., 1994). The characteristics behavior shows that there is a significant interaction between temperature and soaking time. After 2 hours of soaking, the moisture increase was gradual, with the curves becoming almost flat at about three hours of soaking indicating that the grains are approaching saturation level (Figures 1 and 2). According to Battacharya (1985), the end of soaking is the attainment of moisture content saturation. In general, type of rice, temperature and time all had significant effect ($P < 0.05$) on water absorption (Adesina, 2014). The behaviour of the paddy grains water absorption showed a typical exponential increase with time at all attempted temperatures.

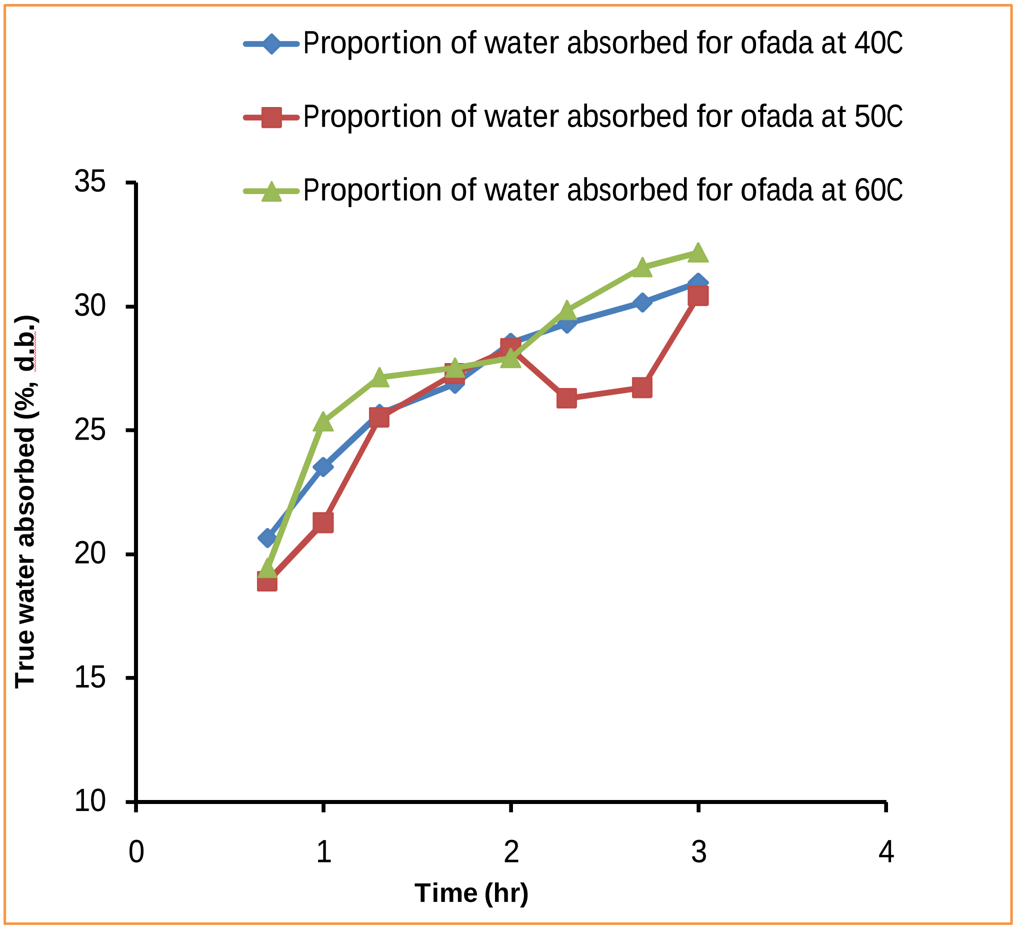

Figure 1. Water absorption profile of ofada paddy at different temperatures

Peleg's model is applicable to what is called the 'clearly curved' part of the sorption curve (Peleg, 1988). Peleg's constant K_1 is related to mass transfer rate (Turhan et al., 2002). For both paddies, Peleg's rate constant K_1 increased fairly as the hydration temperature was increased, suggesting a corresponding increase in the initial water absorption rate (Figures 3 and 4).

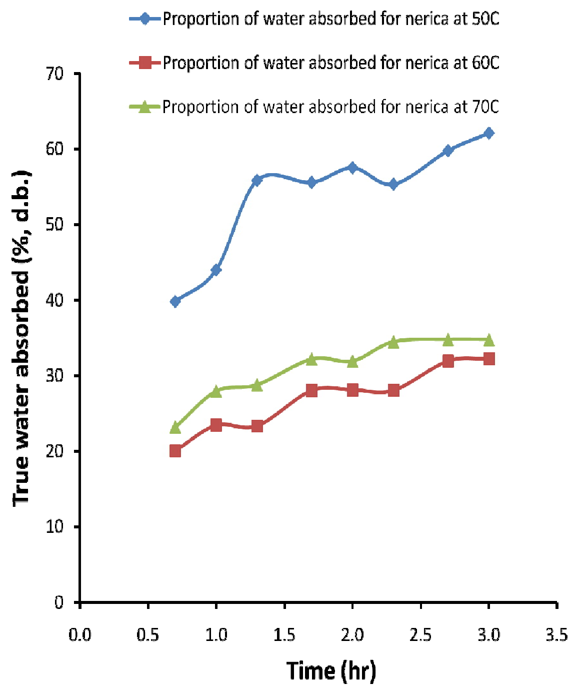

Figure 2. Water absorption profile of Nerica paddy at different temperatures

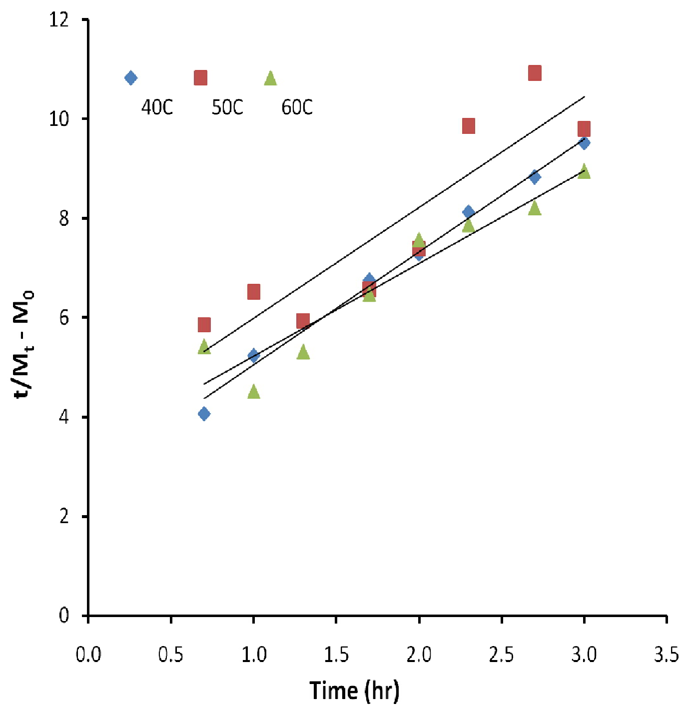

Figure 3. Fitting of Peleg's model to water absorption data from soaking of Ofada paddy at different temperatures

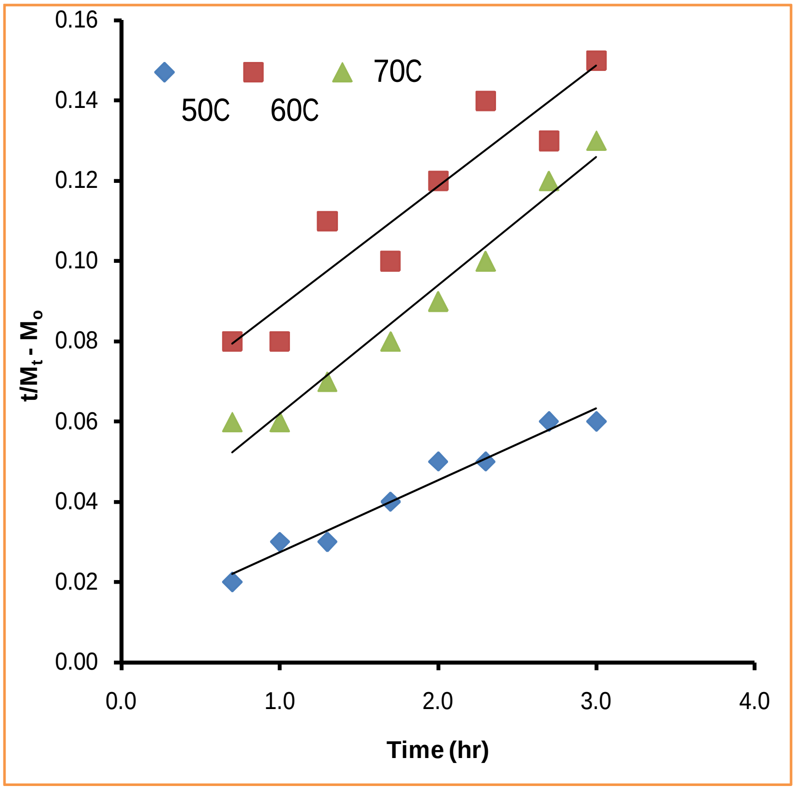

Figure 4. Fitting of Peleg's model to water absorption data from soaking of Nerica paddy at different temperature

Solomon (2007) reported a decrease in Peleg rate constant K_1 for lupin seeds, Sopade and Obekpa (1990) and Sopade et al. (1994) found that K_1 was inversely related to temperature. Its reciprocal (1/ K_1), is equivalent to the initial rate of hydration and its sensitivity to temperature is indicative of the positive effect of increased temperature on the rate of water absorbed. This was more pronounced at 50 °C for Nerica paddy where K_1 values have the lowest value. They observed large hydration rate (1/ K_1) for 50 °C is probably attributed to changes in the properties of the grains at this temperatures (Maharaj and Sankat, 2000).

The constant K_2 is related to maximum water absorption capacity (Turhan et al., 2002; Peleg, 1988; Sopade and Obekpa, 1990). The constant K_2 is also inversely related to the absorption ability of foods (Sopade and Obekpa, 1990). Peleg capacity constant K_2 is fairly constant with increase in temperature for ofada, demonstrating that the water absorption capacity is not affected with increase in temperature. Maharaj and Sankat (2000) in their water absorption studies using the Peleg model, also reported no effect of temperature on K_2 Values. Capacity constant, K_2 at 50 °C was high for Nerica and falls as the temperature increase (Table 2).

Effect of temperature on water absorption of food materials, namely on K_2, is mixed and depends on type of material and if soluble solids loss during soaking is considered in the calculation of moisture content of samples (Jideani and Mpotokwana, 2009). Nerica has the higher absorption capacity.

Table 2. Constants in peleg's equation at different soaking temperatures

Paddy	Temp(°C)	K_1	$1/K_1$	K_2	R^2
Ofada	40	3.15	0.32	0.04	0.998
	50	3.16	0.32	0.04	0.900
	60	3.43	0.29	0.03	0.949
Nerica	50	0.75	1.34	0.11	0.972
	60	3.79	0.26	0.03	0.897
	70	2.03	0.49	0.03	0.982

The statistical analysis of the relevant kinetic parameters shows that the proposed models are statistically fit. The coefficients of determination, R^2 values, varied from 0.900 - 0.998 and 0.897-0.982 for Ofada and Nerica respectively indicating a good fit to the experimental data. Hence, Peleg's equation was suitable for describing the water absorption characteristics of Ofada and Nerica paddies.

The relationship between the specific rate of absorption ($1/k_1$) and temperature was investigated using the Arrhenius equation. An Activation energy, Ea, of 0.42 and 1.78 kJ/mol were obtained for Ofada and Nerica respectively. The lower value obtained for Ofada suggests that the rate of water absorption for Ofada is faster when compared to Nerica with higher activation energy. The Arrhenius equation represents well the variation of the parameters with temperature especially for Ofada. This is in line with the result of Gowen et al. (2007), Sopade and Obekpa (1990), which found that high soaking temperatures led to complete hydration in a much shorter time. If compete hydration can be achieved during the soaking stage of parboiling, then steaming stage which is aimed basically to achieve complete saturation and gelatinization can be completely eliminated, thereby saving energy and time.

CONCLUSION

Gelatinization temperatures were determined for Ofada and Nerica. The range of soaking temperature selected was two levels below and one level above the gelatinization temperature (Igathinathane et al., 2005). The effect of temperature on absorbed water was more intense. Increased temperature resulted in reduced time taken to achieve equilibrium moisture. Soaking temperature, time and type of paddy, all had significant effect ($p < 0.05$) on water absorption of Ofada and Nerica paddy grains.

Peleg's equation was suitable for describing the water absorption characteristics of Ofada and Nerica at the investigated hydration temperatures, with high values of coefficient of determi nation, R^2, indicating a good fit to the experimental data.

The rate of water absorption for Ofada was faster when compared to Nerica with higher activation energy. The higher values of Ea and free energy of activation for Nerica indicate that the grains experience a large change and hydration was more influenced by temperature. Changes during the hydration of Ofada and Nerica were associated with exothermic and energetically favourable transformation.

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