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Research Article

The Effect of Temperature on Water Absorption (Hydration Kinetics) of Three Varieties of Rice (Oryza sativa L.) In Sierra Leone

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Abstract

In this study we examined the effect of temperature on the absorption of water (hydration) by some rice varieties grown in Sierra Leone. This study was carried out at Rokupr Agricultural Research Centre (RARC) laboratory of the Sierra Leone Agricultural Research Institute (SLARI). Dry samples of paddy from three rice varieties (Nerica-19, Nerica-21 and Rok-24) were hydrated in a water bath at temperatures of 30, 50 and 70°C respectively. Model parameters for Peleg's equation (k1 and k2) were estimated from experimental data and used to fit the equation for the three cultivars at different temperatures. Results suggest that the initial absorption rates, saturation moisture content as well as water absorption capacities increased for all three varieties with increasing temperatures. Values of both Peleg's constants show temperature and varietal dependence. Both constants appeared to decrease linearly with rising temperature conditions. The key difference noted among rice varieties was that whereas for Nerica-19 and Rok-24, which took up moisture slowly, k1 and k2 had fairly similar values, (ranging from 7.248 to 1.273 for k1, and 0.039 to 0.025 for k2), Nerica-21, which took up moisture more rapidly, had significantly lower values (ranging from 3.972 to 0.814 for k1, and 0.025 to 0.019 for k2). The results show that Peleg's equation can provide a satisfactory mathematical model of hydration phenomena in rice grains although its applicability for different rice grain varieties might require variety-specific or grain-type-specific grain-class-specific calibration.

Keywords

Hydration Kinetics, Peleg's Equation, Paddy

1. Introduction

Food grains and legumes are normally handled and stored in their dry forms until required for use or further processing. While this form is suitable for dry processing such as milling and flour production, a number of transformative grain processing operations like fermentation [1] (Liang, et al., 2008), parboiling [2] (Fofana, et al., 2011) and germination processing for value addition and quality enhancement in some cereals and legumes require wet grains [3] (Ohtsubo, et al., 2005). In most cereals and legumes, the harvest moisture content is such that additional moisture will be necessary to make them suitable for wet processing. This implies that the use of dry grains as inputs for wet processes demand that such

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grains be rehydrated to suitable moisture levels. Thus, hydration or rehydration (i.e., addition of water) of grains is an essential preparative stage for wet processing of all food grains and legumes.

Hydration may be regarded as the reverse of drying and involves the uptake of water by the grain matrix. From a biological perspective high moisture in grains triggers a range of endogenous and exogenous reactions and processes that facilitate subsequent transformations resulting from the activation of enzymes and microorganisms. Depending on the viability and biochemical properties of the grains, in relation to existing environmental conditions, in terms of temperature, water activity, and relative humidity rehydrated grains are will undergo various forms of transformation including mineralization, proteolysis, starch swelling and hydrolysis, germination, fermentation and rotting. The goal of grain process engineering is to direct, optimize and control the fate of grains by providing the right combination and levels of process conditions leading to certain desired outputs. For these and similar reasons, grain process engineers and scientists have made numerous attempts over the past few decades to understand the hydration process from different points of view.

The physical processes of hydration involve moisture uptake through a combination of diffusion and capillary action to offset a concentration gradient in an equilibration process. This process, like most other chemical reactions, is influenced by the conditions of the grain as well as the conditions of its physical environment. Studies show that the soaking of grains at high temperatures result in swelling and the development of cracks [4, 5] (Genkawa et. al., 2011; Perez, et. al., 2011) mentioned by [6] Shanthilal & Anandharamakrishnan et al., 2013. Cracks on the grain surface increase water absorption rate by the grain.

The modeling of water absorption by rice grains has been investigated by many researchers whose works have been summarized in [6] Shanthilal and Anandharamakrishnan (2013). Generally, hydration models may be theoretical, semi-theoretical and empirical types. The Fickian diffusion models have been use by [7] Davey, et al., (2002), [8] Bello, et al., (2004), [9] Kashenhaninejad, et al., (2007) as theoretical models based on moisture diffusion to study hydration in rice grains. The complex nature of the laws of diffusion and the various functions and parameters they involve, make the use of Fickian models cumbersome for practical computation under most situations. This led to the proposition of simpler non-exponential empirical equations by [10] Peleg (1988). Peleg's equation (1) has been used by a number of researchers to successfully model water absorption characteristics of cereal grains [11, 12] (Sopade, et al., 1992 & Sopade and Kaimur, 1999) and legumes [13, 14] (Sridhar & Manohar, 2003; Oliveira, et al. 2012).

$$M(t) = M_0 + t/(K_1 + K_2\ t) \tag{1}$$

This work was carried out with the aim of studying the hydration process of paddy using Peleg's model. The water absorption of husk rice differs from that of dehulled and milled rice. Milled rice has higher water absorption rate than both dehulled and husk rice, with husk rice having the least value. One might be tempted to say it is therefore better to hydrate dehulled or milled rice. But due to safety problems during processing, it is thus advisable to use husk rice in the hydration process.

2. Materials and Methods

2.1. Description of Method

Dried paddy grains of three rice varieties (Nerica 19, Nerica 21 and Rok 24) collected from the Rokupr Agricultural Research Centre (RARC) of the Sierra Leone Agricultural Research Institute (SLARI); with initial moisture content of 11.14, 11.26 and 11.65% (w.b.) respectively. The grains were manually cleaned by winnowing and hand picking to remove all foreign matter before analysis. During analysis, samples of 10g mass were weighed out and put in meshed nylon material bags which were then immersed in water in a water bath at preset temperatures of 30, 50 and 70 ℃. Grain samples were withdrawn and blotted to eliminate lingering moisture on the surface of grains before the determination of moisture content by the standard oven method.

2.2. Data Analysis

All data were analyzed to determine mean values from three replications and modeled using spreadsheets in Microsoft Excel 2007 computer software. Model adequacy was estimated by statistically in terms of coefficients of determination coefficient (R2), mean relative error (MRE), and standard error of estimate (SEE) (Equations 2&3) as measures of the goodness of fit of Peleg's model to the experimental data.

$$MRE = \frac{100}{n}\sum_{i=1}^{n}\left[\frac{|M_{exp}-M_{pre}|}{M_{exp}}\right] \tag{2}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(M_{exp}-M_{pre})^2}{D_f}} \tag{3}$$

3. Results and Discussion

3.1. Moisture Hydration Pattern

Results obtained from the experimental data shows a rapid hydration rate at the start of the hydration reducing its value as the process progresses to saturation. The general hydration pattern is similar for grains of all varieties and hydration temperatures. However, variation in hydration rate for Nerica-21 from Rok-24 and Nerica-19 was observed (Figure 1). The latter varieties show similar and generally low hydration rates compared to Nerica-21 which depicted relatively high hydration rate.

Temperature has an important influence on hydration of paddy for all varieties tested (Figure 2). The initial hydration rate, hydration capacity and therefore saturation moisture content, appear to increase linearly with rising temperature. However, while the rates of increase appear to be similar for Nerica-19 and Rok-24 Nerica-21 appears to contrast drastically thus implying very similar hydration properties Nerica-19 and Rok-24 which is completely different from that of Nerica-21.

3.2. Hydration Modeling

Peleg's equation is an empirical model that has been used by other researchers to predict the water uptake behavior of seeds. The equation contains two important model parameter K1 which is the hydration rate constant and K2 the Peleg's capacity constant. As expected, the values of K1 and K2 decreased with increase in temperature and varied among varieties (Table 1) Nerica-21 presented with the lower values. Although some values of the coefficient of determination (Table 3) are low, the decrease was linear. In agreement with the earlier statement, Peleg's constants decreased with increase in temperature for wheat flour [15] (Maskan, 2002), amaranth grain [16] (Resi et al., 2006), husk rice [14] (Oliveira et. al., 2012), wheat grain [17] (Vengaiah et. al., 2012) etc. Contrary view by McKenna (1997) for kidney beans found that Peleg's constant K2 was fairly constant with increase in temperature. Predicted moisture values calculated from the hydration model were superimposed on the experimental data and it fitted satisfactorily as seen in Figures 3 and 4 (see Appendix for figures). The models goodness of fit was determined by statistical methods mean relative error (MRE), standard error of estimate (SEE) and coefficient of determination (R2) (Table 2). These results show that all values of MRE where less than ten percent (the allowable limit for acceptable fits) and values for coefficients of determination (R2) were all greater than 0.92, except for Nerica-19 at 30 ℃ (which had an R2 value of 0.88).

Table 1. *Peleg's model parameters during the husk rice hydration process are function of hydration temperature.*

Variety	Temperature	K_1	K_2
	30	5.432	0.019
Nerica 19	50	2.222	0.014
	70	1.176	0.011
	30	3.048	0.011
Nerica 21	50	1.191	0.009
	70	0.638	0.006
	30	4.074	0.022
Rok 24	50	2.395	0.014
	70	1.023	0.012

Table 2. *Temperature dependent equations for the parameters (k1 and k2) in Peleg's Equation determined for three rice cultivars (represented in Figure 4: see Appendix for figure).*

Parameter	Equations (with respective coefficients of determination, r^2)		
	Nerica-19	Nerica-21	Rok-24
$K_1 =$	$y = -0.106T + 8.263 \ (r^2 = 0.92)$	$y = -0.060T + 4.638 \ (r^2 = 0.91)$	$y = -0.076T + 6.311 \ (r^2 = 0.99)$
$K_2 =$	$= -\left(\frac{20}{100000}\right) + \left(\frac{25}{1000}\right) \ (r^2 = 0.98)$	$y = -\left(\frac{13}{100000}\right) + \left(\frac{15}{1000}\right) \ (r^2 = 0.99)$	$y = -\left(\frac{25}{100000}\right)T + \left(\frac{29}{1000}\right) \ (r^2 = 0.89)$

Table 3. *Mean relative error (MRE), standard error of estimate (SEE) and coefficient of correlation (R2) obtained for three rice varieties fitted at three temperatures using Peleg's model.*

Temperature (℃)	Nerica 19	Nerica 21	Rok 24
MRE			
30	8.506	9.005	6.070
50	6.640	7.108	7.361
70	6.239	6.830	4.377
SEE			
30	3.539	3.566	4.947
50	5.929	5.815	8.536

Temperature (℃)	Nerica 19	Nerica 21	Rok 24
70	2.955	4.504	3.361
R^2			
30	0.880	0.935	0.920
50	0.947	0.945	0.922
70	0.941	0.949	0.978

Interestingly, close observation of values for mean relative error (MRE) suggest a progressive decrease in MRE as temperature increases. This suggests an improvement in relative error with increase in hydration temperature.

3.3. Discussions

The higher initial hydration rate of husk rice can be explained by capillary inhibition of external layers from pericarp (Bello et. al., 2004). When grains are dried to equilibrium moisture content and rehydrated, water moves in rapidly to fill the pores. The variation in model parameters with grain varieties, suggest that classes of grain exist for water uptake behavior of food grains and the similar hydration rate exhibited by Rok-24 and Nerica-19 further suggest that they belong to the same class different from that of the Nerica-21. This could be as a result of the larger size of Nerica-21 grain relative to the smaller sizes of the grains of Rok-24 and Nerica-19. Which is in contrast to reports by [12] Sopade and [18] Tang et al. (2002) the smaller the seed is, the larger is its water absorption capacity because of the increased surface area for absorption capacity. The nature of the surface, especially in terms of size of cuticle pores and fissures, influence the permeability of the seed coat to water uptake [18] (Tang et. al, 2002). It is likely that the greater pubescence of husk on Nerica-21 grains (i.e., more-hairier surface) than Nerica-19 and Rok-24 grains could be the basis for the enhanced moisture uptake by the grain. Hydration patterns show consistent increase in water uptake with temperature. The spectacular water absorption by grains at 70 ℃ is as a result of the high temperature, which is known to expand and soften grains [19] (Kale et. al., 2013). Similar results were reported by [13] Sridhar and Manohar (2003) for indica paddy.

Low values of MRE (less than 10%) and the high values of R2 suggest that Peleg's equation provided good predictions of hydration pattern in rice grains and resulted in a curve which fitted satisfactorily to experimental data. Also, since both parameters of the model (K1 and K2) have inverse relationships with hydration rates and capacities and so the relatively lower values estimated for Nerica-21 provide an indication of their higher hydration rates and capacities as experimental data showed. The pattern was also consistent with increasing temperature, for which a linear decrease is suggested with increasing temperature. Thus, the parameters of Peleg's Model estimated at a given temperature can be used to compare the hydration properties of rice varieties and (if a linear temperature dependence relation holds) could provide the basis for predicting hydration rates and capacities at temperatures other than those at which they had been determined.

4. Conclusions

Data from this study leads to the conclusion that Peleg's equation can provide a satisfactory mathematical model of hydration phenomena in rice grains but its applicability for different rice grain varieties might require variety-specific calibration. However, grain size influences water absorption capacity where as the smaller the grain is the larger is its water absorption capacity because of the increased surface area for absorption capacity, tough other factors such as cuticle pores influence the seed coat permeability.

Abbreviations

$M(t)$	Moisture Content at Time t % Wet Basis
M_0	Initial Moisture Content, % Dry Basis
t	Soaking Time in Minutes
K_1	Peleg'S Rate Constant in Minutes
K_2	Peleg's Capacity Constant, Dimensionless
M_{exp}	Experimental Value of Moisture Content Dry Basis
M_{pre}	Values Predicted by the Model of Moisture Content Dry Basis
D_f	Degrees of Freedom of Regression (n-2)
n	Number of Data Points

Author Contributions

Georgiana Allie: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing

Joseph Sherman-Kamara: Conceptualization, Formal Analysis, Supervision, Validation, Writing – original draft, Writing – review & editing

Sallu Karteh: Formal Analysis, Investigation, Methodology, Writing – review & editing

Dominic Musa Ibrahim-Sayo: Formal Analysis, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

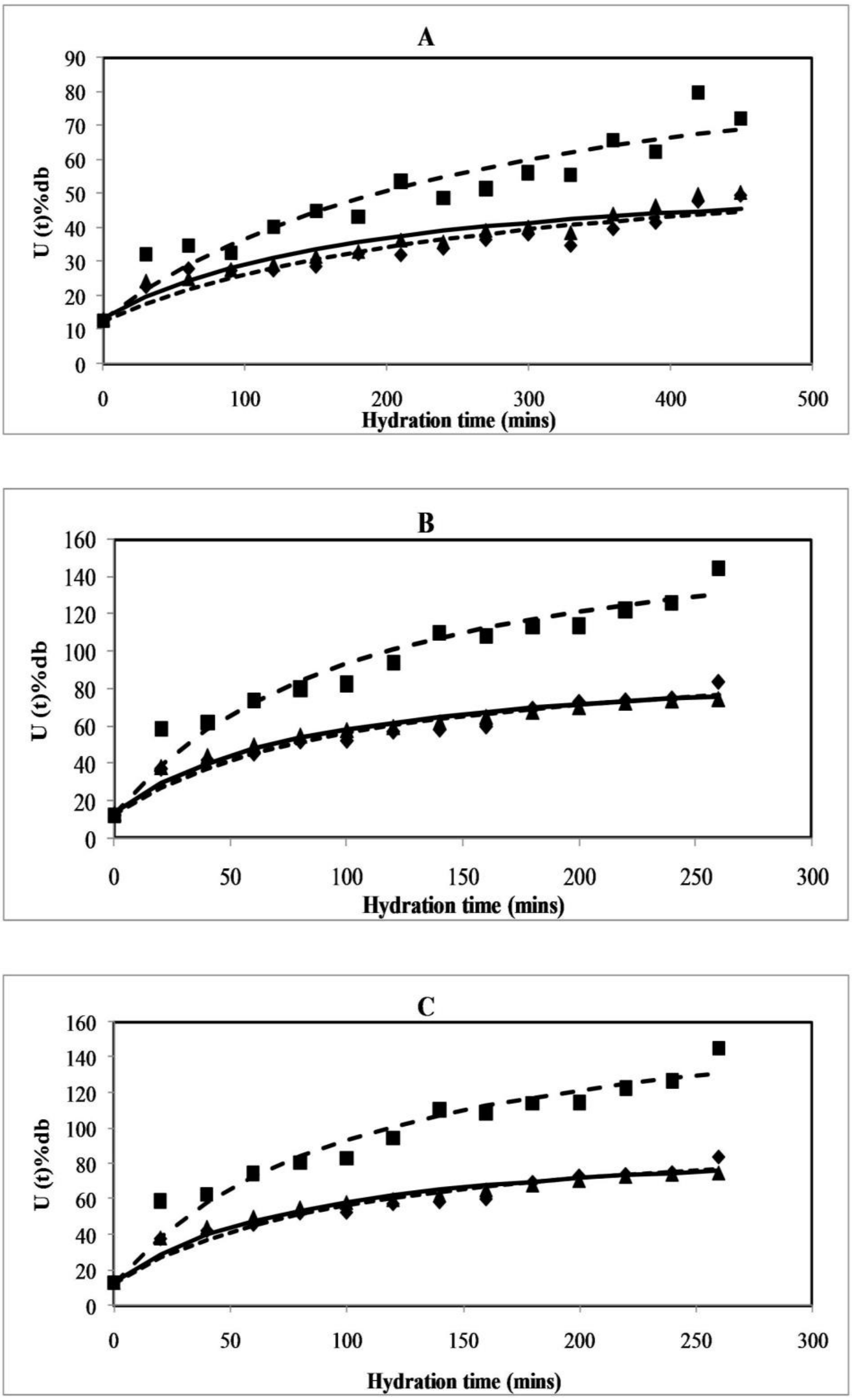


Figure 1. *Hydration curves showing experimental data fitted with predicted values of grain moisture content determined by Peleg's hydration model using model parameters estimated for three rice varieties (Nerica-19 (♦), Nerica-21 (■), and Rok-24 (▲)) hydrated in distilled water at temperatures of 30 (panel A), 50 (panel B) and 70 ℃ (panel C).*

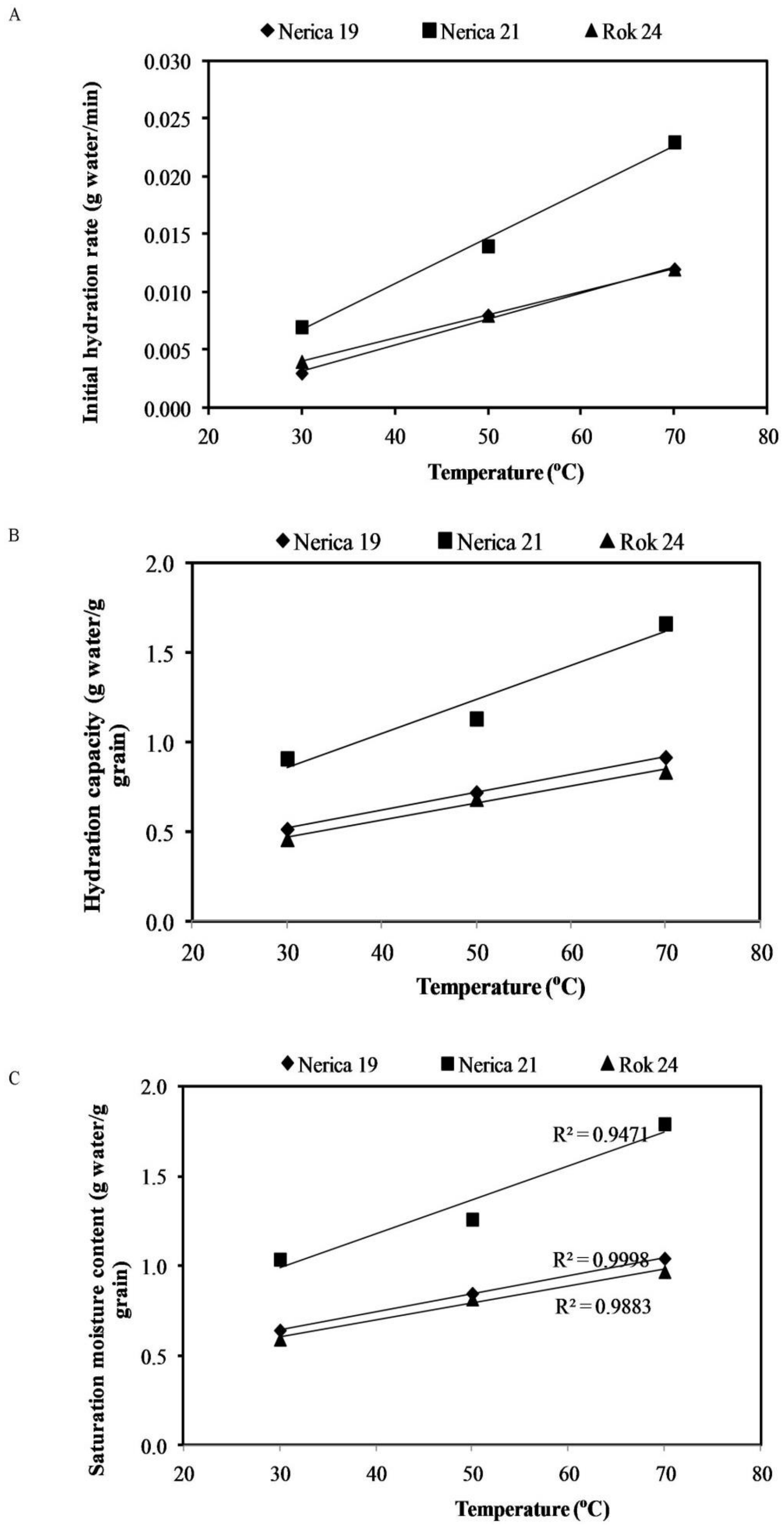


Figure 2. *Changes in some hydration properties of three rice varieties (Nerica-19 (♦), Nerica-21 (■), and Rok-24 (▲)) hydrated in distilled water with temperature; showing initial hydration rates (A), hydration capacity (B) and saturation moisture contents at temperatures of 30, 50 and 70 ℃.*

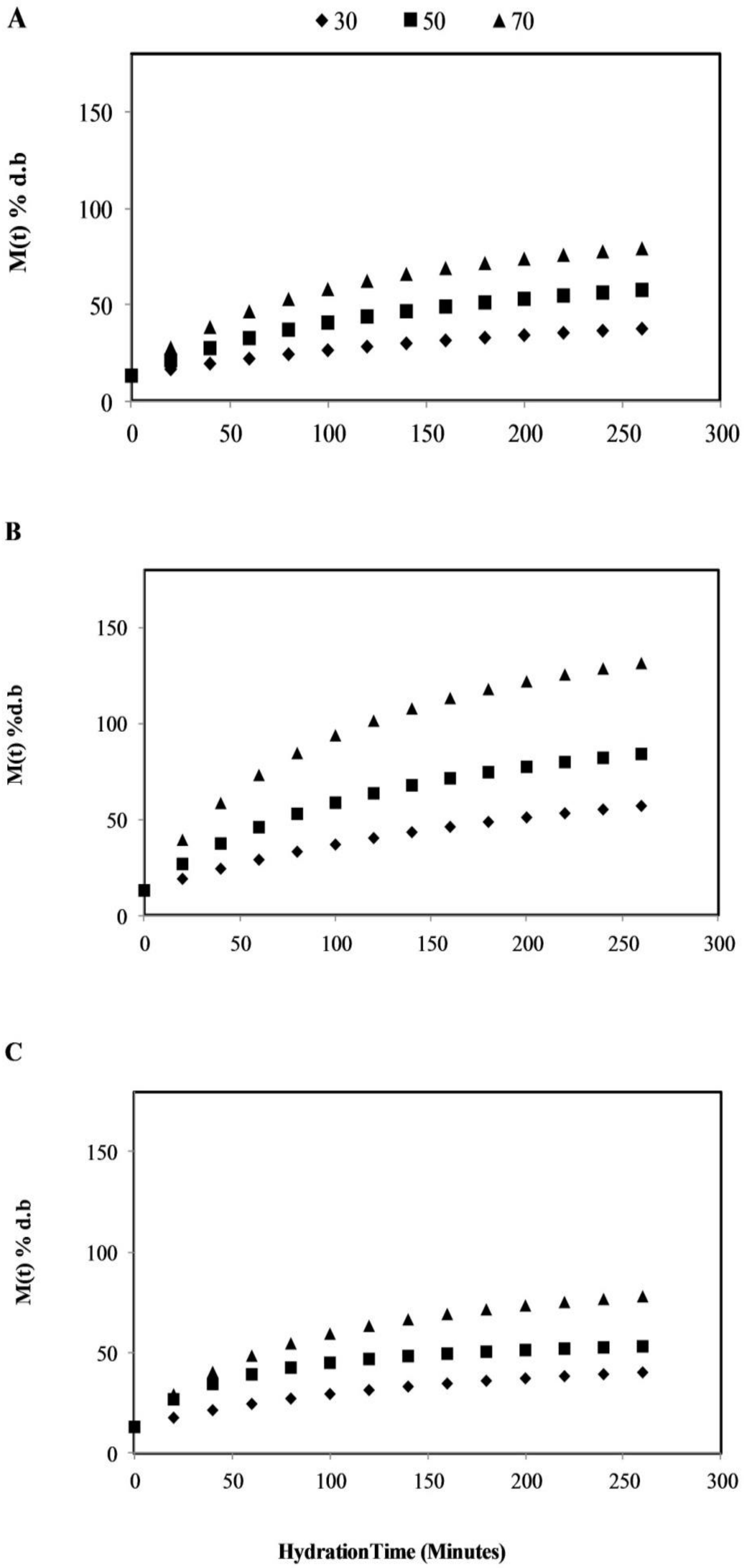
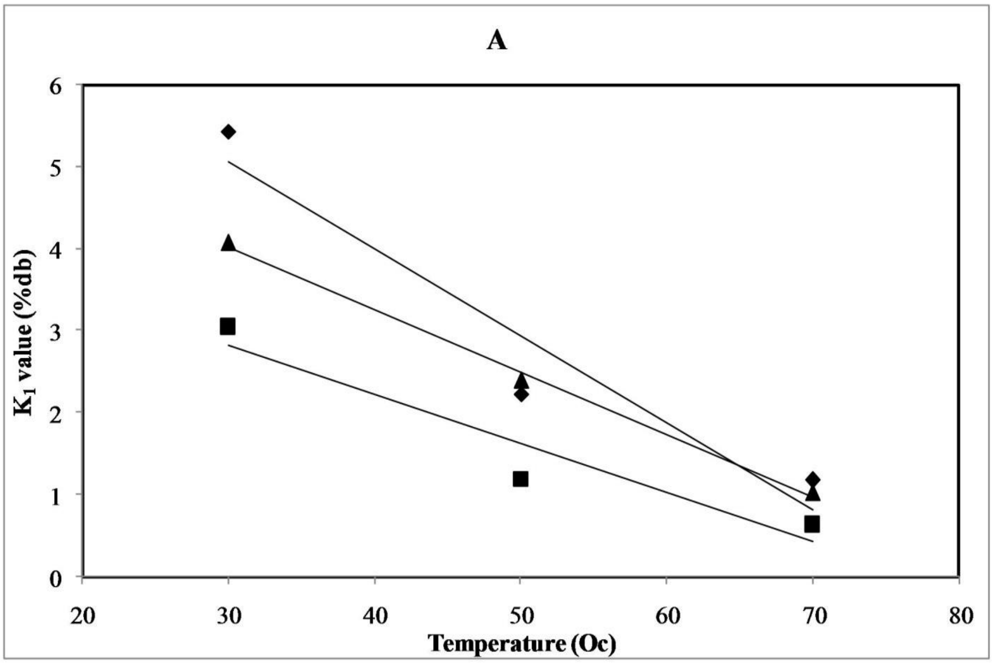


Figure 3. *Hydration curves plotted for predicted data fitted for Peleg's hydration model using model for parameters determined at hydration temperatures of 30 (♦), 50 (■), and 70℃ (▲) based on the values estimated for three rice varieties Nerica-19 (A), Nerica-21(B), and Rok-24(C).*



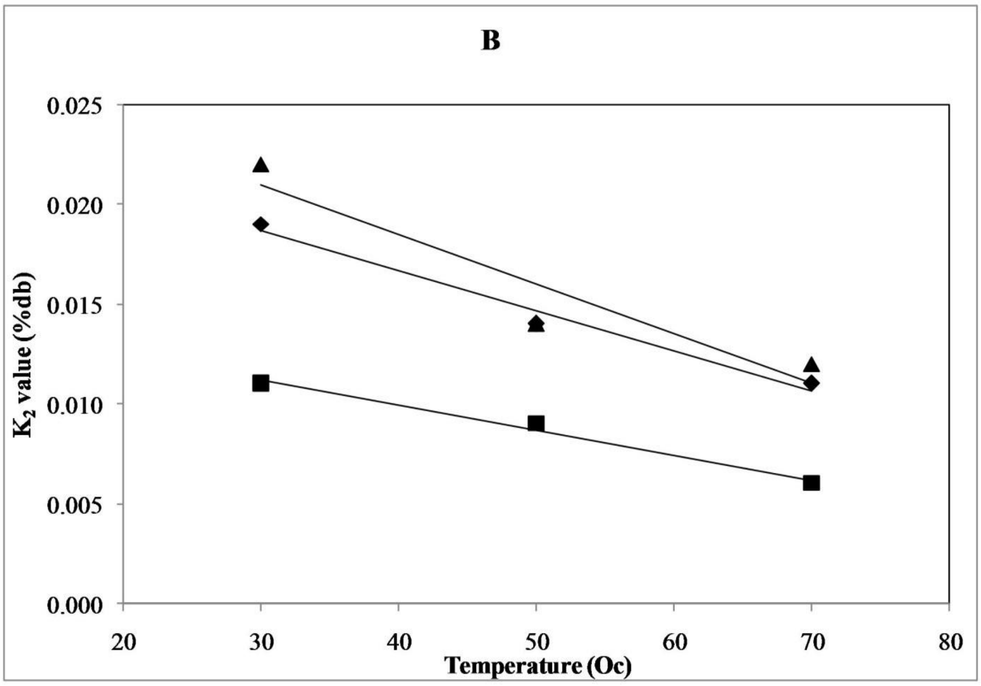


Figure 4. *Illustration of the temperature dependence of the two parameters k_1 (A), and k_2 (B) used in fitting Peleg's hydration model three rice varieties (♦Nerica-19, ■Nerica-21 and ▲Rok 24. See Table 3 for equations).*

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