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HIDRATION OF BEAN (*Phaseolus vulgaris*) VAR. "Pinto" BY ULTRASOUND

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Abstract *In order to evaluate the effect of ultrasound intensity in the hidration properties of bean var. pinto, three treatment were applied (5, 12 and 19 W at a frequency of 20 kHz and a temperature of 30 °C) and a control treatment. Data obtained by hydration kinetics were adjusted to three mathematic models (first order, Peleg and Sigmoid). Sigmoid model provided the best goodness fit. The effective difusivity of the treatments T1 (5 W 20 kHz), T2 (12 W 20 kHz), T3 (19 W 20 kHz), and T4 (control) was calculate using the value of k, with the following values* $3.76x10^{-10}$, $5.31x10^{-10}$, $10.1x10^{10}$ *and* $2.50x10^{-10}$ m^2s^{-1}, *respectively. Ultrasound reduced the time of soaking of bean, noting that more power provided to a higher water absortion and a partial separation of cotyledons (16.6%).*

1. INTRODUCTION

Bean (*Phaseolus vulgaris*), together with corn, constitute the staple diet of most Mexicans, and it is used in the preparation of various dishes. Prolonged preparation time stands out as one of the main problems in bean consumption [1], especially during soaking, since it requires an average of 12 hours at room temperature [2]

Some Works use the literature as factor to accelerate the hydration of bean [3][4], however, in more recent studies, emerging technologies are included as high hydrostatic pressure [5] and ultrasound [6]. Ultrasound (US) is important in mass transfer processes such as hydration [7]. Therefore, the aim of this work was to evaluate the effect of ultrasound treatment on the hydration kinetics and their modeling on bean var. Pinto.

2. MATERIALS AND METHODS

2.1.Raw material and its preparation

Bean var. Pinto was used, which is preferred to consumption a national level [8]. Beans were obtained from supply market in Tepic, Nayarit, Mexico. Seeds were cleaned and selected manually to remove foreign matter and damaged seeds.

2.2.Phisical and chemical characterization of beans

On chemical characterization was determined humidity (H), following method described by the AOAC [9].

On physical characterization was evaluated weight (p), length (l), width (w), thickness (d), mean geometric diameter (Gm), mean arithmetic diameter (Am), mean square diameter (Sm) and calculated radius (r) from 100 seeds, according to Gafhoor et al. [6]. See equations 1, 2, 3 and 4.

$$Gm = (lwd)^{1/3} \tag{1}$$

$$Am = \frac{l+w+d}{3} \tag{2}$$

$$r = \frac{1}{2}\left\{\frac{Gm + Am + Sm}{3}\right\} \tag{3}$$

$$Sm = \left(\frac{lw+wd+ld}{3}\right)^{1/3} \tag{4}$$

2.3.Determination of water absorption during soaking

Soaking of beans was development using a sonic equipment GE-130 Ultrasonic Processor, which worked at fixed frequency of 20 kHz and power of 5, 12 and 19 W, besides this, a treatment was development without ultrasound (control). A sample of 5 g of bean was placed in a beaker of 100 ml and 50 ml of distilled water at 30 °C were added. After, a probe was introduced up to 2 cm from the water surface. Sonic soaking treatments were made at regular intervals of 10 min, seeds were recovered at each interval, removing excess of water with a paper towel, weighing and retreated with ultrasound. Weighing process for the control treatment was performed every 30 min. The moisture content at each interval (Mt) was calculated using weight gain, taking into a count the initial sample mass (Mo), moisture (M), and the mass obtained in each time interval. The soaking treatments concluded at obtain equilibrium moisture or saturation (Me). Soak treatments were performed in triplicate.

2.4.Modeling of hydration kinetics

The water absorption data were fitted to models Peleg ([10]; eq. (5)), First order ([11]; eq. (6)) and Sigmoid ([3]; eq. (7)). This models are described below:

$$Mt = Mo + \left[\frac{t}{k1+k2t}\right] \tag{5}$$

$$\frac{Mo-Mt}{Mo-Me} = 1 - exp(-kt) \tag{6}$$

$$Mt = \frac{Me}{1+exp[-k*(\tau-t)]} \tag{7}$$

Where t is equal to time (min), Mo is the initial moisture content (% d.b.), Mt is moisture content at a given time (% d.b.), and Me is the moisture content in equilibrium or saturation, while k, τ, α, β, k1 y k2 are parameters of the models used, which were calculated by nonlinear regression using statistical package Statgraphics Plus version 4.0. ANOVA and Tukey test were performed using SPSS version 20, considering a significance level of $P<0.05$ to determine the effect of treatments on different parameters estimated. Additionally, effective diffusivity was evaluate according to method reported by Kaptso et al. [12] (Eq. 8).

$$k = \frac{\pi^2 D\text{eff}}{r^2} \tag{8}$$

Where D_{eff} (m^2s^{-1}) is effective diffusivity, k (s^{-1}) is the constant of rate diffusion of Sigmoid model obtained from Eq. 7, and r (m) is the value of calculated radius obtained from eq. 3.

Three criteria were used to evaluate the goodness of fit of each model, the coefficient of determination (R^2), root mean square error (RMSE) and chi-square (χ^2). RMSE gives the deviation between predicted and experimental values. The highest values of R^2 and the lowest values of χ^2 and RMSE are better adjustment. χ^2, RMSE and R^2 can be calculated with the equations 9, 10 and 11 respectively.

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,\,i}\right)^2}{N-z} \tag{9}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,\,i})^2\right]^{1/2} \tag{10}$$

$$R^2 = \frac{\sum_{i=1}^{N}(MR_{exp,\,i}-MR_{exp\ ave})^2-\sum_{i=1}^{N}(MR_{exp,\,i}-MR_{pre,\,i})^2}{\sum_{i=1}^{N}(MR_{exp,\,i}-MR_{exp\ ave})^2} \tag{11}$$

Wherein $MR_{exp,i}$ is the *ith* relation of experimental moisture, $MR_{pre,i}$ is the ith relation of predicted moisture, $MR_{exp\ ave}$ is the average moisture content oserved, N is the number of observations and Z is the number of constants.

2.5.Statistical analysis of results

To analyze the hydration process was used a completely randomized factorial design, with three replicates per treatment (Table 1). The unit experimental was 5g of bean seeds.

Table 1. Experimental design to hydration of bean var. "Pinto"

Soaking conditions	Treatments			
	1	2	3	4 (Control)
Temperature (°C)	30	30	30	30
Power (W)	5	12	19	-
Frequency (kHz)	20	20	20	-

°C = grado Celsius. W = watt. kHz = kilohertz.

3. RESULTS AND DISCUSSION

According to physical characterization, average data obtained were moisture (M) 11.02 ± 0.38%, weight (p) 0.36 ± 0.05 g, large (l) 1.25 ± 0.08 cm, width (w) 0.73 ± 0.05 cm and thickness (d) 0.56 ± 0.05 cm. From these data, the value of the geometric mean diameter (Gm), arithmetic mean diameter (Am), mean square diameter (Cm) and the calculated radius (r) were estimated at 0.79 ± 0.04 cm, 0.85 ± 0.05cm, 0.41 ± 0.01 cm and 0.34 ± 0.02 cm respectively.

The water absorption kinetics of bean var. pinto in different treatments are shown in figure 2.

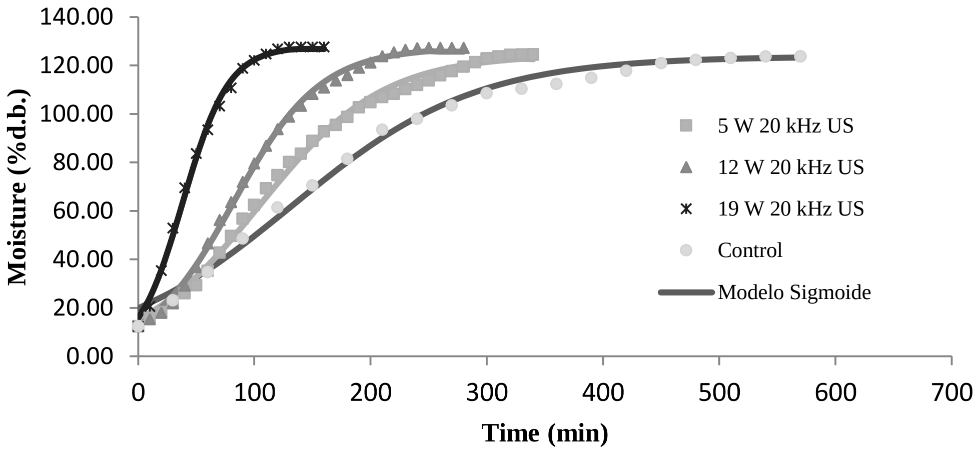

Figure 2. Average moisture content from predicted values by Sigmoid model and experimental ones (% d.b.) of bean var. pinto during different treatments of soaking. 5W 20kHz, 12W 20kHz, 19W 20kHz, Control, Sigmoid model.

Most of studies are based on the use of theoretical models to describe mathematically the transport of liquid water, however, transport of water can be described not only as a diffusion process [13]. Therefore, it is necessary to evaluate empirical models to accurately predict the kinetics of hydration.

First order and Peleg model are widely used to describe food hydration kinetics [1][2][6], however, experimental values of kinetics hydration of treatments 1 (5 W 20 kHz US), 2 (12 W 20 kHz US) and the control (without US) had an initial phase of latency o delay, resulting in a low absorption rate in the initial phase, which was noted in the low values of R^2 (0.922 – 0.994) and high values of χ^2 (0.014 - 0.002) and RMSE (0.112 - 0.038). Piergiovanni [1] classified in three groups in relation to their hydration rate. The seeds belonging to the groups with rapid or intermediate hydration rate showed no initial lag phase; the slow hydration of the seeds is characterized by display an initial lag phase.

Table 2. Constants and statistical estimators of the models Sigmoid, first order and Peleg adjusted to experimental data of hydration of vean var. Pinto.

			5 W 20 kHz US		
	R^2	χ^2	RMSE	Constante	Constante
Sigmoid	0.996	0.001	0.024	k= 0.0190	τ = 104.5164
First order	0.940	0.009	0.091	k= 0.00742549	
Peleg	0.979	0.003	0.053	k1= 156.8111	k2= 0.3657
Weibull	0.998	0.000	0.016	α= 139.9523	β= 1.6079
			12 W 20 kHz US		
	R^2	χ^2	RMSE	Constante	Constante
Sigmoid	0.998	0.000	0.019	k= 0.02681369	τ = 82.2123331
First order	0.922	0.014	0.112	k= 0.00965895	
Peleg	0.971	0.005	0.067	k1= 123.7158	k2= 0.3115
Weibull	0.999	0.000	0.014	α= 107.8498	β= 1.7888
			19 W 20 KHZ US		
	R^2	χ^2	RMSE	Constante	Constante
Sigmoid	0.997	0.001	0.023	k= 0.0510	τ = 38.6611
First order	0.951	0.009	0.087	k= 0.02050382	
Peleg	0.979	0.004	0.057	k1= 51.4853	k2= 0.4301
Weibull	0.999	0.000	0.013	α= 51.5790	β= 1.5884
			Control		
	R^2	χ^2	RMSE	Constante	Constante
Sigmoid	0.997	0.001	0.027	k= 0.0126	τ = 131.7551
First order	0.991	0.002	0.046	k= 0.00576187	
Peleg	0.994	0.002	0.038	k1= 160.6798	k2= 0.5697
Weibull	0.999	0.000	0.013	α= 181.539392	β= 1.3364

Data represent the average (n=3). R^2= coeficient of determination, χ^2= Chi-cuadrada, RMSE= root mean square error.

The sigmoid model includes the initial lag phase and this model provided the best fit to experimental data since were observed higher values of R^2 and lower values of χ^2 and RMSE (Table 2), this was reflected in the graph of the kinetic of water absorption (Figure 1). For sigmoid model, constant k describes water absorption rate of the seeds (Table 2); k increased in value as the increase of ultrasound power. The treatment with higher power (19 W) presented the highest value of k (0.0510), being control which had the lowest value (0.0126).

Constant tau (τ) is defined as the time required to reach medium saturation (50%) of the seeds, which was decreasing at higher power ultrasound, control treatment (without ultrasound) presented the highest value. This downward trend is similar to reported by Kaptson et al. [12], that increasing the temperature of soaking of cowpea seeds and bambara groundnut, the τ value was lower.

It is difficult to compare the water diffusivity reported in the literature with data obtained in this investigation, because different methods are used to determine this, besides, foods with different dimensions and chemical compositions are used. In the present study was used the parameter *k* from Sigmoid model to calculate the effective diffusivity (D_{eff}). The effective diffusivity and the equilibrium moisture (Me) increased as increased power of ultrasound (5 W, 12 W y 19 W) as shown in table 3. In figure 1 is observed the effect of ultrasound in the reduction of time of hydration compared with the control. This behavior is similar to sonic soaking of chickpeas reported by Yildirim et al. [14]. It is noteworthy that treatment 3 (19 W) was the only one in rupturing pericarp (Table 3), suggesting that ultrasound may have damaged the pericarp of seeds and caused their breakup.

Table 3. Properties of hydration of bean sedes var. Pinto at 30 °C and 20 kHz by effect of ultrasound power.

Properties of hydration	5 W	12 W	19 W	Control
Equilibrium moisture (Me %g/g d.b.)	124.46^b	127.24^a	127.69^a	123.72^b
Time to reach Me (min)	320^b	240^c	123^e	540^a
Effective difussivity (D_{eff} x10^{-10} m^2s^{-1})	3.76^c	5.31^b	10.1^a	2.5^d
Rupture of pericarp (%)	-	-	16.6^a	-

Data represent the average of n=3. Means with the same superscript along lines are not significantly differents at P<0.05. Tukey's Test.

4. CONCLUSIONS

Treatment 1 (5 W 20 kHz US), 2 (12 W 20 KHz US) and the control presented initial lag phase, decreasing the goodness fit of the models Peleg and First Order. From the models used, the Sigmoid model presented the best goodness fit, it had the higher values of R^2 and the lowest of RMSE and χ^2.

The ultrasound in the soaking of bean var. pinto increase significantly the diffusion rate in relation with time of soaking and the ultrasound power (5, 12 and 19 W). Treatment 3 (19 W 20 kHz) had the highest value of effective diffusivity $10.1\mathrm{x}10^{-10}$ m^2s^{-1}, higher moisture content 127.69 (% d.b.) and the shortest time to reach equilibrium moisture (123 min), however, this presented breaks in the pericarp of 16% of seeds.

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