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Water Absorption and Physical Characteristics of Maize (Zea mays L.) Varieties

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Abstract: In this study, the water absorption and physical characteristics of maize varieties were studied. The physical dimensions determined. Water absorption and the moisture gains of the maize seed during immersion in water were determined at 50,70 and 90°C by recording the weight increase of the seed with respect to soaking time. A nonlinear moisture diffusion equations was used to modelling of the water absorption curves of the maize varieties at studied temperatures. Page equation and exponential rise equation were chosen for modeling the water absorption of maize in this study. R2 values ranged between 0.9793-0.9934 for the predictions of Page's equation and between 0.9728-0.9899 for the predictions of exponential rise equation. The values of RMSE ranged 0.0453-0.1291 and the values of and MBE ranged -0.0017 / -0.0071. All these indicators showed that both model made predictions close to perfect fit. However, Page's equation was recommended for representing the water absorption of maize because of its simplicity.

Keywords: Maize, mathematical modeling, moisture, physical characteristics

Farklı Mısır (Zea mays L.) Çeşitlerinin Nem Alma ve Fiziksel Özelliklerinin Belirlenmesi

Öz: Bu çalışmada, mısır çeşitlerinin fiziksel ve nem alma özellikleri incelenmiştir. Fiziksel boyutlar ölçülmüştür. Suya daldırma işlemi 50, 70 ve 90°C'e sıcaklıklarda mısır tohumunun nem alması, tohumun ağırlık artışı kaydedilerek belirlenmiştir. Lineer olmayan nem alma oranları belirlenen sıcaklılar ve her çeşit için ayrı ayrı matematiksel olarak modellenmiştir. Nem alma işlemini modellemek için Page ve Exponential rise eşitlikleri kullanılmıştır. Modelleme işlemi sırasında belirlenen R^2 değerleri Page eşitliği için 0.9793-0.9934 arasında, Exponential rise eşitliği için 0.9728-0.9899 arasında bulunmuştur. RMSE değerleri 0.0453-0.1291 ve MBE değerleri -0.0017 / -0.0071 arasında değişmektedir. Tüm bu göstergeler her iki modelin de mükemmel uyuma yakın tahminler yaptığını göstermiştir. Bununla birlikte, basitliği nedeniyle mısırın nem alma işlemini en iyi Page eşitliği tahmin etmiştir.

Anahtar kelimeler: Mısır, matematiksel modelleme, nem, fiziksel özellikler

1. Introduction

Maize is widely cultivated and consumed of all cereals after wheat and rice in the world. Zea mays seed is important sources of the carbohydrate and protein. World maize production is 875.1 million tonnes and Turkey produces about 5.9 million tonnes of Zea mays annually (Anonımous 2018).

The physical properties are necessary considerations in the design and effective utilization of the machine used in the post harvest technologies such as processing, transportation, , storage and packaging teratmentsof biological materials.. The water absorption of maize in soaking is related to the changes in textural characteristics of maize for processing (Torres et al. 2018). The water absorption characteristics of maize seeds are needed to the design of the processing equipment and to optimize the soaking conditions (prediction of time and temperature).

In preparing a product from maize and other cereals, hydration and cooking characteristics, the rate of water absorption are important in the formulation of foods. The addition of dry ingredients into the mixture and a dry ingredient need to the mixture are affected by the rate of water uptake of maize seed (Pilosof et al. 1985). Processing of maize seeds often requires that the seeds be hydrated first to facilitate operations such as cooking or canning. The principal reason for soaking is to gelatinize the starch in the grain which can either be achieved either through conditioning below the gelatinization temperature and then cooking above the gelatinization temperature or through direct cooking above the gelatinization temperature. Understanding water absorption in seeds during soaking is of practical importance as it governs subsequent operations and quality of the final product. (Turhan et al. 2002).

Several researchers have investigated the physico- mechanical characteristics and water absorption characteristics of soybean (Pan and Tangratanavalee 2003), kidney bean (Abu-Ghannam 1998), wheat and barley (Murammatsu et al. 2006), chickpea (Turhan et al. 2002). However, studies conducted on the and water absorption and physical characteristics of Zea mays varieties have not been adequately or comparatively studied. The objective of this study was to investigate the water absorption and physical characteristics of maize varieties at high soaking temperature as 50, 70 and 90°C.

2. Materials and methods

In this study, the maize seeds were obtained from Department of Field Crops, Gaziosmanpasa University, Faculty of Agriculture, Tokat-Turkey. The maize seeds were manually cleaned to remove dust, immature and broken grains, foreign matter, and dirt. The initial moisture content of the seeds was determined by hot-air oven methods at 105 ± 1˚C for 24 h (Suthar and Das 1996; Battilani et al. 2011). One hundred seeds were randomly selected to determine the maize size. The size dimensions (length, width and thickness) were measured using a dial-micrometer (Accuracy; 0.001 mm). The maize seed mass and 1000-seed mass (m_{1000}) measured using a digital electronic balance with a resolution of 0.001 g. The sphericity (Φ), geometric mean diameters (D_g), volume (V), surface area (S) of maize seed were determined methods presented by Mohsenin (1970).

The water absorption characteristics of maize seeds were determined by soaking experiment and modeling techniques. This experiment was carried out on different of miaze varieties (Helen, Shemal and P32 W) at 50°C, 70°C, and 90±1°C water temperatures in a thermostatic water bath. Before the start of the experiments, the beakers, distilled water and seeds were equilibrated at the required temperatures, so that the initial temperature of the immersing fluid, the seeds and beakers were almost equal to the temperature studied. The samples were removed at predetermined time interval of 15 min, thereafter, the time interval was shifted to 30 min. At specific time intervals, the seeds were removed from the water, blotted dry of excess water and then weighed using an electronic balance. The increase in sample mass during soaking in water was considered to be an increase in sample moisture content. The saturation moisture content was determined when the subsequent increase in weight of soaked grain was less than 0.001 g. Three replicates were performed for each variety at the temperature range studied. Similar methods have been reported by Turhan et al. (2002), Maskan (2002).

2.1. Modelling

In this study three maize varieties and three different temperatures (50°C, 70°C and 90°C) are used. Each experiment moisture gain was determined by determining the weight increase of samples with a balance having the sensitivity of 0.001. Before each weighing, water drops remaining on the surface of the maize grains are removed. During the experiment, the first two weight measurement was performed in 15-minute intervals, further weight measurements were performed in 30-minute intervals.

$$MR = \frac{M - M_0}{M_e - M_0} \tag{1}$$

In the above equation MR is the moisture ratio, M is the moisture content of material at any sampling time (db%); Me the equilibrium moisture content of material based on drying conditions (db%); M0 is the initial moisture content of material (db%).

Mathematical models used in the present study are listed below (Khazaei 2008)

1. Page

$$MR = t / (a + (b \times t)) \quad (2)$$

2. Exponential Rise to Maximum; Single, 2 Parameter

$$MR = a \times (1 - \exp(-b \times x)) \quad (3)$$

In the above equation "t" represents time of treatment, while the other variables represent the model parameters. One-way analysis of variance (ANOVA) was performed blocking on replication because uncontrolled variables differed between replications. Duncan's New Multiple-range test was performed for comparison of mean values. The effects of water absorption on moisture content were statistically analyzed.

3. Results and discussion

3.1.Physical chracteristics

The effects of water absortion characteristic of maize varieties at high soaking temperature as 50, 70 and 90°C on physical properties such as size, sphericity, surface area and volume were determined. Initial moisture ratios of seed maize for Helen, Shemal and P32W86 varieties were 11.8%, 11.6% and 12.1% respectively.

3.2. Size dimension and sphericity

The average length (*L*), width (*W*), thickness (*T*) and thousand seed mass (m_{1000}) of maize varieties were as 13.35 mm, 8.30 mm, 4.36 mm and 402.79 g (Helen); 12.64 mm, 7.88 mm, 3.76 mm and 414.96 g (Shemal); 11.54 mm, 8.30 mm, 4.13 mm and 400.84 g (P32W86), respectively (Table 1). The size dimensions (L, W and T) were higher in Helen variety, whereas, thousand seed mass (m_{1000}) of maize was higher in Shemal variety.

Table 1. Physical characteristics of maize seed for Helen, Shemal and P32W86 varieties.
Çizelge 1. *Helen, Shemal ve P32W86 çeşitleri için mısır tohumunun fiziksel özellikleri*

Physical characteristics properties	Maize varieties		
	Helen	Shemal	P32W86
Length, *L* (mm)	13.35 (0.604)*	12.64 (0.964)	11.538 (0.882)
Width, *W* (mm)	8.30 (0.726)	7.88 (0.514)	8.297 (0.736)
Thickness, *T* (mm)	4.36 (0.616)	3.76 (0.519)	4.125 (0.271)
Thousand seed mass, m_{1000} (g)	402.79 (23.18)	414.96 (27.53)	400.84 (16.67)

(*): standard deviation

The average geometric mean diameters (D_g) of maize seeds ranged from 9.21 to 9.81 mm (Helen), 8.62 to 9.35 mm (Shemal) and 8.48 to 9.42 mm (P32W) as soaking temperature increased from 50°C to 90°C, respectively. The average D_g was found as 7.81 mm, 7.17 and 7.31 mm in Control. The geometric mean diameters of maize seeds increase of 6.51%, 8.47% and 11.07% observed in Helen, Shemal and P32W varieties as soaking temperature increased from 50°C to 90°C, respectively. The size dimensions were higher in Helen variety than the other maize varieties, whereas, Helen was lower increase according to geometric mean diameter than Shemal and P32W varieties. The relationship the soaking temperature (S_k) and geometric mean diameter (D_g) of maize varieties linear can be represented by the regression equations:

For Helen: $D_g = 0.618S_k + 7.513$ ($R^2 = 0.847$)
For Shemal: $D_g = 0.653S_k + 6.805$ ($R^2 = 0.8519$)
For P32W: $D_g = 0.660S_k + 6.841$ ($R^2 = 0.935$)

The values of geometric mean diameter and sphericity of maize seeds and the results obtained are presented in Figure 1. The average sphericity for maize varieties under soaking temperature were as 0.586, 0.570 and 0.635 (Control); 0.604, 0.612 and 0.653 (50°C); 0.652, 0.611 and 0.647 (70°C); 0.690, 0.656 and 0.716 (90°C) for Helen, Shemal and P32W maize varieties, respectively (Fig 2). The sphericity of maize seeds increase of 14.13%, 7.24% and 9.64% occurred with soaking temperatures from 50 to 90°C, respectively. The sphericity was higher in P32W than those of Helen and Shemal varieties. The relationship the soaking temperature (S_k) and sphericity (ϕ) of maize varieties linear can be represented by the regression equations:

For Helen: $\phi = 0.036\ S_k + 0.544$ (R^2 =0.974)
For Shemal: $\phi = 0.026\ S_k + 0.548$ (R^2 =0.895)
For P32W: $\phi = 0.024\ S_k + 0.604$ (R^2 =0.710)

Similar trends of increase geometric mean diameters of maize seeds have been reported by Princewill and Ezinne (2014) for brown-speckled African yam bean.

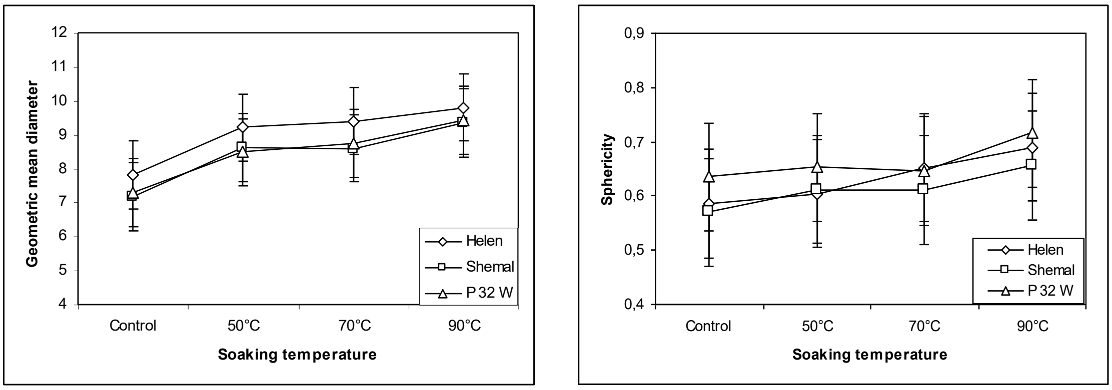

Figure 1. Effect of soaking temperature on geometric mean diameter (mm), sphericity of maize seeds for Helen, Shemal and P32W varieties.
Şekil 1. *Nem alma suyu sıcaklığının Helen, Shemal ve P32W çeşitleri için geometrik ortalama çap (mm), mısır tohumlarının küreselliği üzerine etkisi.*

3.3.Surface area and volume of seed

The values of surface area and volume of maize seeds and the results obtained are presented in Figure 2. The average surface area for maize varieties at soaking temperatures linearly increased from 267.09 to 302.98 mm^2, 234.08 to 275.18 mm^2 and 226.85 to 279.41 mm^2 in magnitude with an increase in soaking temperatures, respectively (Fig. 2). The surface area of maize seeds increase of 13.44%, 14.56% and 23.17% occurred for Helen, Shemal and P32W varieties, respectively. The surface area were higher in Helen than the other varieties. The relationship the soaking temperature (S_k) and surface area (S) of maize varieties linear can be represented by the regression equations:

For Helen: $S = 34.34S_k + 174.58$ (R^2 =0.865)
For Shemal: $S = 34.872S_k + 41.26$ (R^2 =0.887)
For P32W: $S = 34.664S_k + 141.98$ (R^2 =0.945)

The average volume of seed for maize varieties under soaking temperatures were as 414.66, 340.25 and 324.86 mm^3 (50°C); 444.17, 372.06 and 352.18 mm^3 (70°C); 501.17, 433.18 and 443.08 mm^3 (90°C); 254.29, 195.25 and 207.11 mm^3 (Control) for Helen, Shemal and P32W maize varieties, respectively (Fig 2). The volume of maize seeds increase of 20.86%, 27.31% and 36.39% occurred with soaking temperatures from 50 to 90°C, respectively. The volume was higher in P32W than those of Helen and Shemal varieties. The relationship the soaking temperature (S_k) and volume of seed (V) of maize varieties linear can be represented by the regression equations:

For Helen: $V = 77.015S_k + 211.03$ (R^2 =0.883)
For Shemal: $V = 74.559S_k + 148.79$ (R^2 =0.909)
For P32W: $V = 73.521S_k + 148.00$ (R^2 =0.952)

Similar trends of increase volume of maize seeds have been reported by Princewill and Ezinne (2014) for brown-speckled African yam bean.

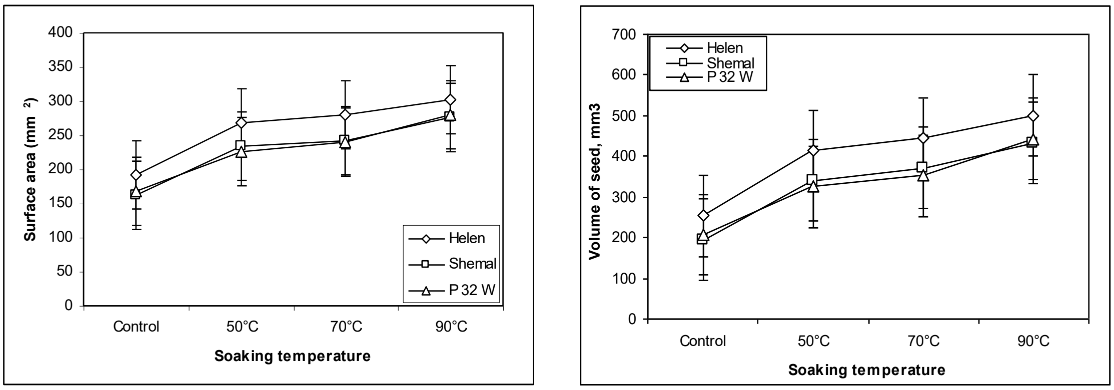

Figure 2. Effect of soaking temperature on surface area (mm^2), volume of maize (mm^3) seeds for Helen, Shemal and P32W varieties.
Şekil 2. *Nem alma suyu sıcaklığının Helen, Shemal ve P32W çeşitleri için yüzey alanı (mm^2), mısır tohumu hacmi (mm^3) üzerine etkisi.*

3.4. Modelling results

Parameters and goodness of fit values for mathematical water absorption models of maize varieties (R^2, RMSE and MBE) are given in Table 2.

Table 2. Parameters and goodness of fit of mathematical water absorption models of maize varieties
Çizelge 2. *Mısır çeşitlerinin matematiksel nem alma modellerinin uygunluk parametreleri ve iyiliği*

MODELS		MAIZE VARIETY AND SOAKING TEMPERATURES								
		HELEN			SHEMAL			P 32 W		
		50°C	70°C	90°C	50°C	70°C	90°C	50°C	70°C	90°C
PAGE	a	1,1522	1,0840	1,0392	1,2088	1,2131	1,3547	1,3167	0,9618	1,2325
	b	0,8280	0,7874	0,6533	0,7959	0,7609	0,5132	0,7862	0,8148	0,509
	p	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
	R^2	0,9930	0,9934	0,9797	0,9934	0,9927	0,9817	0,9928	0,9981	0,9793
	MBE	-0,0058	-0,0052	-0,0053	-0,0062	-0,0059	-0,0064	-0,0071	-0,0017	-0,0068
	RMSE	0,0889	0,0830	0,1190	0,0889	0,0873	0,1144	0,0918	0,0453	0,1291
EXPONENTIAL RISE;	a	0,9634	0,9903	1,0971	0,9912	1,0056	1,3066	0,9920	0,9701	1,3518
	b	0,6938	0,7415	0,7648	0,6540	0,6681	0,5197	0,6082	0,8448	0,5475
	p	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
	R^2	0,9813	0,9844	0,9727	0,9850	0,9847	0,9785	0,9839	0,9899	0,9755
	MBE	-0,0133	-0,0113	-0,0086	-0,0132	-0,0115	-0,0087	-0,0141	-0,0070	-0,0095
	RMSE	0,1455	0,1273	0,1380	0,1336	0,1261	0,1242	0,1374	0,1032	0,1406

According to Table 2 all of the models are significant because the “p” values are smaller than 0.05. Model goodness of fit values (R^2, RMSE and MBE) confirmed that there were no biases or inaccuracy in predictions. The coefficient of determinations for Page’s equation are determined between 0.9793-0.9934 and for Exponential rise equation are determined between 0.9728-0.9899 so they were close to 1 (perfect fit) while the values of RMSE and MBE were very close to zero (no deviation). Therefore, Page’s equation was determined to be an easy to use model for representing the water absorption of maize. In previous studies, Page equation has been selected as the most appropriate equation for modeling Moisture ratio (MR) (Mohsenin 1986; Khazaei 2008; Lin 1993). Time-dependent changes of moisture ratio are given in the following figures according to water temperatures. The predictions made with Page and Exponential rise equations for Helen, Shemal and P-32 W maize varieties are presented in Figure 3 and 4, respectively.

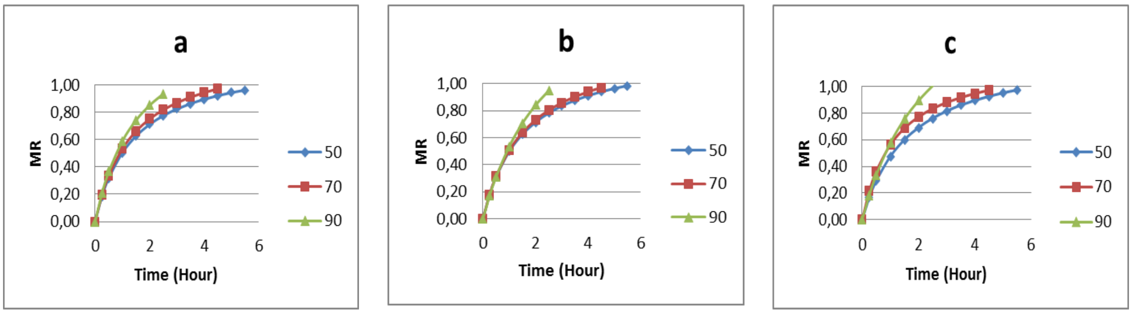

Figure 3. The predictions made with Page equation (a: Helen variety, b: Shemal variety, c: P-32 W variety)

Şekil 3. *Page eşitliği ile yapılan tahminler (a: Helen çeşidi, b: Shemal çeşidi, c: P-32 W çeşidi)*

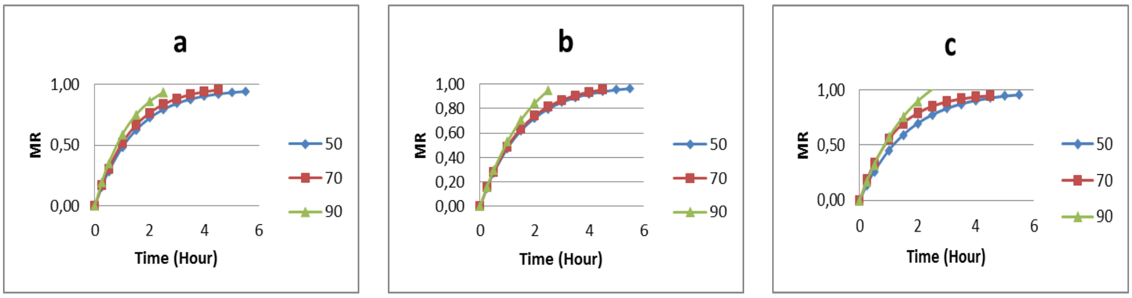

Figure 4. The predictions made with exponential rise equations (a: Helen variety, b: Shemal variety, c: P-32 W variety)

Şekil 4. *Exponential rise eşitliği ile yapılan tahminler (a: Helen çeşidi, b: Shemal çeşidi, c: P-32 W çeşidi)*

4. Conclusion

The water absorption and physical characteristics of maize varieties (Helen, Shemal and P32W) are highly dependent on soaking temperatures (50,70 and 90°C).

1. As soaking temperature increased from 50°C to 90°C, respectively, the geometricmean diameter of maize seed for Helen was higher than Shemal and P32W varieties. The sphericity was higher in P32W than those of Helen and Shemal varieties.

2. The surface area increase of maize seeds was lower for Helen than Shemal and P32W varieties, whereas the surface area values were higher in Helen than the other varieties. The volume was higher in P32W than those of Helen and Shemal varieties.

3. For the predictions of Page's and Exponential rise equations equation, R^2 values were higher in Page equation than Exponential rise equations.

4. Page's equation was recommended for representing the water absorption of maize because of its simplicity.

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