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Effect of Ultrasound Pre-treatment on the Physical Characteristics of Corn During Drying

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ABSTRACT

In this study, the effect of some pre-treatments (conventional and 40 kHz 200 W ultrasound soaking) on corn drying was studied. One-hour pre-treated corn samples were dried at 80, 90 and 100 °C in the laboratory type convective air dryer for 240 min time. The moisture contents and physical characteristics such as length, width, thickness, equivalent diameter, equivalent volume, sphericity, thousand kernel weight and hectoliter weight of pre-treated corn samples at each temperature were analyzed for every 60 min during 240 min drying. When the conventional and ultrasound soaking pre-treatments were compared in the temperature range of 80-100 °C during 240 minutes drying of corn, the changes in the reduction rates in moisture content, thousand-kernel weight, hectoliter weight, equivalent diameter and equivalent volume values were 77-86% and 87-90%, 24-27% and 26-29%, 10-13% and 19-20%, 3-10% and 4-9%, 9-25% and 11-25%, respectively. When the results of the research were analyzed, the effect of ultrasound pre-treatment, drying temperature and drying time on moisture content, dimensions (length, width, thickness), equivalent diameter, equivalent volume, sphericity, thousand kernel weight and hectoliter weight of corn grains were found to be significant ($P \leq 0.05$).

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ÖZET

Bu çalışmada, bazı ön işlemlerin (geleneksel ve 40 kHz 200 W ultrases ıslatma) mısırın kurutma sırasındaki etkisi incelenmiştir. Bir saat ön işlem görmüş mısır numuneleri, laboratuvar tipi konveksiyon hava kurutucusunda 80, 90 ve 100 °C'de 240 dakika süreyle kurutulmuştur. 240 dakikalık kurutma süresince her 60 dakikada bir ön işlem görmüş mısır numunelerinin uzunluk, genişlik, kalınlık, eşdeğer çap, eşdeğer hacim, küresellik, bin tane ağırlığı ve hektolitre ağırlığı gibi fiziksel özellikleri ve nem miktarları analiz edilmiştir. Mısırların 240 dakikalık kurutma sırasında 80-100 °C'lik sıcaklık aralığı için geleneksel ve ultrases ıslatma ön işlemleri kıyaslandığında, nem, bin tane ağırlığı, hektolitre ağırlığı, eşdeğer çap ve eşdeğer hacim değerlerindeki azalma oranlarının değişimleri sırasıyla %77-86 ve %87-90, %24-27 ve %26- 29, %10-13 ve %19-20, %3-10 ve %4-9, %9-25 ve %11-25 şeklinde olmuştur. Araştırmanın sonuçları analiz edildiğinde, ultrasonik ön işleminin, kurutma sıcaklığının ve kurutma süresinin mısır tanelerinin nem içeriğine, boyutlara (uzunluk, genişlik, kalınlık), eşdeğer çap, eşdeğer hacim, küresellik, bin tane ağırlığına ve hektolitre ağırlığına etkisi önemli bulunmuştur ($P \leq 0.05$).

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INTRODUCTION

Corn is one of the most important plants in the world that is widely used in the food, chemical, pharmaceutical and agricultural industries due to its high starch content (Miano et al., 2017). Its homeland is America, and it is known that it spread all over the world from here. It came to Turkey from Egypt through Syria in 1600.

The ripening of the corn is understood from the part where the grain is attached to the cob. If there is a black spot at this tip, it is an indication that the ripening of the grain has been completed. Average corn moisture is around 30% and it is suitable for harvesting (Babaoglu, 2005). The drying process is very important, as corn is a product that can be susceptible to mold and deterioration if not properly dried after harvest. When the ideal corn moisture is 20-28%, it is harvested and dried under suitable conditions and the ideal moisture content is reduced to 12-14%.

Open air drying and hot air-drying methods are frequently used in corn drying in Turkey. While open air drying is preferred in rural areas, hot air drying is the most common technique used for drying corn in industrial applications. The hot air-drying method has some disadvantages such as low thermal conductivity, long drying time and quality deterioration in terms of nutritional values. For this reason, new techniques are being developed that increase drying rates and improve product quality (Tuncel et al., 2010).

Ultrasonics are a pressure wave with a frequency in the range of 20 kHz-100 kHz above the hearing limit of the human ear. Sound waves are used in the food industry for pasteurization, sterilization, formation of chemical reactions, acceleration of oxidation, acceleration of fermentation, inhibition of enzyme activity, formation of emulsions, extraction, crystallization, drying, hydration, filtration and gas removal (Yıldırım et al., 2009; Ulusoy and Karakaya, 2011).

Some researchers have studied ultrasound application on food such as; potatoes (De la Fuente-Blanco et al., 2006), rice (Jafari and Zare, 2017), banana (Fernandes and Rodrigues, 2007), melon (Fernandes et al., 2008), soybean (Karki, 2009), pineapple (Fernandes et al., 2009), strawberry (Garcia-Noguera et al., 2010), apple (Nowacka et al., 2012), red bell pepper (Schossler et al., 2012), green pepper (Szadzińska et al., 2017) and carrot (Chen et al., 2016). The results of some of the aforementioned studies have shown that ultrasound application significantly reduces the drying time (Carcel et al., 2007; Garcia-Perez et al., 2007; Rodriguez et al., 2014). Tüfekçi and Özkal (2015) reported that in the drying of foods, ultrasound pre-treatment applied on drying is effective on the drying performance of the product. Ultrasound pre-treatment has been used in drying of some foods before, but limited research has been done in drying of maize. In this context, the aim of this study was to determine the effect of pre-treatment (conventional and ultrasound soaking), temperature and time on moisture content, hectoliter weight, thousand kernel weight, dimensions (thickness, length, width), equivalent diameter, sphericity and equivalent volume of corn during drying.

MATERIAL and METHODS

Material

The PR32T83 variety of corn used in this research was obtained from the Dora Village, Mecburi Hamlet, Kızıltepe, Mardin in 2017. The corn used in the study was harvested manually to avoid foreign materials such as broken and garbage. Corn in the form of cob collected from the field was hand-picked from the cob. Afterwards, the products were stored in vacuum packages in a deep freezer (-18 ºC) to prevent moisture loss.

Determination of Moisture Content of Raw Corns

Moisture content of raw corns was analyzed according to method of AOAC 15.950.01 (AOAC, 1990).

Determination of Physical Properties of Corns

One hundred corn kernels were randomly chosen to determine the physical properties. The selected kernels were weighed using an electronic balance (AS 220/C/2, Radwag-Wagi, Poland) with 0.001 g accuracy. The average dimensions (L: length, W: width and T: thickness in mm) of wheat kernels were measured with digital caliper (Mutitoyo No. 505-633, Japan) with an accuracy of 0.002 mm. The thousand kernel weight of corn samples were determined by the methods of Youssef (1978), Williams et al. (1983), Adebowale et al. (2005) and Singh et al. (2005). Hectoliter weights of corn samples were determined by the method of AACC International Method 55-10.01 (AACC, 1999). The equivalent diameter (D_e), sphericity (ϕ), equivalent volume (V_e) of samples were calculated by Eqs. (1-3) (Mohsenin, 1986).

$$D_e = (L * W * T)^{1/3} \quad (1)$$

$$\phi = \frac{D_e}{L} \quad (2)$$

$$V_e = \frac{\pi * (D_e)^3}{6} \quad (3)$$

Pre-treatments

Before drying, the corn was soaked for 1 hour without ultrasound (conventional soaking) and with ultrasound pre-treatment (40 kHz 200 W, 100% amplitude, acoustic energy density (EAD) of 0.029 W cm^{-3}) at 25 °C. Approximately 100 g of corn kernels were immersed in 7 liter of deionized water that performed in ultrasonic (US) bath (Model WUC-D10H, DAIHAN Scientific Co., Ltd., Gangwon-do, 220-821, KOREA) for both conventional and ultrasonic soaking. In order to prevent the temperature increase, the temperature was kept constant with ice water. After the soaking process (1 hour), the samples were removed from the soaking solution, drained for 2 min, blotted with tissue paper, and weighed, analyzed for physical characteristics, and immediately subjected to drying processes. After 1hour soaking process, moisture content of samples in dry basis was calculated by the Eq. 4:

$$M_t = \left[\frac{(M_o+1)*W_t}{W_o} - 1\right] * 100 \quad (4)$$

where W_o is initial weight (g), W_t is weight of sample (g) at any process time (t). M_o and M_t are the moisture contents of samples in dry basis initially and at different processing time, respectively.

Drying Process

Pre-treated samples were dried in the laboratory type convective air dryer (1.2 m s^{-1} air velocity, Heraeus brand UT-12, Germany) at 80, 90, 100 °C for 4 hours. During drying, samples were taken out of the dryer in certain periods (60 min), and moisture, hectoliter weight, thousand kernel weight, length, width, thickness, equivalent diameter, sphericity and equivalent volume were examined. One hundred grams of pre-treated corn samples was uniformly spread in one layer over drying pan of dryer. The moisture content of the pre-treated corn during drying was determined every 60 min, by taking the dryer sample pan and rapidly weighing the sample with an electronic balance (AS 220/C/2, Radwag-Wagi, Poland). The moisture content of samples (%) at any drying time was calculated by Eq (4).

Statistical Analysis The data obtained as a result of the analyzes were statistically evaluated using the SPSS package program (SPSS 22.0 software for Windows, SPSS Inc., USA) and analysis of variance (ANOVA). Comparisons between parameters were made according to the confidence limit of 0.05 by Duncan comparison test. All analyzes were done in triplicate (Efe et al., 2000; Kaygısız and Tümer, 2009).

RESULTS and DISCUSSION

Moisture and Physical Characteristics of Raw and Pre-Treated Corns

Average moisture content, thousand kernel weight, hectoliter weight, length, width, thickness, equivalent diameter, sphericity and equivalent volume of raw corns were found to be 28.14 (%, wet-basis) or 39.16 (%, dry basis), 350.03 g, 71.60 kg hl^{-1}, 11.22 mm, 9.11 mm, 4.98 mm, 7.98 mm, 0.70 and 266.17 mm^3, respectively (Table 1). Peplinski et al. (1992) found the hectoliter weight of seven different yellow whole-grain corn varieties as to be 73.2-76.2 kg hl^{-1}. Pan et al. (1996) reported that the hectoliter weight of three different corn varieties was between 69.7-74.6 kg hl^{-1}. In another study, the thousand-kernel weight of corn variety samples was found to be 359.16-384.22 g (Altinel, 2002). Vartanlı and Emeklier (2007) reported that moisture contents of 12 hybrid corn varieties in Ankara conditions were in the range of 21.15-28.60 (%, w.b.) and hectoliter weights were 65.43-73.53 kg hl^{-1}. Saygı and Toklu (2016), found a thousand kernel weight of 311.5 g and a hectoliter weight of 69.70 kg hl^{-1} of P32T83 corn variety. The values determined in this study are consistent with the values in the literature. In a study for dent corn variety grown in Turkey, the length, width, thickness, moisture content and thousand kernel weights were found to be 11.63±0.64 mm, 8.52±1.00 mm, 4.55±0.53 mm, 25-30% and 388.40±9.24 g, respectively. Length, width, thickness, moisture content and thousand kernel weight of flint corn variety were also determined to be 11.31±0.62 mm, 8.89±0.89 mm, 4.99±0.79 mm, 37% and 441.84±10.40 g, respectively. When they analyzed the size of the sweet corns in the same study, they found that the length, width and thickness were 12.07±0.95 mm, 7.37±0.89 mm and 3.38±0.70 mm (Özler et al., 2006). In a study conducted on Helen, Shemal and P32W86 corn varieties, moisture content, length, width, thickness, sphericity and equivalent volume values were found to be 11.80, 11.60, 12.10%; 13.35, 12.64, 11.54 mm; 7.30, 7.88, 8.30 mm; 4.36, 3.76, 4.13 mm; 0.586, 0.570, 0.635 and 254.29, 195.25, 207.11 mm^3, respectively (Polatcı et al., 2020). It can be concluded that the results of present study are compatible with the corn dimensions found in previous studies.

Before drying, harvested corn kernels were soaked in water without and with ultrasound treatment for 1 hour at 25 °C temperature. The average moisture content of the raw corn samples was 39.16 (%, d.b.) or 28.14 (%, w.b.) and it increased to 41.81 (%, d.b.) and 45.17 (%, d.b.), respectively, after conventional and ultrasound pre-treated soaking, (Table 1). It was observed that the moisture content of the corn samples increased with the ultrasound pre-treated soaking. This increase was statistically significant ($P \leq 0.05$). Miano et al. (2017), found that ultrasound treatment increased the water absorption of maize grains. Yıldırım and Öner (2005) reported that the water absorption rate of chickpeas increased with the increase of ultrasound.

Depending on the soaking pre-treatments, due to the water absorption of the corn kernels, swelling and weight gain were observed in the grain. While the increase in thousand kernel weight and equivalent volume of corn samples with pre-treatment application was statistically significant ($P \leq 0.05$), the increase in length, width, thickness, equivalent diameter and sphericity were not significant ($P > 0.05$). The hectoliter weights of corns decreased during conventional and ultrasound pre-treatment soaking processes, and also this decrease was not statistically significant (P>0.05) (Table 1).

Bart-Plange and Baryeh (2003) reported that when the moisture content of cocoa beans on wet basis increased from 7.56 to 19.00%, the thousand grain weight increased from 1125.02 to 1247.19 g. It has been reported that the mass of 1000 grains increase linearly with the increase in moisture content of spinach seeds (Kilickan et al., 2010) and red pepper seeds (Üçer et al., 2010), which is consistent with the results found in this study. In another study, it was reported that the water absorption rate of the wheat grain increased with the ultrasound application and the wheat grain swelled as it absorbs water (Yüksel and Elgün, 2013). In the study of soaking cowpeas, it was reported that the size of cowpea increased with the absorption of water (Yıldırım and Atasoy, 2017). It has been reported that the size of the samples increased as the time and temperature increased during the soaking of soybean (Bayram et. al., 2004) and three different corn samples (Polatcı et al., 2020). It was seen that the size of the samples increased depending on time and temperature of soaking. This study was found to be consistent with the pre-treatment soaking studies in the literature.

Table 1. Change in moisture and physical characteristics of raw, soaking without US and soaking with US corns.
Çizelge 1. Hammadde, ultrasonsuz ıslatılmış ve ultrasonlu ıslatılmış mısırların nem ve fiziksel özelliklerindeki değişim.

Analyzes	Raw corn	Soaking Without US*	Soaking With US**
Moisture content (%, d.b.)	39.16±0.03^{b}	41.81±0.84^{ab}	45.17±0.64^{a}
1000-kernel weight (g)	350.03±0.69^{b}	370.25±0.68^{ab}	372.46±0.72^{a}
Hectoliter weight (kg hl^{-1})	71.60±0.79^{a}	70.59±0.01^{a}	68.76±0.42^{a}
Length (mm)	11.22±0.30^{a}	11.89±0.43^{a}	12.21±0.46^{a}
Width (mm)	9.11±0.16^{a}	9.89±0.18^{a}	10.36±0.52^{a}
Thickness (mm)	4.98±0.29^{a}	5.08±0.32^{a}	5.43±0.13^{a}
Equivalent diameter (mm)	7.98±0.19^{a}	8.42±0.12^{a}	8.82±0.34^{a}
Sphericity	0.70±0.01^{a}	0.71±0.01^{a}	0.72±0.00^{a}
Equivalent volume (mm^{3})	266.17±10.90^{b}	312.62±2.06^{ab}	360.14±40.22^{a}

*Soaking Without US: Soaking without ultrasound, **Soaking With US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different letters (a-c, pre-treatment) are significant according to the 0.05 confidence limit.

Moisture Content Change During Drying

Table 2 indicated the effect of drying temperature and pre-treatments on moisture content of the corn samples. It was observed that the moisture content of conventional-soaked corn samples during 240 minutes of drying decreased from 41.81 to 9.62% at 80 °C and from 41.81 to 5.44% at 100 °C. The moisture content of ultrasound soaking pre-treated corn samples decreased from 45.17 to 6.32% during 240 minutes of drying at 80 °C and from 45.17 to 4.52% at 100 °C. As the temperature of drying increased, drying rate increased and moisture content decreased for the entire period of drying (P≤0.05). Higher initial rate of drying and higher moisture content decrease was observed for the first one hour of drying, which confirmed the earlier result (Özdemir and Devres, 1999) for hazel nuts. The effect of the ultrasonic pre-treatment was mainly observed during the hot air-drying where a significant decrease in moisture content was observed (P≤0.05) (Table 2). Yilmaz (2010) dried the corn in a convection drying system with hot air and stated that the drying time shortened as the drying temperature increased. This study is consistent with the present study.

The ultrasonic pre-treatment had a positive effect on drying because the decrease in the moisture content resulted in shorter hot air-drying time when compared with conventional pre-treated (Table 2). In the drying of foods, time and ultrasound application increase the drying performance depending on the appropriate methods performed different conditions (Tüfekci and Ozkal, 2015). Ultrasonic waves can cause a sponge effect, which means that continuous contractions and expansions occur (Gallego-Juarez et al., 2007), so moisture can be easily removed by the microscopic channels created.

Thousand Kernel Weight Change During Drying

The thousand kernel weight of cereal grains is a useful index for milling efficiency in measuring the amount of foreign material and the amount of shriveled or immature grains in a given grain (Varnamkhasti et al., 2008). It is extensively used as quality criteria in cereal industry.

Table 2 shows the moisture content (%, d.b.), thousand kernel weight (g) and hectoliter weight (kg hl^{-1}) changes of corn with pre-treatment, temperature and time during drying. When the temperature increased from 80 to 100 °C, the thousand grain weight of the conventional and ultrasound-soaked corn samples decreased from 370.25 to 272.86 g and from 372.46 to 263.54 g, respectively. The decrease in thousand kernel weights with time, temperature and pre-treatments (conventional and ultrasound soaking) was found to be statistically significant (P≤0.05). It is thought that as the moisture content is removed from the corn samples during drying, the weight of the corn samples decreases proportionally to the thousand kernel weight. A significant decrease was observed in thousand kernel weights of corn samples dried in hot air dryer depending on the time (P≤0.05).

Table 2. Moisture content (%, d.b.), thousand kernel weight (g) and hectoliter weight (kg hl^{-1}) change of corn with pre-treatment, temperature and time during drying.
Çizelge 2. Kurutma sırasındaki ön işlem, sıcaklık ve süre ile mısırın nem içeriği (%, d.b.), bin tane ağırlığı (g) ve hektolitre ağırlığı (kg hl^{-1}) değişimi.

Pre-treatment	Time (min)	Moisture content (%)			1000-kernel weight (g)			Hectoliter weight (kg hl^{-1})		
		Temperature								
		80°C	90°C	100°C	80°C	90°C	100°C	80°C	90°C	100°C
*Without US	0	41.81±0.11^{ax2}	41.81±0.12^{ax2}	41.81±0.09^{ax2}	370.25±0.68^{ex1}	370.25±0.68^{ex1}	370.25±0.68^{ex1}	70.59±0.01^{ex1}	70.59±0.01^{ex1}	70.59±0.01^{ex1}
	60	22.58±0.09^{bx1}	19.65±0.14^{by1}	17.56±0.04^{bz1}	312.88±0.11^{dz2}	310.80±0.65^{dy2}	303.09±0.25^{dx2}	66.87±0.00^{dz2}	64.09±0.01^{dy2}	63.04±0.01^{dx2}
	120	15.47±0.10^{cx1}	12.96±0.19^{cy1}	10.87±0.08^{cz1}	287.31±0.05^{cz2}	285.92±0.40^{cy2}	278.35±0.40^{cx2}	65.14±0.00^{cz2}	61.88±0.00^{cy2}	59.16±0.01^{cx2}
	180	11.71±0.05^{dx1}	9.20±0.16^{dy1}	7.11±0.14^{dz1}	282.12±0.11^{bz2}	280.20±0.90^{by2}	274.04±0.30^{bx2}	64.10±0.01^{bz2}	60.80±0.01^{by2}	58.17±0.00^{bx2}
	240	9.62±0.04^{ex1}	6.27±0.14^{ey1}	5.44±0.12^{ez1}	279.78±0.08^{az2}	277.75±0.13^{ay2}	272.86±0.23^{ax2}	63.45±0.01^{az2}	59.13±0.01^{ay2}	57.28±0.00^{ax2}
**With US	0	45.17±0.09^{ax1}	45.17±0.12^{ax1}	45.17±0.13^{ax1}	372.46±0.72^{ex2}	372.46±0.72^{dx2}	372.46±0.72^{dx2}	68.76±0.61^{ex1}	68.76±0.61^{dx1}	68.76±0.61^{dx1}
	60	19.42±0.12^{bx2}	16.71±0.13^{by2}	14.91±0.05^{bz2}	300.10±1.00^{dz1}	290.96±0.91^{cy1}	284.56±0.83^{cx1}	64.69±0.00^{dz1}	62.79±0.00^{cy1}	61.97±0.00^{cx1}
	120	11.74±0.06^{cx2}	9.49±0.12^{cy2}	7.68±0.04^{cz2}	276.71±0.17^{cz1}	271.07±0.81^{by1}	269.87±0.42^{bx1}	62.15±0.00^{cz1}	59.92±0.01^{by1}	57.84±0.01^{bx1}
	180	8.58±0.04^{dx2}	7.68±0.14^{dy2}	6.32±0.12^{dz2}	272.42±0.13^{bz1}	266.36±0.28^{ay1}	264.36±0.06^{ax1}	61.07±0.00^{bz1}	58.19±0.01^{ay1}	56.21±0.00^{ax1}
	240	6.32±0.06^{ex2}	5.42±0.10^{ey2}	4.52±0.14^{ez2}	270.67±0.04^{az1}	265.44±0.04^{ay1}	263.54±0.32^{ax1}	60.02±0.00^{az1}	57.62±0.00^{ay1}	55.56±0.01^{ax1}

*Without US: Soaking without ultrasound, **With US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-2, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) are significant according to the 0.05 confidence limit.

It was observed that as the temperature increased and ultrasound soaking applied, the drying time was shortened and the thousand kernel weight decreased. Ampah (2011) reported that as the moisture of the cowpea sample decreased from 19.00 to 9.58% during drying, the thousand kernel weight of the cowpea sample also decreased from 132.85 to 120.13 g. In a study by Alibaş (2012), the artichoke slices were dried at 50 ºC for 300 minutes, at 75 ºC for 210 minutes and at 100 ºC for 130 minutes. He reported that the drying time was shortened with the increase in temperature, and the weight of the artichoke slices decreased depending on the temperature. The studies are consistent with this study.

Hectoliter Weight Change During Drying

It has been reported that the hectoliter weight is an important and used attribute in the transportation and storage processes of corn grain (Yuan and Flores, 1996). Factors affecting hectoliter weight are grain size, shape, shell structure, moisture content, foreign material ratio, broken grains and specific weight. While corns with full and hard endosperm have a high hectoliter weight, immature corns have a low hectoliter weight (Rooney and Suhendro, 2000). Table 2 shows the hectoliter weight change of the pre-treated corn at different drying conditions and temperatures during 240 min drying. Hectoliter weights of conventional soaked corn samples during drying at 80, 90 and 100 °C decreased from 70.59 to 63.45 kg hl^{-1} from 70.59 to 59.13 kg hl^{-1} from 70.59 to 57.28 kg hl^{-1}, respectively. It was observed that the hectoliter weights of ultrasound-soaked corn samples during drying at 80, 90 and 100 °C decreased from 68.76 to 60.02 kg hl^{-1} from 68.76 to 57.62 kg hl^{-1} from 68.76 to 55.56 kg hl^{-1}, respectively. When comparing the conventional and ultrasound-soaked corn samples during drying at 80 °C, the hectoliter weight values decreased from 70.59 to 63.45 kg hl^{-1} and from 68.76 to 60.02 kg hl^{-1}. Similar decreases in hectoliter weights were obtained for 90 and 100 °C drying. Changes in temperature, pre-treatment and time showed statistically significant decrease in hectoliter weight of corn samples during drying (P≤0.05).

As the temperature increased and ultrasound pre-treatment applied, it was observed that the hectoliter weight decreased due to increase of drying rate and mass loss of corn kernel. In a study, it was determined that the hectoliter weight of corn grains dried at 25-100 ºC decreased as the temperature increased (Peplinski et al., 1994). The research is consistent with this study.

Dimensional (Length, Width and Thickness), Equivalent Diameter, Sphericity and Equivalent Volume Change During Drying

The measurement of dimensions of grains is used in the design of grain measuring devices, separating sieves, pneumatic conveying systems and fields connected to combines. The sorting systems in grain processing also depend on the size and shape dimensions (Stroshine and Hamann, 1995). The major diameter, length is the longest dimension of the longest projected area. Small diameter, thickness is the shortest dimension of the shortest projected area. Intermediate diameter, width, is the minimum diameter over the maximum projected area (Stroshine and Hamann, 1995). The dimensions of the corn grains are used in the selection of sieves for separators and energy determinations during the milling process. It is also used to determine for the surface area and volume of kernels, which is important during grain drying, aeration, heating and cooling modeling. Dimensional changes are important in the design of drying, storage and seed coat threshers (Varnamkhasti et al., 2007; Karimi et al., 2009).

The change in size of corn during drying was given in Table 3. As the time increased, the lengths of the corn samples decreased with pre-treatment and temperature during drying due to water removal and decrease in kernel size. The decrease in the lengths of corn samples between 0-120 min at 80, 90 and 100 ºC during drying with conventional soaking was statistically significant (P≤0.05), while decrease in that of between 120-240 min at the same temperatures was not statistically significant (P>0.05). The decrease in the lengths of the corn samples between 0 and 60 minutes at 80, 90 and 100 ºC drying with ultrasound-soaked was statistically significant (P≤0.05), while the decrease in the lengths of the corn samples was not statistically significant (P>0.05) after 60 min drying. As the drying time increased, the widths of the conventional soaked samples decreased with the temperature and this decrease was found to be statistically significant at all drying times (P≤0.05).

Table 3. Length (L, mm), width (W, mm) and thickness (T, mm) change of corn with pre-treatment, temperature and time during drying.
Çizelge 3. Kurutma sırasındaki ön işlem, sıcaklık ve süre ile mısırın uzunluk (L, mm), genişlik (W, mm) ve kalınlık (T, mm) değişimi.

Pre-treatment	Time (min)	Length (mm)			Width (mm)			Thickness (mm)		
		Temperature								
		80°C	90°C	100°C	80°C	90°C	100°C	80°C	90°C	100°C
*Without US	0	11.89±0.13[bx1]	11.89±0.06[bx1]	11.89±0.43[bx1]	9.89±0.06[dx1]	9.89±0.02[dx1]	9.89±0.03[cx1]	5.08±0.02[ax1]	5.08±0.06[ax1]	5.08±0.09[ax1]
	60	11.54±0.05[bx1]	11.52±0.16[bx1]	11.48±0.38[bx1]	9.72±0.12[cy1]	9.61±0.14[cx1]	9.67±0.13[byx1]	5.05±0.11[ax1]	5.02±0.17[ax1]	4.99±0.09[ax1]
	120	11.48±0.32[ax1]	11.46±0.26[ax1]	11.41±0.28[ax1]	9.66±0.24[by1]	9.55±0.22[cbx1]	9.60±0.13[bayx1]	5.04±0.11[ax1]	5.01±0.21[ax1]	4.98±0.02[ax1]
	180	11.39±0.21[ax1]	11.36±0.15[ax1]	11.29±0.13[ax1]	9.65±0.21[by1]	9.52±0.13[bx1]	9.57±0.31[bayx1]	5.03±0.10[ax1]	5.00±0.16[ax1]	4.95±0.10[ax1]
	240	11.35±0.08[ax1]	11.32±0.12[ax1]	11.26±0.15[ax1]	9.57±0.22[ay1]	9.43±0.34[ax1]	9.54±0.32[ay1]	4.99±0.13[ax1]	4.96±0.11[ax1]	4.94±0.07[ax1]
**With US	0	12.21±0.46[bx1]	12.21±0.42[bx1]	12.21±0.32[bx1]	10.36±0.52[bx1]	10.36±0.32[bx1]	10.36±0.34[bx1]	5.43±0.12[bx2]	5.43±0.11[bx2]	5.43±0.02[bx2]
	60	11.35±0.53[ax1]	11.32±0.32[ax1]	11.34±0.31[ax1]	9.60±0.13[ax1]	9.60±0.05[ax1]	9.54±0.07[ax1]	4.96±0.37[ax1]	4.92±0.12[ax1]	4.91±0.16[ax1]
	120	11.26±0.50[ax1]	11.24±0.30[ax1]	11.19±0.35[ax1]	9.48±0.15[ax1]	9.49±0.04[ax1]	9.41±0.05[ax1]	4.94±0.38[ax1]	4.90±0.13[ax1]	4.88±0.12[ax1]
	180	11.20±0.30[ax1]	11.14±0.32[ax1]	11.12±0.38[ax1]	9.46±0.14[ax1]	9.46±0.01[ax1]	9.38±0.04[ax1]	4.92±0.34[ax1]	4.88±0.18[ax1]	4.85±0.13[ax1]
	240	11.17±0.33[ax1]	11.12±0.35[ax1]	11.08±0.31[ax1]	9.45±0.13[ax1]	9.45±0.02[ax1]	9.36±0.07[ax1]	4.90±0.33[ax1]	4.86±0.19[ax1]	4.83±0.15[ax1]

*Without US: Soaking without ultrasound, **With US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-2, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) are significant according to the 0.05 confidence limit.

Although the decrease in width of ultrasound pre-treated and dried corn samples at 80, 90 and 100 ºC was found to be statistically significant in the first hour (P≤0.05), the decrease after one hour was not statistically significant (P>0.05).

With the increase of the time, the thickness of the conventional soaked corn samples dried in the hot air dryer at 80, 90 and 100 ºC decreased from 5.08 to 4.99 mm, from 5.08 to 4.96 mm, from 5.08 to 4.94 mm, respectively, but this decrease was not statistically significant (P>0.05). While the thickness reduction of ultrasound pre-treated corn samples during drying at 80, 90 and 100 ºC was statistically significant in the first 60 min (P≤0.05), the decrease was not statistically significant in the following times (P>0.05).

Table 4 shows the dimensional analysis of corns dried in hot air dryer during 240 minutes under different conditions. Equivalent diameters of conventional soaked corn samples during drying at 80, 90 and 100 ºC decreased from 8.42 to 8.16 mm, from 8.42 to 8.09 mm and from 8.42 to 8.10 mm, respectively. This decrease was statistically significant during drying (P≤0.05). Equivalent diameters of ultrasound-soaked corn samples during drying at 80, 90 and 100 ºC decreased from 8.82 to 7.95 mm, from 8.82 to 8.01 mm and from 8.82 to 8.03 mm, respectively. It was found to be statistically significant in the first 60 min, but not statistically significant for drying times greater than 60 min (P>0.05). As the time increased, the sphericity values of conventional and 100% amplitude ultrasound-soaked corn samples dried at 80, 90 and 100 ºC did not statistically different (P>0.05). When the temperature increased from 80 to 100 ºC, the equivalent volumes of conventional-soaked and ultrasound-treated corn samples decreased from 312.62 to 284.00 mm^3 and from 360.14 to 271.55 mm^3, respectively. This decrease was statistically significant in the first 60 min, but not statistically significant for drying times greater than 60 min (P>0.05). Equivalent diameter (D_e) and equivalent volume of the samples dried in hot air dryer for all conditions and times decreased. This decrease is thought to be due to the removal of water from the grain.

When the temperature changed between 80-100 ºC, the equivalent diameter, sphericity and an equivalent volume of the examined corn samples decreased, but this decrease was not statistically significant (P>0.05) (Table 4). It is thought that the reason for this is that the corn was dried at high temperatures and the temperatures were close to each other. The effect of different pre-treatments on the equivalent diametersphericity, and equivalent volume of the corn samples during drying was not found significantly (P>0.05).

The size of corn decreased rapidly in 0-60 minutes of drying (P≤0.05). This is because the corn begins to heat up with the warm air around it, and it is thought that the corn quickly decreases in size as the moisture on its surface dries out first. As the drying time increased, the decrease in the size of the corn slowed down. It is thought that the reason for this is that the moisture in the corn dries later and this drying takes more time. Lilhare and Bawane (2012) stated that the size of the paddy sample decreased with increasing time and temperature during drying. Reported studies show consistent with this study.

Table 4. Equivalent diameter (D_e, mm), sphericity (Φ) and equivalent volume (V_e, mm^3) change of corn with pre-treatment, temperature and time during drying.
Çizelge 4. Kurutma sırasındaki ön işlem, sıcaklık ve süre ile mısırın eşdeğer çap (D_e, mm), küresellik (Φ) ve eşdeğer hacim (V_e, mm^3) değişimi.

Pre-treatment	Time (min)	Equivalent diameter (mm)			Sphericity			Equivalent volume (mm³)		
		Temperature								
		80°C	90°C	100°C	80°C	90°C	100°C	80°C	90°C	100°C
*Without US	0	8.42±0.02^{bx1}	8.42±0.05^{cx1}	8.42±0.01^{bx1}	0.71±0.01^{ax1}	0.71±0.01^{ax1}	0.71±0.01^{ax1}	312.62±2.06^{bx1}	312.62±2.06^{cx1}	312.62±2.06^{bx1}
	60	8.28±0.06^{bx1}	8.22±0.15^{bx1}	8.21±0.17^{bx1}	0.72±0.02^{ax1}	0.71±0.01^{ax1}	0.72±0.02^{ax1}	296.72±6.84^{ax1}	290.83±4.50^{bx1}	289.84±11.99^{abx1}
	120	8.24±0.13^{ax1}	8.18±0.21^{ax1}	8.17±0.13^{ax1}	0.72±0.01^{ax1}	0.71±0.02^{ax1}	0.72±0.01^{ax1}	292.44±6.78^{ax1}	286.60±4.45^{abx1}	285.09±11.11^{ax1}
	180	8.21±0.03^{ax1}	8.15±0.14^{bax1}	8.12±0.10^{ax1}	0.72±0.01^{ax1}	0.72±0.01^{ax1}	0.72±0.01^{ax1}	289.25±6.73^{ax1}	282.94±5.16^{abx1}	279.88±10.97^{ax1}
	240	8.16±0.05^{ax1}	8.09±0.01^{ax1}	8.10±0.12^{ax1}	0.72±0.00^{ax1}	0.71±0.01^{ax1}	0.72±0.01^{ax1}	284.00±6.65^{ax1}	277.25±4.36^{ax1}	277.82±10.90^{ax1}
**With US	0	8.82±0.32^{bx1}	8.82±0.35^{bx1}	8.82±0.22^{bx1}	0.72±0.01^{ax1}	0.72±0.01^{ax1}	0.72±0.01^{ax1}	360.14±40.22^{bx1}	360.14±40.22^{bx1}	360.14±40.22^{bx1}
	60	8.05±0.30^{ax1}	8.16±0.16^{ax1}	8.10±0.11^{ax1}	0.72±0.02^{ax1}	0.72±0.02^{ax1}	0.72±0.01^{ax1}	273.70±30.24^{ax1}	284.14±16.99^{ax1}	278.26±1.46^{ax1}
	120	7.99±0.28^{ax1}	8.08±0.17^{ax1}	8.00±0.21^{ax1}	0.72±0.01^{ax1}	0.72±0.03^{ax1}	0.72±0.01^{ax1}	267.64±29.79^{ax1}	276.39±17.41^{ax1}	267.58±0.71^{ax1}
	180	7.97±0.26^{ax1}	8.03±0.12^{ax1}	8.06±0.16^{ax1}	0.72±0.02^{ax1}	0.72±0.02^{ax1}	0.70±0.00^{ax1}	265.63±29.64^{ax1}	271.44±16.65^{ax1}	274.32±15.87^{ax1}
	240	7.95±0.29^{ax1}	8.01±0.13^{ax1}	8.03±0.18^{ax1}	0.72±0.01^{ax1}	0.72±0.00^{ax1}	0.70±0.02^{ax1}	263.64±29.49^{ax1}	268.76±16.37^{ax1}	271.55±16.13^{ax1}

*Without US: Soaking without ultrasound, **With US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-2, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) are significant according to the 0.05 confidence limit.

CONCLUSION

In this study, the chemical and technological analysis of corn grains grown widely in the Mardin region were examined, and ultrasound (40 kHz 200 W, 100% amplitude) pre-treatment was applied and they were dried in a laboratory type hot air dryer at 80, 90 and 100 ºC, and the results during drying analyzes (size (length, width, thickness), equivalent diameter, sphericity, equivalent volume, thousand grain weight and hectoliter weight) were examined. It was observed that the moisture content of corn increased with ultrasound pre-treatment during soaking and decreased during drying at all drying temperatures due to sponge and cavitation effect. The effect of ultrasound pre-treatment on the size of the corn kernels during drying was not significant (P>0.05), while the effect on the thousand kernel weight and hectoliter weight values was significant (P≤0.05). As the drying time increased, the decrease in the size of the corn kernels, thousand kernel weight and hectoliter weight were significant (P≤0.05). While the drying temperature increased, the reduction in the size of the corn kernels was not significant (P>0.05), the reduction in thousand kernel weight and hectoliter weight was significant (P≤0.05). It is thought that the use of ultrasound in direct drying instead of ultrasound pre-treatment for corn may affect drying more effectively. At the same time, comparisons can be made in terms of energy consumption in drying with ultrasound pre-treatment.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ali Yıdırım: Contributed as the thesis supervisor. The Master's thesis student Zana Karaboğa carried out the preparation of samples, analyses, reporting, and writing and correction of literature sources. Both of authors were responsible for interpretation and discussion of the results. Both of authors approved the submitted version.

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