DOI: 10.29050/harranziraat.1036363
Harran Tarım ve Gıda Bilimleri Derg. 2022, 26(1): 118-132

Research Article/Araştırma Makalesi

Change in some physical characteristics of ultrasound pre-treated corn during hot-air convection and vacuum drying

Ultrason ön işlem görmüş mısırın sıcak hava konveksiyonu ve vakum kurutma sırasındaki bazı fiziksel özelliklerinin değişimi

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To cite this article:
Karaboğa, Z. & Yıldırım, A. (2022). Change in some physical characteristics of ultrasound pre-treated corn during hot-air convection and vacuum drying. Harran Tarım ve Gıda Bilimleri Dergisi, 26(1):118-132.
DOI:10.29050/harranziraat.1036363

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Received Date:
14.12.2021
Accepted Date:
21.02.2022

ABSTRACT

The objective of this study was to investigate the effect of ultrasound pre-treatment (50% US and 100% US-soaking), temperature (80, 90 and 100 °C) and dryer type (hot-air convection and vacuum) on some physical characteristics such as hectoliter weight, thousand kernel weight, dimensions (thickness, length, width, equivalent diameter and sphericity) of corn during drying. Before drying, corn samples were pre-treated without ultrasound (conventional-soaking) and with ultrasound (40 kHz 200 W, 50 and 100% amplitude) during 1 hour soaking. Pre-treated samples were dried at 80, 90 and 100 °C in the laboratory type vacuum dryer and hot-air convection dryer. Moisture content, dimensions (length, width, thickness, equivalent diameter and sphericity), thousand kernel weight and hectoliter weight of pre-treated corn samples at each temperature were analyzed for every 60 min during 240 minutes of drying processes. When the research results were analyzed, the length, width and equivalent diameter values of the corn samples dried in vacuum and hot air convection dryer were found significantly different between 0-60 minutes (P≤0.05), but insignificant (P>0.05) in the following periods. While the decrease in thickness of corn samples dried in vacuum dryer was significant (P≤0.05), the decrease in thickness of corn samples dried in hot air convection dryer was found insignificant (P>0.05). The increase in sphericity of the corn samples dried in vacuum dryer during drying was significant (P≤0.05), but the increase in the hot air convection dryer was insignificant (P>0.05). The effect of ultrasonic pre-treatment and dryer temperature on the size of the corn samples was found to be insignificant (P>0.05), while the effect of vacuum drying on the size of the corn samples was significant (P≤0.05). The effect of ultrasound pre-treatment, drying temperature and drying time on moisture content, thousand kernel weight and hectoliter weight of corn grains were found to be significant (P≤0.05). As a result, the vacuum dryer, allowed the corn to dry in a short time without much change in the structure of the corn.

Key Words: Corn, Vacuum and hot-air convection drying, Ultrasound, Physical properties

ÖZ

Bu çalışmanın amacı, ultrases ön işlemi (%50 US ve %100 US ıslatma), sıcaklık (80, 90 ve 100 °C) ve kurutucu tipinin (sıcak hava konveksiyonu ve vakum) mısırın kurutulması sırasında hektolitre ağırlığı, bin tane ağırlığı, boyutlar (kalınlık, uzunluk, genişlik, eşdeğer çap ve küresellik) gibi bazı fiziksel kalite özellikleri üzerindeki etkisini araştırmaktır. Kurutmadan önce, mısır numuneleri 1 saatlik ıslatma sırasında ultrasonsuz (geleneksel ıslatma) ve ultrasonlu (40 kHz 200 W, %50 ve %100 genlik) ön işleme tabi tutulmuştur. Ultrases ön işlemi (40 kHz 200 W, %50 ve %100 genlik) uygulanmış mısır taneleri laboratuar tipi vakum kurutucu ve konveksiyon sıcak hava kurutucuda 80, 90, 100 °C 'de kurutma yapılmıştır. Her sıcaklıkta ön işlem görmüş mısır örneklerinin nem içeriği, boyutları (uzunluk, genişlik, kalınlık, eşdeğer çap ve küresellik), bin tane ağırlığı ve hektolitre ağırlığı 240 dakikalık kurutma işlemi boyunca 60 dakikada bir analiz edilmiştir. Araştırma sonuçları analiz edildiğinde, vakum ve sıcak hava konveksiyonlu kurutucuda kurutulan mısır numunelerinin kurutma sırasındaki uzunluk, genişlik ve eşdeğer çap değerleri 0-60 dakikada önemli derecede farklı (P≤0.05) iken, sonraki sürelerde önemsiz bulunmuştur (P>0.05). Vakum kurutucuda kurutulan mısır numunelerinin kurutma sırasındaki kalınlık azalışı istatistiksel olarak önemli (P≤0.05) bulunmuşken, sıcak hava konveksiyonlu kurutucuda kurutulan mısır numunelerinin kalınlık azalışı önemsiz bulunmuştur (P>0.05). Vakum kurutucuda kurutulan mısır numunelerinin kurutma sırasındaki küresellik artışı istatistiksel olarak önemli (P≤0.05) bulunmuş, fakat sıcak hava konveksiyonlu kurutucudakilerin artışı önemsiz bulunmuştur (P>0.05). Ultrasonik ön işlem ve kurutucu sıcaklığının mısır numunelerinin boyutlarına etkisi önemsiz bulunurken (P>0.05), vakum kurutucunun mısır numunelerinin boyutlarına etkisi önemli bulunmuştur (P≤0.05). Ultrason ön işlemi, kurutma sıcaklığı ve kurutma süresi mısır numunelerinin nem içeriğine, bin tane ağırlığı ve hektolitre ağırlığına etkisi önemli bulunmuştur (P≤0.05). Sonuç olarak yeni bir kurutma tekniği olan vakum kurutucu mısırın yapısında fazla bir değişiklik yapmadan mısırın kısa sürede kurumasını sağlamıştır.

Anahtar Kelimeler: Mısır, vakum ve sıcak havalı konveksiyonel kurutma, ultrases, fiziksel özellikler

Introduction

Corn (Zea mays L.), which is among the most produced cereals in the world, is a product that is very valuable in terms of both human and animal nutrition and has a variety of uses due to its rich nutrients. Industrially, many products are obtained from corn; Hundreds of products, mainly flour, oil, starch, sweeteners, can be counted (Algül, 2012; Miano et al., 2017). Corn whose homeland is the American continent entered in Turkey through North Africa (Babaoglu, 2005). The ripening of the corn grain can be understood from the black dot on the part where the grain attaches to the cob. It is harvested when the moisture content of corn is around 30% on average (Babaoğlu, 2005). The drying process is very important as corn kernels are prone to mold and spoilage after harvest. The ideal moisture for the storage of corn grains should be 12-14%.

Vacuum drying has some distinctive features such as higher drying rate, low drying temperature and so on compared to other drying methods. These properties help to improve the quality and nutritional value of dried products (Wua et al., 2007).

The purpose of the pre-treatment of agricultural products before drying is to remove the moisture inside the products more quickly, to preserve/increase the colours, tastes and nutritional values of the products, to prevent possible microbial activities on them, to ensure their hygienic properties, and to obtain the shape and size properties in accordance with the standards (Özler et al., 2006).

Ultrasound is sound waves with a frequency of more than 20 kHz that cannot be perceived by the human ear in the food industry (Yıldırım et al., 2011, 2013; Firouz et al., 2019; McKenzie et al., 2019; Dedebaş et al., 2021). The use of ultrasound technology is a new and emerging technology to improve food quality, extend shelf life, increase processing efficiency and efficiency and ensure food safety (Huang et al., 2017). Ultrasonic sound waves have found application in the food industry in many different areas such as cooking, enzyme and microbial inactivation, foaming, degassing, marinating, filtration, homogenization/emulsification, cleaning and cutting, mass transfer processes (Ulusoy and Karakaya, 2011; Yıldırım et al., 2013). Some researchers have found that such as apple slices (Yılmaz, 2016), rice (Jafari and Zare, 2017) and green pepper (Szadzińska et al., 2017) in improving the indirect contact drying process with food products and the development of an ultrasonic dehydration method. Also, it has reported that ultrasound application significantly reduces the drying time (Yılmaz 2016). In another study, it was reported that the ultrasound pre-treatment applied before the drying of the food was effective on the drying performance of the product (Tüfekçi and Özkal, 2015). Chen et al. (2016) developed a new drying technique using a combination of ultrasound and vacuum drying to shorten the drying time and improve the quality of carrot slices. They found that ultrasonic drying dried carrot slices in a shorter time and consumed less energy than vacuum drying.

Ultrasound pre-treatment and vacuum drying have been used in drying of some foods before, but limited research has been done in drying of corn. The aim of this study was to determine effect of pre-treatment (conventional, 50 (100 W) and 100% (200 W) amplitude US-soaking), temperature (80, 90 and 100 °C) and time (0-240 minute) on hectoliter weight, thousand kernel weight, dimensions (thickness, length and width), equivalent diameter and sphericity of corn during hot-air convection and vacuum drying.

Material and Methods

Material

The PR32T83 corn variety used in the study was obtained from the Dora Village, Mecburi Hamlet, Kızıltepe, Mardin in 2017. The corn used in this 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. The moisture content of corn was found to be 28.14 (%, wet-basis). After that, the products were stored in vacuum packages in a deep freezer (-18 °C) to prevent moisture loss.

Pre-treatments

Before drying, the corn samples were soaked for 1 hour with conventional soaking and ultrasound soaking (50% (40 kHz, 100 W) and 100% (40 kHz, 200 W) amplitudes, (acoustic energy density (EAD) of 0.029 W cm^{-3})) at 25 °C. Average 100 g of corn kernels were immersed in 7 liter of deionised water; conventional and ultrasonic soaking were both performed in ultrasonic (US) bath (Model WUC-D10H, DAIHAN Scientific Co., Ltd., Gangwon-do, 220-821, KOREA). The conventional soaking was performed in ultrasonic (US) bath without operating the ultrasound device. The temperature of the soaking water was at room temperature (25 °C). Ice water was used to keep the temperature constant. After the soaking pre-treatments (1 hour), the corn samples were drained for 2 min, blotted with tissue paper, and weighed and then analyzed for physical characteristics, and finally immediately subjected to drying processes. The moisture content of samples in dry basis was estimated using Eq. 1 after a 1 hour soaking process:

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

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

The samples were dried in parallel with the laboratory type hot-air convection dryer (Absolute pressure of 101.325 kPa, 1.2 m s^{-1} air velocity, Heraeus brand UT-12, Germany) and laboratory type vacuum dryer (-0.1 MPa atmospheric pressure, WiseVen, WOV-70, Witeg, Germany) at 80, 90 and 100 °C for 4 hours. During drying, the samples were taken out of the dryer in certain periods and moisture, hectoliter, thousand kernel weight, size analysis (length, width, thickness, equivalent diameter and sphericity) were examined. The moisture content of samples (%) at any drying time was calculated by Eq (1).

Moisture content analysis

The moisture contents of raw and pre-treated samples were analyzed using the method of AOAC 15.950.01 at 130 °C (AOAC, 1990).

Determination of physical properties

The average dimensions (L: length, W: width and T: thickness in mm) of corn kernels were measured with digital caliper (Mutitoyo No. 505-633, Japan) with an accuracy of 0.02 mm. The sphericities (Φ) and equivalent diameters (D_e) of grains were calculated by using Eqs.(2, 3) (Mohsenin, 1986).

$$D_e = (L * W * T)^{1/3} \qquad (2)$$

$$\Phi = \frac{(L*W*T)^{1/3}}{L} \qquad (3)$$

The thousand kernel weight and hectoliter weight of samples were obtained by the methods of Adebowale et al. (2005), Singh et al. (2005), Williams et al. (1983), Youssef (1978) and AACC International Method 55-10.01 (1999), respectively.

Statistical analysis

All analyzes were done in duplicate. Data are presented as the mean ± standard deviation. The results were determined by analysis of variance (ANOVA) and Duncan's multiple range test (α = 0.05). All calculations were performed with SPSS 22.0 (SPSS 22.0 software for Windows, SPSS Inc., USA). The significance level of $P \leq 0.05$ was used.

Results and Discussion

Physical properties and moisture content of raw material and pre-treated corns

When the phsical analyzes made on the untreated P32T83 maize variety samples were examined, the thousand kernel weight, hectoliter weight, length, width, thickness, equivalent diameter, sphericity and moisture content of the samples were found to be 350.03±0.69 g, 71.60±0.79 kg hl^{-1}, 11.22±0.30 mm, 9.11±0.16 mm, 4.98±0.29 mm, 7.98±0.19 mm, 0.70±0.02 and 28.14 (%, wet-basis) or 39.16 (%, dry basis), respectively. In some studies, hectoliter weights and thousand kernel weights of corn variety samples were found to be between 65.43-76.2 kg hl^{-1} (Peplinski et al., 1992; Pan et al., 1996; Vartanli and Emeklier, 2007; Saygı and Toklu, 2016) and 311.5-384.22 g values (Altınel, 2002; Saygı and Toklu, 2016). Özler et al. (2006), when they examined the size analysis of dent corn, flint corn and sweet corn in the same study, the length, width, thickness were found to be 11.63, 11.31, 12.07 mm; 8.52, 8.89, 7.37 mm; 4.55, 4.99, 3.38 mm, respectively (moisture 25-30%). In another study, moisture content, length, width, thickness and sphericity values of Helen, Shemal and P32W86 corn varieties were found to be 11.60, 11.80, 12.10%; 12.64, 13.35, 11.54 mm; 7.88, 7.30, 8.30 mm; 3.76, 4.36, 4.13 mm and 0.570, 0.586, 0.635, respectively (Polatcı et al., 2020). When the studies are examined, it is seen that the results of present study compatible with the dimensional analysis.

Harvested corn kernels were soaked in water conventional, 50 and 100% ultrasound-soaking for 1 hour at 25 °C temperature before drying. The moisture content of pre-treated corns with soaking (conventional), 50% ultrasound amplitude (50% US) and 100% ultrasound amplitude (100% US) were increased from 9.16 (%, d.b.) to 41.81 (%, d.b.), 43.28 (%, d.b.) and 45.17 (%, d.b.), respectively. When the ultrasound amplitude increased, the moisture content of the corn samples were increased. Yıldırım et al. (2010), found that high power ultrasound application of chickpea absorbs more water than low power ultrasound application. In another study, it was found that ultrasound treatment increased the water absorption of corn grains (Miano et al., 2017).

In this study, the length of pre-treated corns with soaking without ultrasound, 50 and 100% US were found to be increased from 11.22±0.30 to 11.89±0.43, 12.04±0.10 and 12.21±0.46 mm, respectively. The width increased from 9.11±0.16 to 9.89±0.18, 10.00±0.19, and 10.36±0.52 mm, respectively. The thickness increased from 4.98±0.29 to 5.08±0.32, 5.23±0.17 and 5.43±0.13 mm, respectively. Equivalent diameter increased from 7.98±0.19 to 8.42±0.12, 8.57±0.20 and 8.82±0.34 mm and sphericity increased from 0.70±0.02 to 0.71±0.01, 0.71±0.01 and 0.72±0.00, respectively. Thousand kernel weight increased from 350.03±0.69 to 370.25±0.68, 371.73±0.48 and 372.46±0.72 g in without ultrasound, 50 and 100% US. Hectoliter weights of soaking without ultrasound, 50 and 100% US decreased from 71.60±0.79 to 70.59±0.01, 69.89±0.56 and 68.76±0.42 kg hl^{-1}, respectively.

Depending on the soaking conventional, 50 and 100% US pre-treatments, due to the water absorption of the corn kernels, swelling and weight gain were observed in the grain. Accordingly, an increase was observed in the size (length, width, thickness, equivalent diameter and sphericity) and thousand kernel weights of the corn kernels, while a decrease was observed in the hectoliter values.

Yüksel and Elgün (2013), reported that the water absorption rate of the wheat grain increased with the application of ultrasound and the wheat grain swelled as it absorbs water. It has been reported that the size of the soybean (Bayram et al., 2004), cowpea (Yıldırım and Atasoy, 2017) and three different corn samples (Polatcı et al., 2020) increased as the time and temperature increased during the soaking. In other studies, it has been reported when the moisture content increased, the mass of thousand kernel weights increase of spinach seed and red pepper seeds (Üçer et al., 2010).

Moisture content change during drying

Table 1 indicated the effect of drying temperature, type of dryer and pre-treatments on moisture content of the corn samples. It was observed that the moisture content of conventional, 50% US and 100% US soaked corn samples during 240 minutes of hot-air convection drying at 80 °C decreased from 41.81 to 9.62%, from 43.28 to 6.92% and from 45.17 to 6.32%, respectively. Similar trends of decrease in moisture contents of conventional, 50% US and 100% US-soaked corn samples were observed at 90 and 100 °C during hot-air convection drying (Table 1).

Table 1. Moisture content (%) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 ºC	90 ºC	100 ºC	80 ºC	90 ºC	100 ºC
Without US	0	41.81$^{ax3\alpha}$ ±0.11	41.81$^{ax3\alpha}$ ±0.12	41.81$^{ax3\alpha}$ ±0.09	41.81$^{ax3\alpha}$ ±0.12	41.81$^{ax3\alpha}$ ±0.10	41.81$^{ax3\alpha}$ ±0.13
	60	22.58$^{bx1\alpha}$ ±0.09	19.65$^{by1\alpha}$ ±0.14	17.56$^{bz1\alpha}$ ±0.04	18.81$^{bx1\beta}$ ±0.11	16.31$^{by1\beta}$ ±0.07	12.12$^{bz1\beta}$ ±0.14
	120	15.47$^{cx1\alpha}$ ±0.10	12.96$^{cy1\alpha}$ ±0.19	10.87$^{cz1\alpha}$ ±0.08	11.71$^{cx1\beta}$ ±0.09	10.03$^{cy1\beta}$ ±0.08	8.36$^{cz1\beta}$ ±0.12
	180	11.71$^{dx1\alpha}$ ±0.05	9.20$^{dy1\alpha}$ ±0.16	7.11$^{dz1\alpha}$ ±0.14	9.62$^{dx1\beta}$ ±0.10	8.36$^{dy1\beta}$ ±0.10	6.69$^{dz1\beta}$ ±0.11
	240	9.62$^{ex1\alpha}$ ±0.04	6.27$^{ey1\alpha}$ ±0.14	5.40$^{ez1\alpha}$ ±0.12	8.36$^{ex1\beta}$ ±0.08	5.85$^{ey1\beta}$ ±0.12	5.02$^{ez1\beta}$ ±0.09
50% US	0	43.28$^{ax2\alpha}$ ±0.10	43.28$^{ax2\alpha}$ ±0.12	43.28$^{ax2\alpha}$ ±0.10	43.28$^{ax2\alpha}$ ±0.10	43.28$^{ax2\alpha}$ ±0.11	43.28$^{ax2\alpha}$ ±0.12
	60	21.21$^{bx2\alpha}$ ±0.11	18.61$^{by2\alpha}$ ±0.07	16.45$^{bz2\alpha}$ ±0.11	16.88$^{bx2\beta}$ ±0.12	14.72$^{by2\beta}$ ±0.09	11.69$^{bz2\beta}$ ±0.09
	120	13.42$^{cx2\alpha}$ ±0.15	10.39$^{cy2\alpha}$ ±0.09	8.66$^{cz2\alpha}$ ±0.09	10.82$^{cx2\beta}$ ±0.09	9.52$^{cy2\beta}$ ±0.06	7.36$^{cz2\beta}$ ±0.08
	180	9.52$^{dx2\alpha}$ ±0.13	7.79$^{dy2\alpha}$ ±0.08	6.92$^{dz2\alpha}$ ±0.12	8.66$^{dx2\beta}$ ±0.10	7.36$^{dy2\beta}$ ±0.08	6.06$^{dz2\beta}$ ±0.10
	240	6.92$^{ex2\alpha}$ ±0.08	5.63$^{ey2\alpha}$ ±0.09	4.76$^{ez2\alpha}$ ±0.12	6.49$^{ex2\beta}$ ±0.08	5.19$^{ey2\beta}$ ±0.07	4.33$^{ez2\beta}$ ±0.11
100% US	0	45.17$^{ax1\alpha}$ ±0.09	45.17$^{ax1\alpha}$ ±0.12	45.17$^{ax1\alpha}$ ±0.13	45.17$^{ax1\alpha}$ ±0.14	45.17$^{ax1\alpha}$ ±0.13	45.17$^{ax1\alpha}$ ±0.11
	60	19.42$^{bx3\alpha}$ ±0.12	16.71$^{by3\alpha}$ ±0.13	14.91$^{bz3\alpha}$ ±0.05	14.45$^{bx3\beta}$ ±0.11	10.84$^{by3\beta}$ ±0.12	6.78$^{bz3\beta}$ ±0.10
	120	11.74$^{cx3\alpha}$ ±0.06	9.49$^{cy3\alpha}$ ±0.12	7.68$^{cz3\alpha}$ ±0.04	7.68$^{cx3\beta}$ ±0.09	6.32$^{cy3\beta}$ ±0.10	4.97$^{cz3\beta}$ ±0.12
	180	8.58$^{dx3\alpha}$ ±0.04	7.68$^{dy2\alpha}$ ±0.14	6.32$^{dz3\alpha}$ ±0.12	5.87$^{dx3\beta}$ ±0.10	4.97$^{dy3\beta}$ ±0.09	4.07$^{dz3\beta}$ ±0.09
	240	6.32$^{ex3\alpha}$ ±0.06	5.42$^{ey3\alpha}$ ±0.10	4.52$^{ez3\alpha}$ ±0.14	4.97$^{ex3\beta}$ ±0.07	4.07$^{ey3\beta}$ ±0.08	3.16$^{ez3\beta}$ ±0.07

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

The moisture content of conventional, 50% US and 100% US-soaked corn samples during vacuum drying at 80, 90 and 100 °C decreased from 41.81 to 8.36%, from 41.81 to 5.85% and from 41.81 to

5.02%; from 43.28 to 6.49%, from 43.28 to 5.19% and from 43.28 to 4.33%, and 45.17 to 4.97%, from 45.17 to 4.07% and from 45.17 to 3.16%, respectively (Table 1). As the temperature of drying increased, drying rate increased and moisture content decreased for the entire period of hot-air convection and vacuum drying ($P \leq 0.05$). The moisture content of the corn samples dried in the vacuum dryer decreased faster than the corn samples dried in the hot-air convection dryer ($P \leq 0.05$). Similarly, increase in the amplitude of ultrasound pretreatment decreased in moisture content of corn samples during both hot-air convection and vacuum drying processes (Table 1).

In some studies, it was reported that the drying time of corn samples was shortened as the temperature increased (Correa et al., 2011; Li and Moray, 2013). Daghan et al. (2018) reported that when they dried Isot (Urfa pepper) in hot-air convection and vacuum dryer, the samples dried in vacuum dryer dried in a shorter time. In another study, it was reported that when green bean samples were dried in ultrasound assisted vacuum drying, vacuum dryer and hot-air convection dryer, the samples dried in ultrasound assisted vacuum dryer provided drying in a shorter time (Tekin et al., 2017). These studies are quite close to the results of this investigation.

Dimensional change during drying

The change in length of corn during hot-air convection and vacuum drying was given in Table 2. It was observed that as the time increased, the lengths of the corn samples during drying decreased in all pre-treatment applications and at the temperature. The length of conventional-soaked corn samples during hot-air convection drying at 80, 90 and 100 °C decreased from 11.89 to 11.35 mm, from 11.89 to 11.32 mm and from 11.89 to 11.26 mm, respectively. The length of 50% US-soaked corn samples during hot-air convection drying at 80, 90 and 100 °C decreased from 12.04 to 11.28 mm, from 12.04 to 11.18 mm and from 12.04 to 11.12 mm, respectively. The length of 100% US-soaked corn samples during hot-air convection drying at 80, 90 and 100 °C decreased from 12.21 to 11.17 mm, from 12.21 to 11.12 mm and from 12.21 to 11.08 mm, respectively (Table 2).

The length of conventional-soaked corn samples during vacuum drying at 80, 90 and 100 °C decreased from 11.89 to 11.52 mm, from 11.89 to 11.40 mm and from 11.89 to 11.23 mm, respectively. The length of 50% US-soaked corn samples during hot-air convention drying at 80, 90 and 100 °C decreased from 12.04 to 11.36 mm, from 12.04 to 11.25 mm and from 12.04 to 11.13 mm, respectively. The length of 100% US-soaked corn samples during hot-air convection drying at 80, 90 and 100 °C decreased from 12.21 to 11.28 mm, from 12.21 to 11.13 mm and from 12.21 to 11.09 mm, respectively. While the decrease between 0-120 minutes at 80, 90 and 100 °C in the lengths of corn samples dried in soaking without US, hot-air convention and vacuum dryer was significant ($P \leq 0.05$), the decrease between 120-240 minutes was not significant ($P > 0.05$). While the decrease in 0-60 minutes at 80, 90 and 100 °C in the lengths of the corn samples dried in 50 and 100% US-soaking, hot-air convection and vacuum dryer was significant ($P \leq 0.05$), the decrease after 60 minutes was not significant ($P > 0.05$) (Table 2).

In Table 3, corn was dried in hot-air convection and vacuum dryer for 240 minutes under different conditions and width was measured every 60 minutes as a dimensional analysis. During hot-air convection and vacuum drying as the drying time increased, the width of conventional-soaking corn samples decreased with the temperature and this decrease was found to be significant at all drying times ($P \leq 0.05$). During hot-air convection and vacuum dried at 80, 90 and 100 °C when the decrease in width of corn samples 50 and 100% US pre-treated was found to be significant in the first hour ($P \leq 0.05$), the decrease after one hour was not significant ($P > 0.05$).

Table 2. Length (L, mm) values of corn for different pre-treatments, temperatures and times during hot air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 °C	90 °C	100 °C	80 °C	90 °C	100 °C
Without US	0	$11.89^{bx1\alpha}$ ±0.13	$11.89^{bx1\alpha}$ ±0.06	$11.89^{bx1\alpha}$ ±0.43	$11.89^{bx1\alpha}$ ±0.11	$11.89^{bx1\alpha}$ ±0.16	$11.89^{bx1\alpha}$ ±0.12
	60	$11.54^{bx1\beta}$ ±0.05	$11.52^{bx1\beta}$ ±0.16	$11.48^{bx1\beta}$ ±0.38	$11.79^{bx1\alpha}$ ±0.07	$11.71^{bx1\alpha}$ ±0.10	$11.64^{bx1\alpha}$ ±0.21
	120	$11.48^{ax1\beta}$ ±0.32	$11.46^{ax1\beta}$ ±0.26	$11.41^{ax1\beta}$ ±0.28	$11.68^{ax1\alpha}$ ±0.27	$11.58^{ax1\alpha}$ ±0.15	$11.44^{ax1\alpha}$ ±0.12
	180	$11.39^{ax1\beta}$ ±0.21	$11.36^{ax1\beta}$ ±0.15	$11.29^{ax1\beta}$ ±0.13	$11.59^{ax1\alpha}$ ±0.21	$11.48^{ax1\alpha}$ ±0.43	$11.32^{ax1\alpha}$ ±0.21
	240	$11.35^{ax1\beta}$ ±0.08	$11.32^{ax1\beta}$ ±0.12	$11.26^{ax1\beta}$ ±0.15	$11.52^{ax1\alpha}$ ±0.15	$11.40^{ax1\alpha}$ ±0.32	$11.23^{ax1\alpha}$ ±0.29
50% US	0	$12.04^{bx1\alpha}$ ±0.10	$12.04^{bx1\alpha}$ ±0.17	12.04^{bx1} ±0.12	$12.04^{bx1\alpha}$ ±0.23	$12.04^{bx1\alpha}$ ±0.13	$12.04^{bx1\alpha}$ ±0.21
	60	$11.53^{ax1\beta}$ ±0.33	$11.46^{ax1\beta}$ ±0.18	$11.43^{bax1\beta}$ ±0.31	$11.70^{bx1\alpha}$ ±0.20	$11.61^{bx1\alpha}$ ±0.04	$11.52^{bx1\alpha}$ ±0.12
	120	$11.44^{ax1\beta}$ ±0.32	$11.35^{ax1\beta}$ ±0.16	$11.30^{bax1\beta}$ ±0.39	$11.55^{ax1\alpha}$ ±0.43	$11.46^{ax1\alpha}$ ±0.21	$11.35^{ax1\alpha}$ ±0.19
	180	$11.34^{ax1\beta}$ ±0.31	$11.21^{ax1\beta}$ ±0.17	$11.19^{ax1\beta}$ ±0.12	$11.45^{ax1\alpha}$ ±0.22	$11.35^{ax1\alpha}$ ±0.11	$11.23^{ax1\alpha}$ ±0.11
	240	$11.28^{ax1\beta}$ ±0.30	$11.18^{ax1\beta}$ ±0.10	$11.12^{ax1\beta}$ ±0.24	$11.36^{ax1\alpha}$ ±0.28	$11.25^{ax1\alpha}$ ±0.18	$11.13^{ax1\alpha}$ ±0.28
100% US	0	$12.21^{bx1\alpha}$ ±0.46	$12.21^{bx1\alpha}$ ±0.42	$12.21^{bx1\alpha}$ ±0.32	$12.21^{bx1\alpha}$ ±0.46	$12.21^{bx1\alpha}$ ±0.36	$12.21^{bx1\alpha}$ ±0.54
	60	$11.35^{ax1\beta}$ ±0.53	$11.32^{ax1\beta}$ ±0.32	$11.34^{ax1\beta}$ ±0.31	$11.65^{ax1\alpha}$ ±0.06	$11.54^{ax1\alpha}$ ±0.27	$11.47^{bx1\alpha}$ ±0.32
	120	$11.26^{ax1\beta}$ ±0.50	$11.24^{ax1\beta}$ ±0.30	$11.19^{ax1\beta}$ ±0.35	$11.49^{ax1\alpha}$ ±0.36	$11.37^{ax1\alpha}$ ±0.21	$11.28^{ax1\alpha}$ ±0.31
	180	$11.20^{ax1\beta}$ ±0.30	$11.14^{ax1\beta}$ ±0.32	$11.12^{ax1\beta}$ ±0.38	$11.39^{ax1\alpha}$ ±0.24	$11.25^{ax1\alpha}$ ±0.17	$11.13^{ax1\alpha}$ ±0.23
	240	$11.17^{ax1\beta}$ ±0.33	$11.12^{ax1\beta}$ ±0.35	$11.08^{ax1\beta}$ ±0.31	$11.28^{ax1\beta}$ ±0.12	$11.13^{ax1\alpha}$ ±0.13	$11.09^{ax1\alpha}$ ±0.18

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

Table 3. Width (W, mm) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 °C	90 °C	100 °C	80 °C	90 °C	100 °C
Without US	0	$9.89^{dx1\alpha}$ ±0.06	$9.89^{dx1\alpha}$ ±0.02	$9.89^{cx1\alpha}$ ±0.03	$9.89^{dx1\alpha}$ ±0.09	$9.89^{cx1\alpha}$ ±0.07	$9.89^{dx1\alpha}$ ±0.11
	60	$9.72^{cy1\beta}$ ±0.12	$9.61^{cx1\beta}$ ±0.14	$9.67^{byx1\beta}$ ±0.13	$9.58^{cx1\alpha}$ ±0.16	$9.54^{bx1\alpha}$ ±0.18	$9.49^{cx1\alpha}$ ±0.09
	120	$9.66^{by1\beta}$ ±0.24	$9.55^{cbx1\beta}$ ±0.22	$9.60^{bayx1\beta}$ ±0.13	$9.49^{cbx1\alpha}$ ±0.29	$9.44^{bax1\alpha}$ ±0.25	$9.38^{cbx1\alpha}$ ±0.21
	180	$9.65^{by1\beta}$ ±0.21	$9.52^{bx1\beta}$ ±0.13	$9.57^{bayx1\beta}$ ±0.31	$9.41^{bax1\alpha}$ ±0.13	$9.34^{bax1\alpha}$ ±0.16	$9.27^{bax1\alpha}$ ±0.19
	240	$9.57^{ay1\beta}$ ±0.22	$9.43^{ax1\beta}$ ±0.34	$9.54^{ay1\beta}$ ±0.32	$9.35^{ax1\alpha}$ ±0.12	$9.16^{ax1\alpha}$ ±0.13	$9.13^{ax1\alpha}$ ±0.15
50% US	0	$10.00^{bx1\alpha}$ ±0.19	$10.00^{bx1\alpha}$ ±0.27	$10.00^{bx1\alpha}$ ±0.16	$10.00^{bx1\alpha}$ ±0.21	$10.00^{bx1\alpha}$ ±0.22	$10.00^{bx1\alpha}$ ±0.18
	60	$9.68^{ax1\beta}$ ±0.33	$9.65^{ax1\beta}$ ±0.37	$9.58^{ax1\beta}$ ±0.26	$9.51^{ax1\alpha}$ ±0.15	$9.45^{ax1\alpha}$ ±0.19	$9.40^{ax1\alpha}$ ±0.13
	120	$9.53^{ax1\beta}$ ±0.36	$9.56^{ax1\beta}$ ±0.32	$9.48^{ax1\beta}$ ±0.21	$9.40^{ax1\alpha}$ ±0.13	$9.35^{ax1\alpha}$ ±0.09	$9.31^{ax1\alpha}$ ±0.26
	180	$9.51^{ax1\beta}$ ±0.37	$9.54^{ax1\beta}$ ±0.36	$9.44^{ax1\beta}$ ±0.23	$9.32^{ax1\alpha}$ ±0.22	$9.25^{ax1\alpha}$ ±0.21	$9.19^{ax1\alpha}$ ±0.32
	240	$9.50^{ax1\beta}$ ±0.25	$9.50^{ax1\beta}$ ±0.33	$9.42^{ax1\beta}$ ±0.24	$9.28^{ax1\alpha}$ ±0.11	$9.14^{ax1\alpha}$ ±0.19	$9.12^{ax1\alpha}$ ±0.21
100% US	0	$10.36^{bx1\alpha}$ ±0.52	$10.36^{bx1\alpha}$ ±0.32	$10.36^{bx1\alpha}$ ±0.34	$10.36^{bx1\alpha}$ ±0.44	$10.36^{bx1\alpha}$ ±0.46	$10.36^{bx1\alpha}$ ±0.35
	60	$9.60^{ax1\beta}$ ±0.13	$9.60^{ax1\beta}$ ±0.05	$9.54^{ax1\beta}$ ±0.07	$9.47^{ax1\alpha}$ ±0.33	$9.43^{ax1\alpha}$ ±0.35	$9.39^{ax1\alpha}$ ±0.31
	120	$9.48^{ax1\beta}$ ±0.15	$9.49^{ax1\beta}$ ±0.04	$9.41^{ax1\beta}$ ±0.05	$9.34^{ax1\alpha}$ ±0.23	$9.28^{ax1\alpha}$ ±0.21	$9.22^{ax1\alpha}$ ±0.24
	180	$9.46^{ax1\beta}$ ±0.14	$9.46^{ax1\beta}$ ±0.01	$9.38^{ax1\beta}$ ±0.04	$9.26^{ax1\alpha}$ ±0.13	$9.18^{ax1\alpha}$ ±0.25	$9.10^{ax1\alpha}$ ±0.21
	240	$9.45^{ax1\beta}$ ±0.13	$9.45^{ax1\beta}$ ±0.02	$9.36^{ax1\beta}$ ±0.07	$9.18^{ax1\alpha}$ ±0.03	$9.07^{ax1\alpha}$ ±0.15	$8.97^{ax1\alpha}$ ±0.11

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

The thickness variation of the corn samples is shown in Table 4. With the increase of the time, the thickness of the without US and 50% US-soaked corn samples, dried in the hot-air convection dryer at 80, 90 and 100 °C, decreased in all times, but this decrease was not significant (P>0.05). The thickness of corn samples dried in 100% US-soaking hot-air convection dryer at 80, 90 and 100 °C was decreased from 5.43 to 4.96 mm, from 5.43 to 4.92 mm and from 5.43 to 4.91 mm, respectively and was significant in the first 60 minutes (P≤0.05). The decrease was not significant in the following times (P>0.05). The thicknesses of corn samples dried in without US, 50 and 100% US-soaked vacuum dryer at 80, 90 and 100 °C increased with increasing time. The thickness increase of conventional-soaking, 50 and 100% US pre-treated corn samples during vacuum drying at 80, 90 and 100 °C was significant in the first 60 min (P≤0.05). The thickness of the corn samples after the 60th minute remained constant until 240 minutes and was not significant (P>0.05).

Table 4. Thickness (T, mm) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 °C	90 °C	100 °C	80 °C	90 °C	100 °C
Without US	0	5.08$^{ax1\alpha}$ ±0.02	5.08$^{ax1\alpha}$ ±0.06	5.08$^{ax1\alpha}$ ±0.09	5.08$^{ax1\alpha}$ ±0.03	5.08$^{ax1\alpha}$ ±0.05	5.08$^{ax1\alpha}$ ±0.11
	60	5.05$^{ax1\beta}$ ±0.11	5.02$^{ax1\beta}$ ±0.17	4.99$^{ax1\beta}$ ±0.09	5.49$^{bx1\alpha}$ ±0.23	5.52$^{bx1\alpha}$ ±0.11	5.55$^{bx1\alpha}$ ±0.06
	120	5.04$^{ax1\beta}$ ±0.11	5.01$^{ax1\beta}$ ±0.21	4.98$^{ax1\beta}$ ±0.02	5.62$^{bx1\alpha}$ ±0.12	5.64$^{bx1\alpha}$ ±0.25	5.69$^{bx1\alpha}$ ±0.07
	180	5.03$^{ax1\beta}$ ±0.10	5.00$^{ax1\beta}$ ±0.16	4.95$^{ax1\beta}$ ±0.10	5.62$^{bx1\alpha}$ ±0.21	5.64$^{bx1\alpha}$ ±0.18	5.69$^{bx1\alpha}$ ±0.15
	240	4.99$^{ax1\beta}$ ±0.13	4.96$^{ax1\beta}$ ±0.11	4.94$^{ax1\beta}$ ±0.07	5.62$^{bx1\alpha}$ ±0.23	5.64$^{bx1\alpha}$ ±0.13	5.69$^{bx1\alpha}$ ±0.11
50% US	0	5.23$^{ax21\alpha}$ ±0.17	5.23$^{ax21\alpha}$ ±0.12	5.23$^{ax21\alpha}$ ±0.13	5.23$^{ax21\alpha}$ ±0.19	5.23$^{ax21\alpha}$ ±0.21	5.23$^{ax21\alpha}$ ±0.03
	60	5.00$^{ax1\beta}$ ±0.22	4.99$^{ax1\beta}$ ±0.06	4.97$^{ax1\beta}$ ±0.20	5.53$^{bax1\alpha}$ ±0.10	5.55$^{bx1\alpha}$ ±0.28	5.58$^{bx1\alpha}$ ±0.26
	120	4.96$^{ax1\beta}$ ±0.23	4.94$^{ax1\beta}$ ±0.05	4.91$^{ax1\beta}$ ±0.21	5.69$^{bx1\alpha}$ ±0.14	5.70$^{bx1\alpha}$ ±0.17	5.77$^{bx1\alpha}$ ±0.21
	180	4.95$^{ax1\beta}$ ±0.21	4.93$^{ax1\beta}$ ±0.02	4.89$^{ax1\beta}$ ±0.28	5.69$^{bx1\alpha}$ ±0.11	5.70$^{bx1\alpha}$ ±0.20	5.77$^{bx1\alpha}$ ±0.15
	240	4.93$^{ax1\beta}$ ±0.19	4.92$^{ax1\beta}$ ±0.07	4.87$^{ax1\beta}$ ±0.26	5.69$^{bx1\alpha}$ ±0.19	5.70$^{bx1\alpha}$ ±0.23	5.77$^{bx1\alpha}$ ±0.26
100% US	0	5.43$^{bx2\alpha}$ ±0.12	5.43$^{bx2\alpha}$ ±0.11	5.43$^{bx2\alpha}$ ±0.02	5.43$^{ax2\alpha}$ ±0.13	5.43$^{ax2\alpha}$ ±0.17	5.43$^{ax2\alpha}$ ±0.14
	60	4.96$^{ax1\beta}$ ±0.37	4.92$^{ax1\beta}$ ±0.12	4.91$^{ax1\beta}$ ±0.16	5.68$^{bx1\alpha}$ ±0.07	5.72$^{bx1\alpha}$ ±0.26	5.78$^{bx1\alpha}$ ±0.12
	120	4.94$^{ax1\beta}$ ±0.38	4.90$^{ax1\beta}$ ±0.13	4.88$^{ax1\beta}$ ±0.12	5.79$^{bx1\alpha}$ ±0.09	5.84$^{bx1\alpha}$ ±0.20	5.91$^{bx1\alpha}$ ±0.17
	180	4.92$^{ax1\beta}$ ±0.34	4.88$^{ax1\beta}$ ±0.18	4.85$^{ax1\beta}$ ±0.13	5.79$^{bx1\alpha}$ ±0.02	5.84$^{bx1\alpha}$ ±0.13	5.91$^{bx1\alpha}$ ±0.10
	240	4.90$^{ax1\beta}$ ±0.33	4.86$^{ax1\beta}$ ±0.19	4.83$^{ax1\beta}$ ±0.15	5.81$^{bx1\alpha}$ ±0.05	5.84$^{bx1\alpha}$ ±0.19	5.91$^{bx1\alpha}$ ±0.08

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

The equivalent diameters (D_e) of the samples dried in hot-air convection and vacuum dryer all conditions decreased at all times (Table 5). This decrease is thought to be due to the removal of water from the grain. The equivalent diameters of corn samples dried in a without US-soaking hot-air convection dryer at 80, 90 and 100 °C were found to be significant at all times (P≤0.05). The equivalent diameters of corn samples dried in 50 and 100% US-soaking hot-air convection dryer at 80, 90 and 100 °C were found to be significant (P≤0.05) in the first 60 minutes, but not significant for periods up to 240 minutes (P>0.05).

Table 5. Equivalent diameter (D_e, mm) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 ºC	90 ºC	100 ºC	80 ºC	90 ºC	100 ºC
Without US	0	$8.42^{bx1\alpha}$ ±0.02	$8.42^{cx1\alpha}$ ±0.05	$8.42^{bx1\alpha}$ ±0.01	$8.42^{ax1\alpha}$ ±0.08	$8.42^{ax1\alpha}$ ±0.05	$8.42^{ax1\alpha}$ ±0.02
	60	$8.28^{bx1\beta}$ ±0.06	$8.22^{bx1\beta}$ ±0.15	$8.21^{bx1\beta}$ ±0.17	$8.56^{ax1\alpha}$ ±0.21	$8.53^{ax1\alpha}$ ±0.15	$8.54^{ax1\alpha}$ ±0.01
	120	$8.24^{ax1\beta}$ ±0.13	$8.18^{ax1\beta}$ ±0.21	$8.17^{ax1\beta}$ ±0.13	$8.53^{ax1\alpha}$ ±0.19	$8.50^{ax1\alpha}$ ±0.13	$8.50^{ax1\alpha}$ ±0.11
	180	$8.21^{ax1\beta}$ ±0.03	$8.15^{bax1\beta}$ ±0.14	$8.12^{ax1\beta}$ ±0.10	$8.48^{ax1\alpha}$ ±0.11	$8.45^{ax1\alpha}$ ±0.21	$8.43^{ax1\alpha}$ ±0.23
	240	$8.16^{ax1\beta}$ ±0.05	$8.09^{ax1\beta}$ ±0.01	$8.10^{ax1\beta}$ ±0.12	$8.44^{ax1\alpha}$ ±0.18	$8.38^{ax1\alpha}$ ±0.10	$8.36^{ax1\alpha}$ ±0.12
50% US	0	$8.57^{bx1\alpha}$ ±0.17	$8.57^{bx1\alpha}$ ±0.21	$8.57^{bx1\alpha}$ ±0.12	$8.57^{ax1\alpha}$ ±0.11	$8.57^{ax1\alpha}$ ±0.10	$8.57^{ax1\alpha}$ ±0.07
	60	$8.21^{ax1\beta}$ ±0.06	$8.21^{ax1\beta}$ ±0.17	$8.16^{sx1\beta}$ ±0.04	$8.51^{ax1\alpha}$ ±0.17	$8.47^{ax1\alpha}$ ±0.11	$8.45^{ax1\alpha}$ ±0.13
	120	$8.11^{ax1\beta}$ ±0.03	$8.15^{ax1\beta}$ ±0.11	$8.07^{sx1\beta}$ ±0.03	$8.52^{ax1\alpha}$ ±0.15	$8.48^{ax1\alpha}$ ±0.17	$8.48^{ax1\alpha}$ ±0.16
	180	$8.06^{ax1\beta}$ ±0.05	$8.10^{ax1\beta}$ ±0.12	$8.02^{sx1\beta}$ ±0.05	$8.47^{ax1\alpha}$ ±0.10	$8.42^{ax1\alpha}$ ±0.18	$8.41^{ax1\alpha}$ ±0.19
	240	$8.04^{ax1\beta}$ ±0.07	$8.05^{ax1\beta}$ ±0.15	$7.99^{ax1\beta}$ ±0.03	$8.43^{ax1\alpha}$ ±0.14	$8.38^{ax1\alpha}$ ±0.15	$8.36^{ax1\alpha}$ ±0.10
100% US	0	$8.82^{bx1\alpha}$ ±0.32	$8.82^{bx1\alpha}$ ±0.35	$8.82^{bx1\alpha}$ ±0.22	$8.82^{ax1\alpha}$ ±0.38	$8.82^{ax1\alpha}$ ±0.33	$8.82^{ax1\alpha}$ ±0.37
	60	$8.05^{ax1\beta}$ ±0.30	$8.16^{ax1\beta}$ ±0.16	$8.10^{ax1\beta}$ ±0.11	$8.56^{ax1\alpha}$ ±0.19	$8.53^{ax1\alpha}$ ±0.17	$8.54^{ax1\alpha}$ ±0.09
	120	$7.99^{ax1\beta}$ ±0.28	$8.08^{ax1\beta}$ ±0.17	$8.00^{ax1\beta}$ ±0.21	$8.53^{ax1\alpha}$ ±0.11	$8.50^{ax1\alpha}$ ±0.12	$8.50^{ax1\alpha}$ ±0.12
	180	$7.97^{ax1\beta}$ ±0.26	$8.03^{ax1\beta}$ ±0.12	$8.06^{ax1\beta}$ ±0.16	$8.48^{ax1\alpha}$ ±0.13	$8.45^{ax1\alpha}$ ±0.16	$8.43^{ax1\alpha}$ ±0.21
	240	$7.95^{ax1\beta}$ ±0.29	$8.01^{ax1\beta}$ ±0.13	$8.03^{ax1\beta}$ ±0.16	$8.44^{ax1\alpha}$ ±0.12	$8.38^{ax1\alpha}$ ±0.10	$8.36^{ax1\alpha}$ ±0.14

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

In Table 6, corn was dried in hot-air convection and vacuum dryer for 240 min different conditions and sphericity was measured every 60 minutes as a dimensional analysis. As the time increased, the sphericity values of corn samples dried in without US, 50 and 100% US-soaking hot-air convection dryer at 80, 90 and 100 °C was not changed significantly. (P>0.05). While the sphericity values of corn samples dried at 80, 90 and 100 °C in a vacuum dryer with without US, 50 and 100% US-soaking increased in the period between 0-120 minutes and this increase were found to be significantly changed (P≤0.05), The change between 180-240 minutes was not significantly changed (P>0.05).

When the temperature changed between 80-100 ºC, the dimensions (length, width, thickness, equivalent diameter and sphericity) of the examined corn samples decreased, but this decrease was not found to be significant (p>0.05) (Tables 2-6). It is thought that the reason for this is that the corn was dried at high temperature and the temperatures were close to each other.

The effect of different pre-treatment applications on the dimensions (length, width, thickness, equivalent diameter and sphericity) of the corn samples during drying was not found significant (p>0.05) (Tables 2-6).

Table 6. Sphericity (Φ) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 ºC	90 ºC	100 ºC	80 ºC	90 ºC	100 ºC
Without US	0	0.71$^{ax1\alpha}$ ±0.00	0.71$^{ax1\alpha}$ ±0.00	0.71$^{ax1\alpha}$ ±0.00	0.71$^{ax1\alpha}$ ±0.00	0.71$^{ax1\alpha}$ ±0.00	0.71$^{ax1\alpha}$ ±0.00
	60	0.72$^{ax1\alpha}$ ±0.01	0.71$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.01	0.73$^{bx1\alpha}$ ±0.00	0.74$^{bx1\alpha}$ ±0.03	0.75$^{bx1\alpha}$ ±0.01
	120	0.72$^{ax1\beta}$ ±0.01	0.71$^{ax1\beta}$ ±0.02	0.72$^{ax1\beta}$ ±0.01	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.01
	180	0.72$^{ax1\beta}$ ±0.00	0.72$^{ax1\beta}$ ±0.04	0.72$^{ax1\beta}$ ±0.00	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.00
	240	0.72$^{ax1\beta}$ ±0.00	0.71$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.00	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.00
50% US	0	0.71$^{ax1\alpha}$ ±0.01	0.71$^{ax1\alpha}$ ±0.01	0.71$^{ax1\alpha}$ ±0.01	0.71$^{ax1\alpha}$ ±0.01	0.71$^{ax1\alpha}$ ±0.01	0.71$^{ax1\alpha}$ ±0.01
	60	0.71$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.00	0.72$^{ax1\beta}$ ±0.02	0.73$^{bx1\alpha}$ ±0.00	0.74$^{bx1\alpha}$ ±0.00	0.75$^{bx1\alpha}$ ±0.02
	120	0.71$^{ax1\beta}$ ±0.03	0.72$^{ax1\beta}$ ±0.00	0.72$^{ax1\beta}$ ±0.01	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.01	0.76$^{cx1\alpha}$ ±0.02
	180	0.71$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.00	0.72$^{ax1\beta}$ ±0.04	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.01	0.76$^{cx1\alpha}$ ±0.03
	240	0.71$^{ax1\beta}$ ±0.02	0.72$^{ax1\beta}$ ±0.00	0.72$^{ax1\beta}$ ±0.01	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.01	0.76$^{cx1\alpha}$ ±0.02
100% US	0	0.72$^{ax1\alpha}$ ±0.00	0.72$^{ax1\alpha}$ ±0.00	0.72$^{ax1\alpha}$ ±0.00	0.72$^{ax1\alpha}$ ±0.00	0.72$^{ax1\alpha}$ ±0.00	0.72$^{ax1\alpha}$ ±0.00
	60	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.02	0.73$^{bx1\alpha}$ ±0.00	0.74$^{bx1\alpha}$ ±0.03	0.75$^{bx1\alpha}$ ±0.01
	120	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.02	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.01
	180	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.01	0.70$^{ax1\beta}$ ±0.01	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.00
	240	0.72$^{ax1\beta}$ ±0.01	0.72$^{ax1\beta}$ ±0.00	0.70$^{ax1\beta}$ ±0.01	0.74$^{cx1\alpha}$ ±0.00	0.75$^{cx1\alpha}$ ±0.03	0.76$^{cx1\alpha}$ ±0.00

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

The dimensions (length, width, thickness, equivalent diameter and sphericity) of the corn samples varied in different dryers and were found to be significant (P≤0.05) (Tables 2-6). The dimensions of the corn samples dried in the vacuum dryer decreased more slowly than the corn samples dried in the hot-air convection dryer. The moisture of corn samples dried in vacuum dryer decreased faster than the moisture of corn dried in hot-air convection dryer. While the moisture of the corn in the vacuum decreased during drying, its dimensions were less than the size of the corn dried in the hot-air convection dryer, since no shrinkage was observed.

The size of corn samples decreased rapidly in 0-60 minutes of hot-air convection and vacuum drying (P≤0.05). The reason for the rapid reduction in size is thought to be due to the drying of moisture on the surface first, as the maize samples begin to heat up with the warm air around them. The decrease in the size of the corn slowed down with the increasing drying time. It is thought that the reason for the slow decrease in the size of the samples is that the moisture in the corn dries later and this drying takes more time. In some studies, it was reported that the size of cowpea (Ampah, 2011) and paddy (Lilhare and Bawane, 2012) samples decreased with increasing time and temperature during drying. This is quite close to the results of this investigation.

The 1000-kernel weight change during drying

Table 7 shows the results of the thousand kernel weight of corn samples during the drying in different pre-treatment applications and hot-air convection and vacuum dryers at different temperatures.

During hot-air convention drying, when the temperature increased from 80 to 100 °C, the thousand kernel weight of the conventional, 50 and 100% US-soaked corn samples decreased from 370.25 to 272.86 g, from 371.73 to 269.72 g and from 372.46 to 263.54 g, respectively. When the temperature increased from 80 to 100 °C during vacuum drying, the thousand kernel weight of the conventional, 50 and 100% US-soaked corn samples decreased from 370.25 to 268.19 g, from 371.73 to 265.78 g and from 372.46 to 260.20 g, respectively. The decrease in thousand kernel weights in ultrasound power, temperature, time and dryer changes was found to be significant (P≤0.05). It is thought that as the moisture is removed from the corn samples during drying, the weight of the corn samples decreases proportionally to the thousand kernel weight (Table 7).

A significant (P≤0.05) decrease was observed in thousand kernel weights of corn samples dried in hot-air convection and vacuum dryer depending on the time. It was observed that as the temperature and ultrasound power increased, the drying time was shortened and the thousand kernel weights decreased. The thousand kernel weights of the corn samples dried in the vacuum dryer decreased faster than the corn samples dried in the hot-air convection dryer. In the literature studies, it has been reported that the drying time was shortened with the increase in temperature, and the weight of cowpea (Ampah, 2011) and artichoke slices (Alibaş, 2012) decreased depending on the temperature and also this is quite close to the results of this investigation.

Table 7. Thousand kernel weight (g) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 °C	90 °C	100 °C	80 °C	90 °C	100 °C
Without US	0	$370.25^{ex1\alpha}$ ±0.68	$370.25^{ex1\alpha}$ ±0.68	$370.25^{ex1\alpha}$ ±0.68	$370.25^{dx1\alpha}$ ±0.68	$370.25^{ex1\alpha}$ ±0.68	$370.25^{dx1\alpha}$ ±0.68
	60	$312.88^{dz3\beta}$ ±0.11	$310.80^{dy3\beta}$ ±0.65	$303.09^{dx3\beta}$ ±0.25	$307.54^{cz3\alpha}$ ±0.13	$302.80^{dy2\alpha}$ ±0.25	$292.05^{cx2\alpha}$ ±0.77
	120	$287.31^{cz3\beta}$ ±0.05	$285.92^{cy3\beta}$ ±0.40	$278.35^{cx3\beta}$ ±0.40	$285.90^{bz3\alpha}$ ±0.39	$282.27^{cy2\alpha}$ ±0.71	$276.07^{bx3\alpha}$ ±1.10
	180	$282.12^{bz3\beta}$ ±0.11	$280.20^{by3\beta}$ ±0.90	$274.04^{bx3\beta}$ ±0.30	$278.62^{az3\alpha}$ ±0.39	$276.88^{by3\alpha}$ ±0.50	$270.33^{ax2\alpha}$ ±1.02
	240	$279.78^{az3\beta}$ ±0.08	$277.75^{ay3\beta}$ ±0.13	$272.86^{ax3\beta}$ ±0.23	$276.13^{az3\alpha}$ ±1.23	$274.90^{ay3\alpha}$ ±0.91	$268.19^{ax3\alpha}$ ±1.38
50% US	0	$371.73^{ex21\alpha}$ ±0.48	$371.73^{ex21\alpha}$ ±0.48	$371.73^{dx21\alpha}$ ±0.48	$371.73^{ex21\alpha}$ ±0.48	$371.73^{ex21\alpha}$ ±0.48	$371.73^{ex21\alpha}$ ±0.48
	60	$306.23^{dz2\beta}$ ±0.35	$303.67^{dy2\beta}$ ±0.31	$298.65^{cx2\beta}$ ±0.66	$302.79^{dy2\alpha}$ ±0.04	$299.80^{dy2\alpha}$ ±0.25	$290.74^{dx2\alpha}$ ±0.45
	120	$285.86^{cz2\beta}$ ±0.04	$281.20^{cy2\beta}$ ±0.01	$273.55^{bx2\beta}$ ±1.39	$284.69^{cz2\alpha}$ ±0.35	$282.27^{cy2\alpha}$ ±0.71	$272.06^{cx2\alpha}$ ±0.55
	180	$279.06^{bz2\beta}$ ±0.16	$275.66^{by2\beta}$ ±0.25	$270.27^{ax2\beta}$ ±0.85	$275.90^{bz2\alpha}$ ±0.04	$273.92^{by2\alpha}$ ±0.21	$268.91^{bx2\alpha}$ ±0.73
	240	$277.40^{az2\beta}$ ±0.74	$274.89^{ay2\beta}$ ±0.04	$269.72^{ax2\beta}$ ±0.94	$274.00^{az2\alpha}$ ±0.09	$270.99^{ay2\alpha}$ ±0.01	$265.78^{ax2\alpha}$ ±0.31
100% US	0	$372.46^{ex2\alpha}$ ±0.72	$372.46^{dx2\alpha}$ ±0.72	$372.46^{dx2\alpha}$ ±0.72	$372.46^{ex2\alpha}$ ±0.72	$372.46^{ex2\alpha}$ ±0.72	$372.46^{dx2\alpha}$ ±0.72
	60	$300.10^{dz1\beta}$ ±1.00	$290.96^{cy1\beta}$ ±0.91	$284.56^{cx1\beta}$ ±0.83	$296.49^{dz1\alpha}$ ±0.23	$286.15^{dy1\alpha}$ ±0.78	$281.29^{cx1\alpha}$ ±0.23
	120	$276.71^{cz1\beta}$ ±0.17	$271.07^{by1\beta}$ ±0.81	$269.87^{bx1\beta}$ ±0.42	$274.55^{cz1\alpha}$ ±0.41	$269.71^{cy1\alpha}$ ±0.81	$267.19^{bx1\alpha}$ ±0.85
	180	$272.42^{bz1\beta}$ ±0.13	$266.36^{ay1\beta}$ ±0.28	$264.36^{ax1\beta}$ ±0.06	$271.63^{bz1\alpha}$ ±0.45	$264.30^{by1\alpha}$ ±0.29	$261.32^{ax1\alpha}$ ±1.04
	240	$270.67^{az1\beta}$ ±0.04	$265.44^{ay1\beta}$ ±0.04	$263.54^{ax1\beta}$ ±0.32	$269.06^{az1\alpha}$ ±0.54	$262.79^{ay1\alpha}$ ±0.57	$260.20^{ax1\alpha}$ ±1.00

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

Hectoliter weight change during drying

In Table 8, the corn was dried for 240 minutes in a hot-air convection and vacuum dryer at different pre-treatment applications and at different temperatures, and the hectoliter weight during drying is given. When comparing the conventional, 50 and 100% US-soaking pre-treated corn samples during hot-air convection drying at 80 °C, the hectoliter weight values decreased from 70.59 to 63.45 kg hl^{-1}, from 69.89 to 61.00 kg hl^{-1} and from 68.76 to 60.02 kg hl^{-1}, respectively. When comparing the conventional, 50 and 100% US-soaking pre-treated corn samples during vacuum drying at 80 °C, the hectoliter weight values decreased from 70.59 to 58.49 kg hl^{-1}, from 69.89 to 57.63 kg hl^{-1} and from 68.76 to 56.68 kg hl^{-1}, respectively. It was observed that when the temperature increased from 80 to 100 °C, the hectoliter value of conventional, 50 and 100% US-soaked samples in the hot-air convection dryer decreased from 70.59 to 57.28 kg hl^{-1}, from 69.89 to 56.01 kg hl^{-1}, from 68.76 to 55.56 kg hl^{-1}, respectively while it decreased from 70.59 to 54.97 kg hl^{-1}, from 69.89 to 53.84 kg hl^{-1}, from 68.76 to 52.72 kg hl^{-1}, respectively in the vacuum dryer. Similar decreases in hectoliter weights were obtained for 90 and 100 °C hot-air convection and vacuum drying. The changes in temperature, ultrasound power, time and drier showed significant decrease in hectoliter weight of corn samples during drying ($P \leq 0.05$).

Table 8. Hectoliter weight (kg hl^{-1}) values of corn for different pre-treatments, temperatures and times during hot-air convection and vacuum drying.

Pre-treatment	Time (min)	Hot-air convection drying			Vacuum drying		
		80 °C	90 °C	100 °C	80 °C	90 °C	100 °C
Without US	0	70.59$^{ex2\alpha}$ ±0.11	70.59$^{ex2\alpha}$ ±0.12	70.59$^{ex2\alpha}$ ±0.13	70.59$^{ex2\alpha}$ ±0.14	70.59$^{ex2\alpha}$ ±0.13	70.59$^{ex2\alpha}$ ±0.11
	60	66.87$^{dz3\beta}$ ±0.05	64.09$^{dy3\beta}$ ±0.11	63.04$^{dx3\beta}$ ±0.11	64.18$^{dz3\alpha}$ ±0.09	62.11$^{dy2\alpha}$ ±0.14	60.25$^{dx3\alpha}$ ±0.05
	120	65.14$^{cz3\beta}$ ±0.06	61.88$^{cy3\beta}$ ±0.10	59.16$^{cx3\beta}$ ±0.21	60.15$^{cz3\alpha}$ ±0.08	58.98$^{cy2\alpha}$ ±0.10	56.99$^{cx3\alpha}$ ±0.09
	180	64.10$^{bz3\beta}$ ±0.04	60.80$^{by3\beta}$ ±0.11	58.17$^{bx3\beta}$ ±0.12	59.24$^{bz3\alpha}$ ±0.06	57.94$^{by3\alpha}$ ±0.16	55.81$^{bx3\alpha}$ ±0.12
	240	63.45$^{az3\beta}$ ±0.07	59.13$^{ay3\beta}$ ±0.04	57.28$^{ax3\beta}$ ±0.12	58.49$^{az3\alpha}$ ±0.07	56.89$^{ay3\alpha}$ ±0.21	54.97$^{ax3\alpha}$ ±0.23
50% US	0	69.89$^{ex21\alpha}$ ±0.56	69.89$^{ex21\alpha}$ ±0.56	69.89$^{ex21\alpha}$ ±0.56	69.89$^{ex21\alpha}$ ±0.56	69.89$^{ex21\alpha}$ ±0.56	69.89$^{ex21\alpha}$ ±0.56
	60	65.63$^{dz2\beta}$ ±0.09	63.61$^{dy2\beta}$ ±0.01	62.14$^{dx2\beta}$ ±0.07	63.51$^{dz2\alpha}$ ±0.11	62.11$^{dy2\alpha}$ ±0.20	59.97$^{dx2\alpha}$ ±0.21
	120	63.98$^{cz2\beta}$ ±0.09	60.43$^{cy2\beta}$ ±0.18	58.86$^{cx2\beta}$ ±0.17	59.73$^{cz2\alpha}$ ±0.13	58.98$^{cy2\alpha}$ ±0.14	55.91$^{cx2\alpha}$ ±0.11
	180	62.40$^{bz2\beta}$ ±0.11	59.27$^{by2\beta}$ ±0.10	57.04$^{bx2\beta}$ ±0.21	58.46$^{bz2\alpha}$ ±0.07	56.98$^{by2\alpha}$ ±0.03	54.44$^{bx2\alpha}$ ±0.02
	240	61.00$^{az2\beta}$ ±0.16	58.00$^{ay2\beta}$ ±0.21	56.01$^{ax2\beta}$ ±0.11	57.63$^{az2\alpha}$ ±0.07	55.81$^{ay2\alpha}$ ±0.02	53.84$^{ax2\alpha}$ ±0.02
100% US	0	68.76$^{ex1\alpha}$ ±0.61	68.76$^{dx1\alpha}$ ±0.61	68.76$^{dx1\alpha}$ ±0.61	68.76$^{ex1\alpha}$ ±0.61	68.76$^{ex1\alpha}$ ±0.61	68.76$^{ex1\alpha}$ ±0.61
	60	64.69$^{dz1\beta}$ ±0.20	62.79$^{cy1\beta}$ ±0.15	61.97$^{cx1\beta}$ ±0.23	62.42$^{dz1\alpha}$ ±0.28	60.29$^{dy1\alpha}$ ±0.26	58.76$^{dx1\alpha}$ ±0.23
	120	62.15$^{cz1\beta}$ ±0.23	59.92$^{by1\beta}$ ±0.11	57.84$^{bx1\beta}$ ±0.19	58.86$^{cz1\alpha}$ ±0.11	56.91$^{cy1\alpha}$ ±0.25	54.74$^{cx1\alpha}$ ±0.21
	180	61.07$^{bz1\beta}$ ±0.21	58.19$^{ay1\beta}$ ±0.12	56.21$^{ax1\beta}$ ±0.18	57.96$^{bz1\alpha}$ ±0.15	55.98$^{by1\alpha}$ ±0.21	53.88$^{bx1\alpha}$ ±0.20
	240	60.02$^{az1\beta}$ ±0.15	57.62$^{ay1\beta}$ ±0.10	55.56$^{ax1\beta}$ ±0.21	56.68$^{az1\alpha}$ ±0.17	54.99$^{ay1\alpha}$ ±0.10	52.72$^{ax1\alpha}$ ±0.21

*Without US: Soaking without ultrasound, **50% US: Soaking with 50% amplitude ultrasound, ***100% US: Soaking with 100% amplitude ultrasound. Differences between values shown in the same column in the Table with different numbers (1-3, ultrasound) and letters (a-e, time) and with different letters in the same line (x-z, temperature) and letters (α-β, dryer) are significant according to the 0.05 confidence limit.

The hectoliter weights of corn samples dried in hot-air convection and vacuum dryers decreased significantly depending on the time (P≤0.05). As the temperature and ultrasound power increased, it was observed that the hectoliter weights decreased because the drying time was shortened. The hectoliter weights of corn samples dried in vacuum dryer decreased faster than corn samples dried in convection hot-air dryer. Peplinski et al. (1994), determined that the hectoliter weight of corn grains dried at 25-100 °C decreased as the temperature increased. The research is in agreement with this study.

Conclusion

In this study, the physical characteristics of corn grains grown in Mardin region were examined. Although the effect of ultrasound pre-treatment on the size of the corn kernels during drying was insignificant (P>0.05), the effect on the moisture content, thousand kernel weight and hectoliter weight values was found to be significant (P≤0.05). At the same time, the increase in ultrasound amplitude (from 50 to 100%) was significant (P≤0.05) effect on the decrease in the moisture content, thousand grain weight and hectoliter weight of the samples. Both in hot-air convection and vacuum dryers, as the drying time increased, the decrease in the size of the corn kernels, moisture content, thousand kernel weight and hectoliter weight were found to be significant (P≤0.05). The reduction in the size of the corn kernels were insignificant (P>0.05) during hot-air convection and vacuum drying with temperature increase, but the reduction in moisture content, thousand kernel weight and hectoliter weight were determined to be significant (P≤0.05). It was observed that the moisture content, thousand grain weight and hectoliter weight values of corn kernels dried in vacuum dryer decreased faster than those dried in hot air convection dryer. The effect of temperature and ultrasound was observed in the hot air dryer, but the effect of vacuum was observed more in the vacuum dryer. It is estimated that the use of ultrasound in direct drying, instead of ultrasound pre-treatment, will affect drying better in the drying of corn kernels.

Acknowledgments

This work was supported by HÜBAP. Project No: 18173.

Conflict of Interest: The authors declare no conflict of interest.

Author Contributions: Ali YILDIRIM was 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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