Akademik Ziraat Dergisi 11(1): 67-76(2022)
ISSN: 2147-6403 e-ISSN: 2618-5881 DOI: http://dx.doi.org/10.29278/azd.990026

Research
(Araştırma)

Change in water activity of some Turkish hazelnut cultivars at different moistures and temperatures*

Saadet KOÇ GÜLER[1]

[1]Ordu Üniversitesi, Teknik Bilimler Meslek Yüksekokulu, Bitkisel ve Hayvansal Üretim Bölümü, Altınordu, Ordu

*This study was supported by Scientific Research Projects Department of Ordu University with the project code of AR-1652 and presented (oral) in the III. Balkan Agrıcultural Congress August 29-September 1, 2021, Edirne, Turkey. Only the abstract of the study was published in this congress.

Alınış tarihi: 2 Eylül 2021, Kabul tarihi: 6 Nisan 2022
Sorumlu yazar: Saadet KOÇ GÜLER, e-posta: saadet.koc@gmail.com

Abstract

Objective: Observation of the changes in water activity values of some Turkish hazelnut cultivars at different moisture levels (ML) at varying ambient temperatures. Thus, especially in hazelnut storage and transfer processes, regulations regarding the protection of the quality of the product under changing humidity and temperature conditions are foreseen.

Materials and Methods: In this study, water activity (a_w) of Tombul, Palaz, Çakıldak and Kalınkara hazelnuts were determined at different ML (2, 4, 6, 8, 9 and 12%) and different temperatures (20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30°C). Regression equations were generated to estimate a_w values of hazelnuts with a known moisture at different ambient temperatures.

Results: Considering the entire temperatures, it was observed that a unit (1%) increase in moisture yielded 0.055 - 0.062 unit increases in Çakıldak cultivar, 0.052 - 0.055 unit increases in Palaz cultivar, 0.047 - 0.050 unit increases in Tombul cultivar and 0.047 - 0.048 unit increases in Kalınkara cultivar. Different a_w values were observed at the same ML of the cultivars and generally the a_w values were tended to increase with increasing temperatures.

Conclusion: It was concluded that water activity influenced several quality parameters (color, lipid oxidation and etc.). Present findings revealed that hazelnut cultivars with the same moisture levels might have different water activity values. The fact that the varieties at the same ML have different water activity values indicates that it will be more objective to use the water activity value in storage or shelf life studies. In the calculations made using the obtained formula, it was seen that Palaz and Kalınkara (at the same ML) cultivars had higher a_w values than the other two cultivars. For this reason, it is thought that storing Palaz and Kalınkara separately from Tombul and Çakıldak cultivars may reduce the possible risks.

Anahtar kelimeler: Storage, Nuts, Quality, Regression analysis

Bazı Türk fındık çeşitlerinin farklı nem ve sıcaklıklardaki su aktivitesi değişimi

Öz

Amaç: Farklı nem değerlerindeki bazı Türk fındık çeşitlerinin değişen ortam sıcaklıklarındaki su aktivitesi değerlerinin değişiminin gözlenmesi. Böylece özellikle fındık depolama ve transfer süreçlerinde değişen nem ve sıcaklık koşullarında ürünün kalitesinin korunması ile ilgili düzenlemelerin ön görülmesi.

Materyal ve Yöntem: Bu çalışmada farklı nem değerlerindeki (%2, %4, %6, %8, %9, %12) Tombul, Palaz, Çakıldak ve Kalınkara çeşitlerinin farklı sıcaklıklardaki (20°C, 21°C, 22°C, 23°C, 24°C, 25°C, 26°C, 27°C, 28°C, 29°C, 30°C) su aktivitesi (a_w) ölçümleri yapılmıştır. Farklı ortam sıcaklıklarında nem değerleri bilinen fındıkların a_w değerlerini tahmin etmek için regresyon denklemleri oluşturulmuştur.

Araştırma Bulguları: İncelenen tüm sıcaklıklar dikkate alındığında nemdeki birim (%1) artışın, a_w değerini Çakıldak çeşidinde 0.055-0.062, Palaz çeşidinde 0.052-0.055, Tombul'da 0.047-0.050 ve Kalınkara'da 0.047-0.048 birim arttırdığı görülmüştür. Ayrıca, aynı nem değerine sahip çeşitlerin farklı a_w değeri aldığı gözlenmiştir ve genel olarak ortam sıcaklığı arttıkça, a_w değeri artış eğiliminde olmuştur.

Sonuç: Sonuç olarak, su aktivitesi ürünlerin pek çok kalite parametresini (mikotoksin oluşumu, renk, yağ oksidasyonu vb) etkilemektedir. Bu çalışma ile aynı nem değerindeki fındık çeşitlerinin farklı su aktivitesi değerlerine sahip olabileceği görülmüştür. Aynı nemdeki çeşitlerin farklı su aktivitesi değerlerine sahip olması, depolama ya da raf ömrü çalışmalarında su aktivitesi değerinin kullanılmasının daha objektif olacağını göstermektedir. Elde edilen formül kullanılarak yapılan hesaplarda Palaz ve Kalınkara'nın (aynı nemde) diğer iki çeşide göre daha yüksek a_w değeri oluşturduğu görülmüştür. Bu nedenle Palaz ve Kalınkara'nın, Tombul ve Çakıldak çeşidinden ayrı depolanmasının olası riskleri azaltabileceği düşünülmektedir.

Keywords: Depolama, Sert kabuklu meyveler, Kalite, Regresyon analizi

Introduction

Water is the primary component of several foodstuffs. Existence and availability of water may influence physical, chemical and biological characteristics of foodstuffs. Water activity (a_w) could be used for estimation of microbial progress and chemical reactions encountered in foodstuffs (Gabriel, 2008). Water activity is generally defined as the ratio of vapor pressure of water in food to vapor pressure of distilled water at the same temperature. It is a critical parameter for post-harvest stability of product storage and shelf life (Staudt et al., 2013).

Water activity should not be confused with moisture content. Total water in foods is so called as moisture content and free water is so called as water activity. Free water has a dissolvent characteristic and may freeze when cooled. Water activity values vary between 0 – 1 and it is among the most significant parameters revealing information about potential microorganism development in products. The products with a high-water activity (>0.65) may offer available media for fungi (Olagunju et al., 2018). With the initiation of microorganism activity and resultant production of secondary metabolites may reduce storage quality of the products and threats are posed on human health. Temperature plays crucial role in microorganism activity. Therefore, control of temperature and water activity is a significant issue. On the other hand, water activity designates the changes (enzymatic or non-enzymatic browning reactions, rancidity and etc.) encountered in product structure throughout the storage. In this sense, water activity should definitely be taken into consideration in storage and shelf-life studies.

World annual hazelnut production is about 1 150 000 tons. Turkey with an annual production of 776 046 tons meets alone about 67% of world production (İslam, 2018). Hazelnut prominent with nutritiveness is served to markets in different fashions (unshelled, natural, whitened, roasted) and largely used in chocolates, cakes and biscuits. Turkey exports an average of 70% of its annual hazelnut production to different countries of the world, primarily Germany, Italy and France (FAO, 2019).

During these transfers, the ambient temperature may change. It is important to determine whether this change has an effect on water activity or not for the continuity of the quality of the product. Therefore, the water activity values of hazelnuts, which are determined by taking into account the moisture content of hazelnut, ambient temperature and variety factors, are of great importance in terms of healthy storage and transfer period.

There are some studies in literature about secondary metabolite formation of microorganisms induced by water activity in nut fruits (Arrus et al., 2005; Venkatachalam and Sathe, 2006; Gallo et al., 2016) or about the effects of different treatments on water activity of the products (Akçin and Bostan, 2019; Marzocchi et al., 2017). Lopez et al., (1995) investigated hygroscopic behavior of Negret, Pauetet and Tonda Romana hazelnut cultivars. However, number of studies investigating the changes in water activity of processed agricultural commodities is quite limited (Turan, 2017; Koç Güler et al., 2012). A study investigating the changes in water activity of Turkish hazelnut cultivars with different moisture contents at changing ambient temperatures was not encountered in present literature.

In this study, relations of moisture content and ambient temperature with water activity of hazelnut (Tombul, Palaz, Çakıldak and Kalınkara) were investigated. Regression equations were generated for estimation of water activity (a_w) values of Tombul, Palaz, Çakıldak and Kalınkara hazelnuts with a known moisture content at different ambient temperatures. The study was designed with the widely cultivated hazelnut cultivars of Turkey (Tombul, Palaz, Çakıldak and Kalınkara), thus conducted in cultivar-based fashion. Water activity measurements were made in hazelnut samples with different moisture contents (2, 4, 6, 8, 9 and 12%) at different temperatures (20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30˚C).

This is the first study evaluating the effects of different ambient temperatures and moisture content of the product on water activity (a_w) in some Turkish hazelnuts.

Material and methods

Material

Tombul, Palaz, Çakıldak and Kalınkara hazelnuts harvested in 2017-2018 harvest season were used as the material of the study. Hazelnuts were obtained from the orchards of the producers in the district of Ordu (Turkey) Perşembe (Şenyurt, Ramazan, Yeniköy neighborhoods). In the orchards where the hazelnuts were taken, TSP (triple super phosphate) was applied in November-December and CAN (Calcium ammonium nitrate-26% N) applications were made routinely between March-May. In May, pesticides were applied against hazelnut worm and powdery mildew with foliar fertilization. Pruning and removal of excess shoots in the ocaks were carried out in the autumn period (September-November). Hazelnuts were harvested by picking from the branch in the second week of August (2017). Attention was paid to the fact that the husk and hard shell colors of the harvested hazelnuts started to turn brown. After the hazelnuts were separated from their husk, they were spread on the threshing floor and dried until the moisture level of the hazelnut kernels reached 6-7%.Hazelnuts were supplied from a grower orchard in Ordu province of Turkey.

Method

Unshelled hazelnuts were placed over nets as not to contact with water in containers and plastic lids of the containers were closed. Samples were taken at certain intervals for moisture measurements. Moisture content was measured with the use of Radwag Mac50 device, Poland. In moisture measurement, device values recommended for nut fruits were referenced.

About 5 g ground sample (grounded in the coffee machine, Sinbo CSM2934, Turkey) was taken from the hazelnuts with desired moisture levels (2, 4, 6, 8, 9 and 12%) and placed into water activity containers. Container lids were closed and sealed with paraffin bands and kept at room temperature until the analyses. Measurement temperatures (20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30˚C) were supplied with the use of an incubator (Infors HT Ecotron, Switzerland). In this process, clamped section of water activity device (Testo 645, Thailand) containing sample container was placed into the incubator and measurement panel was left outside (Figure 1).

Figure 1. Measurement of water activity of hazelnuts with desired moisture levels under controlled temperature change.

Statistical analysis

Experiments were conducted in randomized plots experimental design with 3 replications and 350 g unshelled hazelnuts of 4 hazelnut cultivars (Tombul, Palaz, Çakıldak, Kalınkara) in each replicate. Regression analyses were conducted with the use of Minitab 17 statistical analysis software (Minitab Inc. USA).

Results and discussion

The cultivars with the same moisture level had different water activity values. Water activity values increased with increasing ambient temperatures. Water activity of Tombul, Palaz, Çakıldak and Kalınkara hazelnuts with different moisture levels measured at different ambient temperatures are presented in graphs (Figure 2-7).

At 2% moisture, water activity of Kalınkara, Tombul, Çakıldak and Palaz hazelnuts (25°C) was respectively measured as 0.384, 0.333, 0.306 and 0.270 (Figure 2). Water activity of the cultivars increased with increasing temperatures.

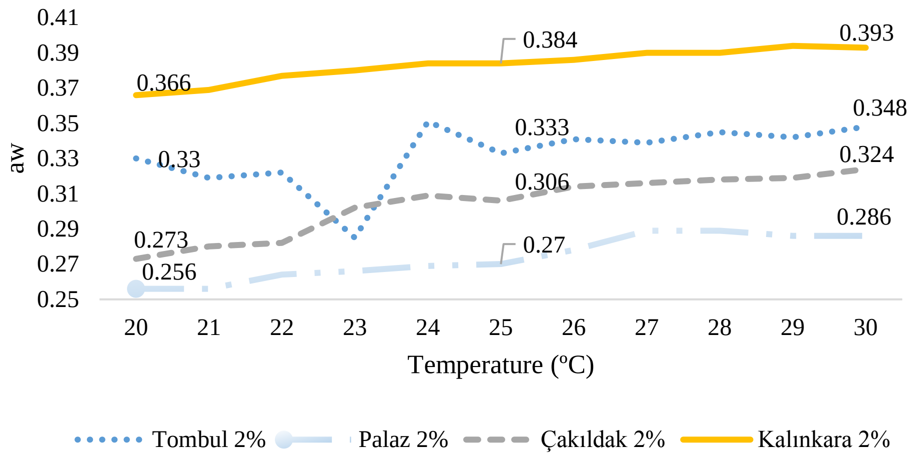

Figure 2. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 2% moisture value at different temperatures

At 4% moisture, water activity of Palaz, Tombul, Kalınkara and Çakıldak hazelnuts (25°C) was respectively measured as 0.626, 0.539, 0.525 and 0.364. The a_w value of greater than 0.60 in Palaz cultivar at 4% moisture level was remarkable (Figure 3). While a_w values of Çakıldak and Kalınkara cultivars increased with increasing temperatures, a_w values of Palaz and Tombul cultivars did not influenced by temperatures as much as the other cultivars.

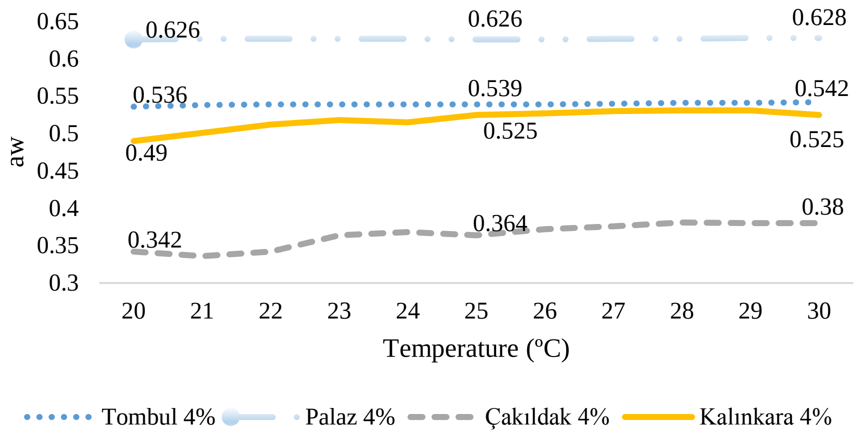

Figure 3. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 4% moisture value at different temperatures

At 6% moisture, water activity of Kalınkara, Palaz, Çakıldak and Tombul hazelnuts (25°C) was respectively measured as 0.787, 0.725, 0.698 and 0.657 (Figure 4). It could be stated that water activity of Kalınkara, Palaz and Çakıldak hazelnuts at 6% moisture level reached to risky levels in terms of microbiological activity. While a_w values of Kalınkara, Çakıldak and Tombul cultivars increased with increasing temperatures, a more stable case was observed in Palaz cultivar.

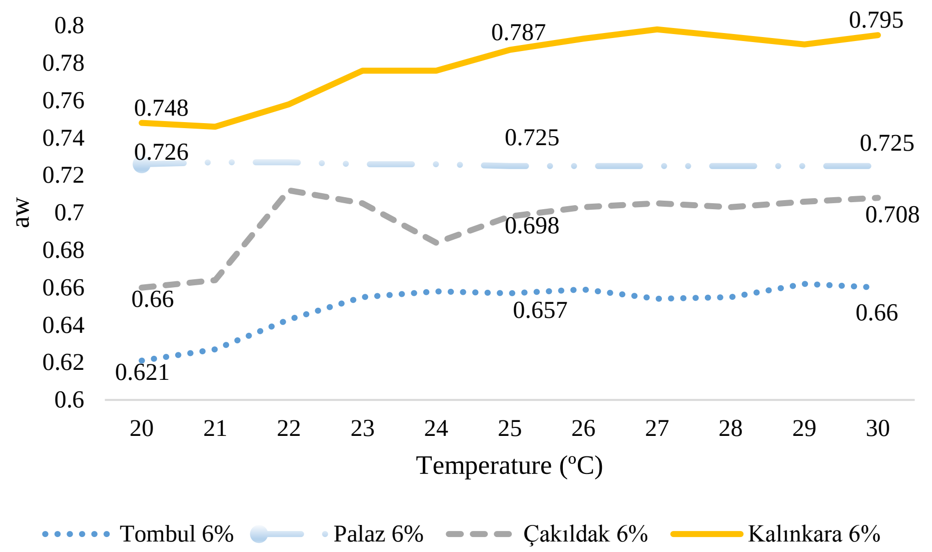

Figure 4. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 6% moisture value at different temperatures

At 8% moisture, water activity of Palaz, Kalınkara, Çakıldak and Tombul hazelnuts (25˚C) was respectively measured as 0.812, 0.755, 0.744 and 0.678 (Figure 5). All cultivars reached to risky levels at 8% moisture level. Water activities of all cultivars did not change much with increasing temperatures.

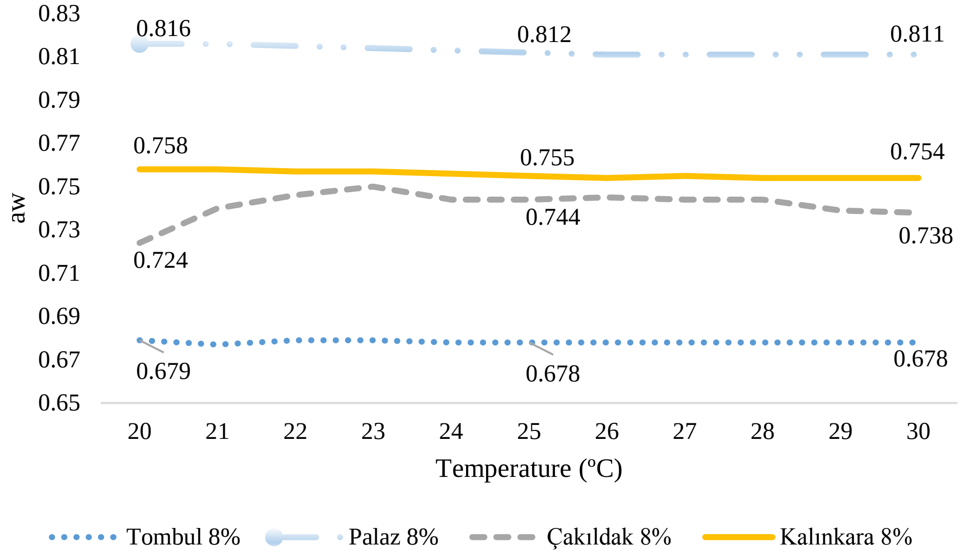

Figure 5. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 8% moisture value at different temperatures

At 9% moisture, water activity of Palaz, Kalınkara, Çakıldak and Tombul hazelnuts (25˚C) was respectively measured as 0.827, 0.825, 0.780 and 0.738 (Figure 6). All these values were microbiologically risky values. While a_w values of Tombul, Palaz and Çakıldak cultivars decreased, a_w values of Kalınkara cultivar increased with increasing temperatures.

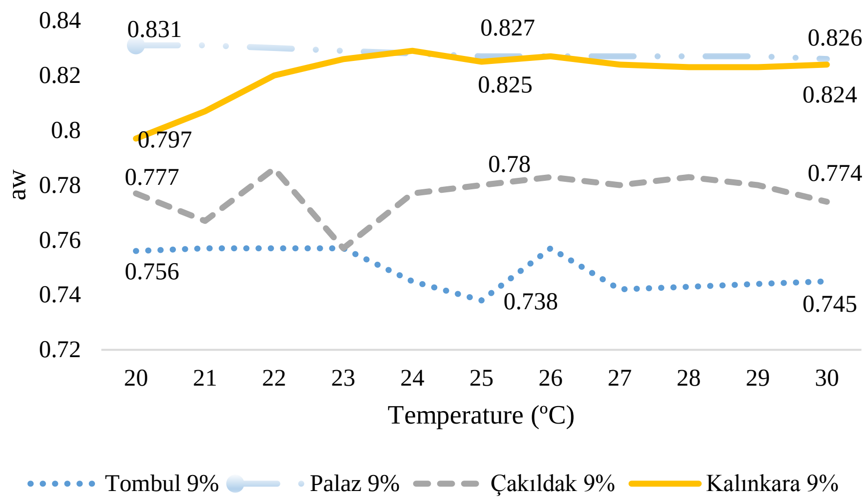

Figure 6. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 9% moisture value at different temperatures

At 12% moisture, water activity of Palaz, Kalınkara, Tombul and Çakıldak hazelnuts (25°C) was respectively measured as 0.861, 0.859, 0.856 and 0.832 (Figure 7). Only the a_w values of Kalınkara increased with increasing temperatures. The a_w values of the other cultivars decreased with increasing temperatures.

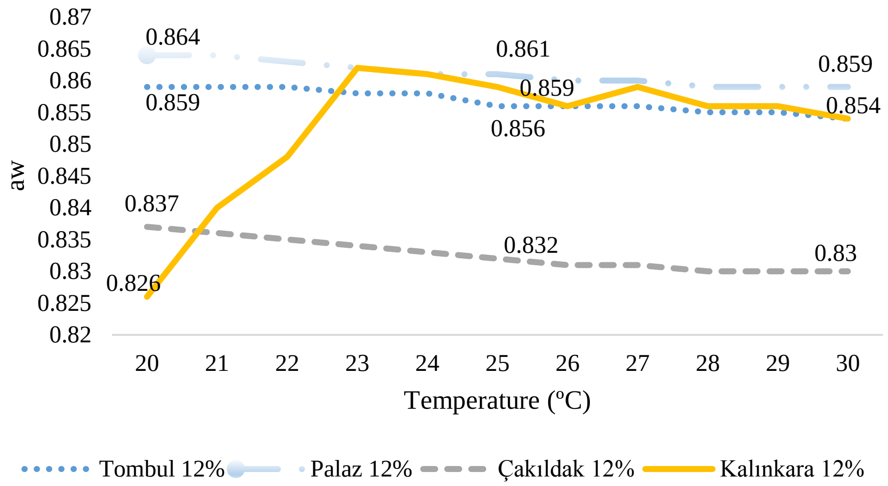

Figure 7. a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnut varieties with 12% moisture value at different temperatures

In hazelnuts at 2%, 4% and 6% moisture levels, an increase in aw values was observed with the increase in temperature. Hazelnut is a nut fruit rich in protein (10-20%) (Köksal et al., 2006). In such foods, the hydrophilic parts of the proteins interact with water molecules (Iglesias and Chirife, 1977). It is thought that high temperature increases the number of free water molecules by damaging the hydrogen bonds between water and hydrophilic molecules and causes an increase in the aw value (Syamaladevi et al., 2016).

In hazelnuts at 2%, 4% and 6% moisture levels, an increase in aw values was observed with the increase in temperature. Hazelnut is a nut fruit rich in protein (10-20%) (Köksal et al., 2006). In such foods, the hydrophilic parts of the proteins interact with water molecules (Iglesias and Chirife, 1977). It

is thought that high temperature increases the number of free water molecules by damaging the hydrogen bonds between water and hydrophilic molecules and causes an increase in the aw value (Syamaladevi et al., 2016). The regression equations generated to estimate water activity (a_w) values of Tombul, Palaz, Çakıldak and Kalınkara hazelnuts with a known moisture level at different ambient temperatures are provided below (Table 1). With the use of the equations provided in Table 1, water activities of Tombul, Palaz, Çakıldak and Kalınkara cultivars with moisture levels of between 2 - 12% could be estimated for ambient temperatures of between 20 - 30˚C. Accuracy of estimations (R^2) varied between 77 – 95%. Such a case indicated that 77 – 95% of the change in water activity of hazelnut cultivars could be explained by moisture levels.

Table 1. Regression equations generated to estimate water activity (a_w) of Tombul, Palaz, Çakıldak and Kalınkara cultivars with a known moisture level at different ambient temperatures.

AT (°C) and R^2	Hazelnut Cultivars			
	Tombul	Palaz	Çakıldak	Kalınkara
20	a_w=0.2890+0.04993xMoist.	a_w=0.3070+0.05553xMoist.	a_w=0.1791+0.06192xMoist.	a_w=0.3376+0.04779xMoist.
R^2	95.3%	77.0%	88.8%	82.8%
21	a_w=0.2838+0.05058xMoist.	a_w=0.3077+0.05548xMoist.	a_w=0.1837+0.06148xMoist.	a_w=0.3384+0.04856xMoist.
R^2	94.3%	76.8%	87.8%	84.8%
22	a_w=0.2905+0.05015xMoist.	a_w=0.3135+0.05475xMoist.	a_w=0.1996+0.06111xMoist.	a_w=0.3481+0.04838xMoist.
R^2	93.6%	77.1%	83.6%	84.4%
23	a_w=0.2689+0.05267xMoist.	a_w=0.3150+0.05448xMoist.	a_w=0.2239+0.05777xMoist.	a_w=0.3518+0.04898xMoist.
R^2	90.6%	77.2%	84.8%	83.8%
24	a_w=0.3150+0.04729xMoist.	a_w=0.3175+0.05413xMoist.	a_w=0.2240+0.05783xMoist.	a_w=0.3533+0.04881xMoist.
R^2	94.1%	77.3%	86.8%	83.7%
25	a_w=0.3038+0.04825xMoist.	a_w=0.3174+0.05406xMoist.	a_w=0.2239+0.05807xMoist.	a_w=0.3618+0.04793xMoist.
R^2	93.1%	77.5%	85.3%	82.1%
26	a_w=0.3085+0.04827xMoist.	a_w=0.3232+0.05337xMoist.	a_w=0.2345+0.05710xMoist.	a_w=0.3665+0.04742xMoist.
R^2	93.4%	77.8%	85.0%	81.0%
27	a_w=0.3073+0.04794xMoist.	a_w=0.3311+0.05250xMoist.	a_w=0.2384+0.05663xMoist.	a_w=0.3709+0.04708xMoist.
R^2	93.6%	78.3%	85.0%	80.8%
28	a_w=0.3124+0.04739xMoist.	a_w=0.3315+0.05242xMoist.	a_w=0.2417+0.05631xMoist.	a_w=0.3715+0.04680xMoist.
R^2	93.8%	78.2%	85.3%	81.0%
29	a_w=0.3121+0.04755xMoist.	a_w=0.3299+0.05260xMoist.	a_w=0.2427+0.05605xMoist.	a_w=0.3732+0.04656xMoist.
R^2	93.1%	77.9%	85.1%	81.6%
30	a_w=0.3164+0.04704xMoist.	a_w=0.3300+0.05257xMoist.	a_w=0.2469+0.05543xMoist.	a_w=0.3717+0.04670xMoist.
R^2	93.5%	77.9%	84.9%	80.6%

R^2: Coefficent of determination, Moist: Moisture (%), AT: Ambient temperature $p<0.05$.

Considering the entire temperatures, it was observed that a unit (1%) increase in moisture yielded 0.055 - 0.062 unit increases in Çakıldak hazelnut cultivar, 0.052 - 0.055 unit increases in Palaz cultivar, 0.047 - 0.050 unit increases in Tombul cultivar and 0.047 - 0.048 unit increases in Kalınkara cultivar (Table 1).

Temperature and water activity are two important parameters playing a great role in fungal spoilage and secondary metabolite formation during the harvest and post-harvest storage and shelf life of foodstuffs. Different combinations of these parameters (temperature, moisture, and cultivar) designate post-harvest quality of the produce. The ideal temperatures for aflatoxin (a toxic secondary metabolite produced by *Aspergillus flavus* and *Aspergillus parasiticus*) production are 28-30˚C. Aflatoxin production decreases when the temperature dropped below 25˚C or went over 37˚C. At greater water activity values, greater fungal development and toxin production is encountered. Germination of spores decelerates when the water activity was 0.85 and is totally terminated at water activity of between 0.70 - 0.75 (Bhatnagar et al., 2006; Schmidt-Heyd et al., 2009). It is also known that the foodstuffs with a water activity of a_w >0.65 offers available ambient for mycotoxin-generating fungi (Olagunju et al., 2018). Aflatoxin formation in nut fruits may be encountered both in the field in pre-harvest period and in post-harvest storages with available conditions for fungal growth and development (Turner et al., 2005). Venkatachalam and Sathe (2006) reported mold development in almond, Brazil nut, cashew nut, hazelnut, macadamia, pecans, pine nuts, pistachios and walnuts in 16th month of storage at 0.753 a_w and in the 4th month of storage at 0.9 a_w. Gallo et al. (2016) reported maximum aflatoxin B_1 production of almonds at 28˚C and 0.96-0.99 a_w conditions. Arrus et al. (2005) indicated that aflatoxin development initiated in Brazilian nuts at ≤0.68 water activity and 30˚C storage temperature. On the other hand, Venkatachalam and Sathe (2006) indicated optimum storage temperature for almond, Brazil nut, cashew nut, hazelnut, macadamia, pecans, pine nuts, pistachios and walnuts as 5˚C and a_w value as < 0.53.

In TS 3074 (Unshelled Hazelnut Standard) and TS 3075 (Kernel Hazelnut Standard), required moisture content of hazelnuts was specified as 7% and 6%, respectively. Taking these values into consideration, a_w values of Tombul, Palaz, Çakıldak and Kalınkara hazelnuts are provided in Table 2. The a_w values were lower than 0.70 in hazelnuts with 6 and 7% moisture. However, a_w values of Palaz and Kalınkara cultivars were quite close to 0.70 at 7% moisture. Such a case may pose some risks during the storage. In other words, microbial contaminations and cracks formed on shells during threshing may result in mold and then mycotoxin development in kernels.

Table 2. Calculated a_w values of Tombul, Palaz, Çakıldak and Kalınkara cultivars at 6 and 7% moisture

		a_w		
Moisture	Cultivars	20°C	25°C	30°C
6%	Tombul	0.590	0.593	0.599
	Palaz	0.640	0.642	0.645
	Çakıldak	0.551	0.572	0.580
	Kalınkara	0.624	0.649	0.652
7%	Tombul	0.639	0.642	0.646
	Palaz	0.696	0.696	0.698
	Çakıldak	0.613	0.630	0.635
	Kalınkara	0.672	0.697	0.699

In “secure moisture level” (the moisture level without fungal development) definition of FDA (Food and Drug Administration), water activity is specified as a_w=0.70 (25°C) for nut fruits. Taking this value into consideration, critical moisture content for Tombul hazelnut cultivar was calculated as 8.23% at 20°C, 8.21% at 25°C and 8.15% at 30°C; the values were respectively calculated as 7.07, 7.07 and 7.03% for Palaz cultivar; as 8.40, 8.19 and 8.17% for Çakıldak cultivar; as 7.58, 7.05 and 7.02% for Kalınkara cultivar.

Lipid peroxidation is also significantly influenced by water activity. Since hazelnuts contain about 50-60% oil and majority of this oil is composed of unsaturated fatty acids, oxidation is a serious risk for hazelnuts. Labuza and Dugan (1971) investigated the relationships between water activity and lipid oxidation and reported four important sections for this relationship: medium lipid oxidation for a_w values close to zero; low oxidation for a_w = 0.2 - 0.3; increased oxidation for a_w = 0.3 - 0.9; re-decreased oxidation for a_w values close to 1. However, such explanations are not valid for all foodstuffs. For instance, the greatest lipid oxidation in wheat flour is encountered at a_w = 0.5 (Lee et al., 2006), increasing lipid oxidation is observed in macadamia with increasing a_w values (Cavaletto et al., 1966). Koç Güler et al. (2017) reported that peroxide values of hazelnut kernels stored at 20˚C and 0.6 a_w went over 1 meqO_2 kg^{-1} since the 6th month of storage. Hazelnut is a nut fruit stored for long durations. Therefore, in terms of lipid oxidation, a_w =0.6 was considered as the critical value for long-term storage. Therefore, it was thought that oxidation will accelerate (25˚C) when the moisture levels went over 5% in Palaz and Kalınkara cultivars and over 6% in Tombul and Çakıldak cultivars.

Industrially, a_w <0.65 was accepted as a reliable value (Gross et al., 2014) and such a value was considered to prevent enzyme activity and browning reactions throughout the storage (Beuchat, 1983). It could then be stated based on these values that enzyme activity and browning reactions will accelerate (25˚C) when the moisture levels went above 5% in Palaz and Kalınkara cultivars and above 6% in Tombul and Çakıldak cultivars.

When values such as temperature and humidity are kept constant, the differences in the water activity value are related to the content of the product (Jin et al., 2019). It can be said that the linear or fluctuating changes in the aw values of different cultivars at the same humidity to the temperature change are due to the fact that the cultivars have different contents (oil, protein, sugar, etc.) (Köksal et al., 2016). The effect of these factors on the change in aw was not evaluated in this study.

Conclusion

It was concluded that water activity influenced several quality parameters (mycotoxin formation, color, lipid oxidation and etc.). Present findings revealed that hazelnut cultivars with the same moisture levels might have different water activity values. Water activity values generally increased with increasing temperatures. Considering the maximum moisture levels specified in TS 3074 and 3075 standards, it was observed that present a_w values of the hazelnut cultivars were mostly below 0.7, thus considered to be reliable. However, a_w values of Palaz and Kalınkara cultivars at 7% moisture were close to critical value of 0.7 for fungus development, thus they should be stored separately from the others. Considering the lipid oxidation, enzyme activity and browning reactions, it was observed that moisture levels of above 5% (25°C) may pose some risks in Palaz and Kalınkara cultivars and above 6% in Tombul and Çakıldak cultivars. Different water activity values of the cultivars at the same moisture level indicated that water activity values should be taken into consideration in storage or shelf-life studies of the foodstuffs. On the other hand, hazelnut is an important product traded around the world. It is thought that estimating the effect of temperature and humidity conditions, which can change during the transfer of the product, on a_w with the formulas will contribute to the realization of this process in a safer way.

Acknowledgement

The author would like to thank Prof. Dr. Saim Zeki BOSTAN for academic support and Agriculture Engineer Saliç SOLMAZ for laboratory analysis.

Conflict of interest

The author declare that there is no conflict of interest regarding the publication of this article.

References

Akçin, Y., Bostan, & S.Z. (2019). Farklı sulama programlarının 'Tombul' fındık çeşidinde depolama süresince su aktivitesine etkisi. *International Journal of Agriculture and Wildlife Science, 5*(2), 308-313 (in Turkish).

Arrus, K., Blank, G., Abramson, D., Clear, R., & Holley, R.A. (2005). Aflatoxin production by *Aspergillus flavus* in Brazil nuts. *J. Stored Prod. Res.*, *41*,513–527. doi:10.1016/j.jspr.2004.07.005.

Beuchat, L.R. (1983). Influence of water activity on growth, metabolic activities and survival of yeasts and molds. *J. Food Prot.*, *46*(2),135–141. doi: 10.4315/0362-028X-46.2.135.

Bhatnagar, D., Cary, J.W., Ehrlich, K., Yu, J., & Cleveland, T.E. (2006). Understanding the genetics of regulation of aflatoxin production and *Aspergillus flavus* development. *Mycopathologica*, *162*, 155-166. doi: 10.1007/s11046-006-0050-9.

Cavaletto, C.G., Dela, Cruz, A., Ross, E., & Yamamoto, H.Y. (1966). Factors affecting macadamia nut stability. Chicago.

FAO, 2019. FAOSTAT (online). Website http://www.fao.org/faostat/en/#data/QC (Accesed 28/01/2021).

Gabriel, A.A. (2008). Estimation of water activity from pH and °Brix values of some food products. *Food Chem.*, *108*, 1106–1113. doi: 10.1016/ j.foodchem.2007. 11.077.

Gallo, A., Solfrizzo, M., Epifani, F., Panzari, G., & Perrone, G. (2016). Effect of temperature and water activity on gene expression and aflatoxin biosynthesis in *Aspergillus flavus* on almon medium. *Int. J. Food Microbiol.*, *217*,162-169.

Gross, K.C., Wang, C., & Saltveit, M. (2014). Hazelnut. The commercial storage of fruits, vegetables, and florist and nursery stocks (HB-66) USDA ARS.

Iglesias, H. A., & Chirife, J. (1977). Effect of heating in the dried state on the moisture sorption isotherm of beef. *Lebensm Wiss Technol*, 10(5), 249–250

İslam, A. (2018). Hazelnut culture in Turkey. *Akademik Ziraat Dergisi*, 7(2), 259-266.

Jin, Y., Tang, J., & Sablani, S.S. (2019) . Food component influence on water activity of low-moisture powders at elevated temperatures in connection with pathogen control. *LWT-Food Sci Technol.*,112, 1-7.

Koç Güler, S., Bostan, S.Z., & Çon, A.H. (2017). Effects of gamma irradiation on chemical and sensory characteristics of natural hazelnut kernels. *Postharvest Biol. Technol.*, *123*,12-21. doi: 10.1016/j.postharvbio.2016.08.007.

Koç Güler, S., Şen, F., & Aksoy, U. (2012). Farklı işlem görmüş kuru meyvelerde su aktivitesinin değişimi üzerine araştırmalar. V. Bahçe Ürünlerinde Muhafaza ve Pazarlama Sempozyumu; İzmir, Türkiye. pp. 381-385 (in Turkish).

Köksal, A.İ., Artik, N., Şimşek, A., & Güneş, N. (2006). Nutrient composition of hazelnut (Corylus avellana L.) varieties cultivated in Turkey. *Food Chem*., 99, 509-515.

Labuza, T.P., & Dugan, L.R. (1971). Kinetics of lipid oxidation in foods. Crit Rev *Food Sci Nutr.*, *2*(3),355–405. doi:10.1080/10408397109527127.

Lee, Y., Lee, J., & Choe, E. (2006). Effects of flour storage conditions on the lipid oxidation of fried products during storage in the dark. *Food Sci. Biotechnol., 15*(3),399–403.

Lopez, A., Pique, M.T., & Clop, M. (1995). The hygroscopic behaviour of the hazelnut. *J. Food Eng., 25*,197-208. doi: 10.1016/0260-8774 (94)00021-Z.

Marzocchi, S., Pasini, F., Verardo, V., Ciemniewska-Zytkiewicz, H., Caboni, M.F., & Romani, S. (2017). Effects of different roasting conditions on physical-chemical properties of Polish hazelnuts (*Corylus avellana* L. var. Katalonski). *LWT-Food Sci Technol., 77*, 440-448. doi: 10.1016/ j.lwt.2016.11.068.

Olagunjua, O., Mchunua, N., Durandb, N., Alterb, P., Montetb, D., & Ijabadeniyi, O. (2018). Effect of milling, fermentation or roasting on water activity, fungal growth, and aflatoxin contamination of Bambara groundnut (*Vigna subterranea* (L.) Verdc). *LWT-Food Sci Technol., 98*, 533-539. doi:10.1016/j.lwt.2018.09.001

Schmidt-Heydt, M., Abdel-Hadi, A., Magan, N., & Geisen, R. (2009). Complex regulation of the aflatoxin biosynthesis gene cluster of *Aspergillus flavus* in relation to various combinations of water activity and temperature. *Int. J. Food Microbiol. 135*, 231-237. doi:10.1016/j.ijfoodmicro.2009.07.026.

Scott, V.*N. & Bernard, D.T. (1983)* .Influence of temperature on the measurement of water activity of food and salt system. *J. Food Sci.,*48, 552-554.

Staudt, P.B., Tessaro, I.C., Marczak, L.D.F., Soares, R.D.P., & Cardozo, N.S.M. (2013). A new method for predicting sorption isotherms at different temperatures: extension to the GAB model. *J. Food Eng., 118*,247–255. doi:10.1016/j.jfoodeng.2013. 04.013.

Syamaladevi, R.M., Tadapaneni, R.K., Xu, J., Villa-Rojas, R., Tang, J., Carter, B., Sablani, S., & Marks, B. (2016) . Water activity change at elevated temperatures and thermal resistance of *Salmonella* in all purpose wheat flour and peanut butter. *Int. Food Res. J.*, 81, 163-170.

TS 3074, Kabuklu Fındık, Türk Standartları Enstitüsü, Ankara (in Turkish).

TS 3075, İç Fındık, Türk Standartları Enstitüsü, Ankara (in Turkish).

Turan, A. (2017) . *Fındıkta Kurutma Yöntemlerinin Meyve Kalitesi ve Muhafazası Üzerine Etkileri*. (Yayınlanmış Doktora Tezi) .Ordu Üniversitesi Fen Bilimleri Enstitüsü, Bahçe Bitkileri Anabilim Dalı, Ordu.

Turner, P., Sylla, A.V., Gong, Y.Y., Diallo, M.S., Sutcliffe, A.E., Hall, A.J., & Wild, C.P. (2005). Reduction in exposure to carcinogenic aflatoxins by the postharvest invention measures in West Africa a community-based intervention study. *Lancet, 365*, 1950-1956.

Venkatachalam, M., & Sathe, S.K. (2006). Chemical composition of selected edible nut seeds. *J. Agric. Food Chem.*, *54*, 4705–4714. doi:10.1021/jf0606959