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Modeling of Drying Processes of Dates *(Phoenix, Arecaceae)* with Oven or TGA and Microbiological Properties of Fresh and Dried Dates

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ABSTRACT

Drying method, which is one of the oldest preservation methods, is important for preserving fruits. Date palm fruit is an important food in human nutrition due to some vitamins, minerals, sugar, phenolic components, and high fiber content. In the literature, date palm drying was not studied sufficiently in the aspect of mathematical modeling and the effect of drying process on the microbiological properties. In this novel study, date palm drying process was applied with four different temperatures of 50°C, 70°C, 90°C, and 110°C with two different drying techniques; drying with oven and drying with thermogravimetric analysis (TGA). Chemical changes in the date palm structure after drying at different temperatures were investigated with FTIR analysis. Fibrous structure of palm fruit is also exhibited with SEM analysis. On the other hand, microbiological studies were applied both for fresh and dried date palm to observe the drying process effect on the growth of different types of microorganisms. Consequently, drying time decreased with increasing drying temperature while the color of the dried date palm fruit became darker with increasing temperature. However, the chemical structure was not affected. Drying time of oven drying technique was longer than drying with TGA technique. The mathematical model of the drying temperature depending on drying time is calculated as $DT = -37,58\ln(t) + 237,74$ for TG-DTA drying experiments and $DT = -3 \times 10^{-5}(t^2) - 0,0218t + 122,5$ for drying process with oven. In addition, the microbiological load has significantly decreased or disappeared with the drying process.

KEYWORDS

Phoenix Arecaceae; date drying; drying method; microbiology

Introduction

Food spoilage poses a risk to human health. Food spoilages can be classified as microbiological and non-microbiological decays. Microbiological spoilage can be caused by bacteria, yeasts, and molds. They can make food risky in terms of health and quality with the toxins or other metabolites they produce. Non-microbiological deterioration occurs due to enzymatic activities and chemical reactions which cause physical, chemical, and sensory properties deterioration of foods (Cemeroğlu et al., 2003). The drying process, which is known as the oldest preservation method, can protect many foods against deterioration factors. Drying is the process of slowing or stopping the growth of microorganisms or chemical reactions by removing water from solids (Karaaslan, 2012). In other words, drying is the process of removing water from food by means of simultaneous heat and mass transfer (Krokida et al., 2002). During drying of the food, the drying rate is influenced by many factors. Physical factors such as temperature, humidity, flowing speed of air in the dryer, and surface area of the food effect the drying

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rate (Krokida et al., 2003). The purposes of drying applied to food stuffs are to prevent deterioration of the product during storage, to reduce the amount of moisture to ensure the preservation of quality properties, to increase transport efficiency by reducing the product volume and to extend shelf life (Eroğlu and Yıldız, 2011).

Dried fruits may be contaminated with microorganisms at different stages such as drying, storage, and selling (Akbal and Vural, 2018). The microflora of the product changes during the drying process. In order to prevent problems caused by microorganisms during drying, it is important to use microbiologically healthy raw materials and to comply with hygienic conditions in drying the raw materials. Microbiological deterioration of storage is not expected if the product moisture content has decreased to a certain level. Accordingly, it is known that there are living microorganisms in dried products, but microorganisms are not active because the conditions such as water activity value, temperature, and pH are not suitable (Cemeroğlu et al., 2003). In general, water activity value of bacteria below 0.85, yeasts under 0.70, and molds under 0.65 can not grow. Dried products tend to spoil easily at high water activity values (Perera, 2005). Drying is conventionally carried out by drying the products by natural convection or forced convection. Following technological developments, faster, hygienic, and homogeneous drying has been applied in hot air drying method (Tunde-Akintunde et al., 2005). It is very important that dried fruits are economical, quality, delicious, and nutritious. These products are required to be rich in vitamins, antioxidant substances, flavor, aroma substances, and color components (Ratti, 2001). Dried fruits can be consumed by individuals of all ages to provide energy and durability (Asghar et al., 2017). Since the moisture content of fresh fruits is more than 80%, they are classified as perishable products (Orsat et al., 2006). The best way to protect them is drying. However, it should not be forgotten that the main purpose of the drying process is not to dry faster, but to obtain a higher quality product (Esper and Mühlbauer, 1998).

Palm tree, is grown in Middle East, Mediterranean, and Aegean regions (Doğanlar and Yiğit, 2008). The palm fruit is a commonly known fruit with high content of fibrous structure (Berhanu et al., 2017), moisture, sugar, and polyphenols. It is a strong antioxidant food due to its content of phenolic substances. It gives energy to human when consumed due to its sugary structure. The palm also contains some types of B vitamins, vitamin A and vitamin C. However, high level of water content leads to a short shelf life and difficulties in transportation and storage (Jia et al., 2019). When the moisture levels are decreased via the drying process, fruit sugar (fructose) and minerals like phosphor, copper, potassium, and iron become more concentrated. In this situation, drying is an important and necessary technique in order to use the fruit effectively in economical aspect and increase the shelf life (Falade Kolawole and Abbo Emmanuel, 2007; Jia et al., 2019; Kayacan et al., 2020; Li et al., 2019). The most commonly used drying techniques are convective hot-air drying, freeze drying (lyophilization), microwave drying, sun drying, oven drying, spray drying, and vacuum drying techniques (Ahmed et al., 2013; Alfaro et al., 2014). Falade Kolawole and Abbo Emmanuel (2007) studied drying and rehydration characteristics of date palm fruit (*Phoenix dactylifera* L.). They dried the date palm fruit between 50°C and 80°C temperatures in an oven and calculated the effective diffusivities and activation energies by applying the Fick's diffusion model.

In the literature, date palm fruit drying was not studied sufficiently in the aspect of mathematical modeling of drying process and microbiological properties of dried and fresh date palm fruit. In order to overcome this deficiency in the literature, in this novel study, the effects of drying technique on drying time in palm fruit drying process were examined and mathematical models were developed by using two different drying methods. In addition, the effect of drying process on the microbiological properties of date palm fruit was also examined.

Materials and Methods

Two different drying processes were applied with thermal gravimetry analysis (TG-DTA, Shimadzu DTG-60) device and oven (Nuve FN 120). First, thermogravimetric analyze device was utilized at four temperatures (50°C, 70°C, 90°C, and 110°C). A computer was connected to

the thermogravimetric analyzer which automatically recorded the changes in weight of palm fruit sample and the heat changes of the palm fruit. In thermogravimetric analysis experiments, Al pans and α-alumina powder as reference material was used. Heating rate was chosen as 10°C/min up to target temperature and the atmosphere temperature holds stable at this target temperature until the palm is dried sufficiently. The palm fruit was also dried in oven at 70°C, 90°C, and 110°C temperatures. Total weight of sample was recorded at time intervals of 10 min. The dried date palm fruit chemical structures were investigated with fourier transform infrared (FTIR) spectrum analysis (JASCO FT/IR-4100) to see the drying temperature effect on the nutrient content of the palm. Mathematical model of drying time as a function of drying temperature for each drying technique was determined by applying trend line and calculating the trend line equation and R^2 values in excel program. Since the Al pans of device are smaller than the palm fruit, the palm fruit samples dried via TG-DTA device were small pieces of the fruit including a piece of fruit shell. However, the palm fruits dried with oven were whole palm fruit which have a thick shell.

The scanning electron microscopy (SEM) (Hitachi SU3500) images of the palm fruit are obtained for investigation of the fibrous structure.

On the other hand, both wet and dried palm fruit exposured to microbiologic studies to see the effect of drying technique on the microorganism growth. In this study, fresh and dried fruit samples were examined with standard analysis methods for total mesophilic aerob bacteria, coliform, *Staphylococcus-Micrococcus* spp., yeast-mold, and sulfite reducing anaerobic bacteria. Fresh date palm fruits (10 samples) and dried date palm fruits (10 samples) were taken into sterile sampling bags. The samples were kept in cold chain (4°C) and used for analysis.

In total, 5 grams of samples taken from fresh and dried fruit samples under aseptic conditions were homogenized with 45 ml physiological saline solutions. Cultures suitable for the microorganism to be analyzed were cultivated. For total number of mesophilic aerobic bacteria (TMAB) count, Plate Count Agar was seeded by cast plate method and colonies were grown after 48 h incubation at 37°C. Sulfite polymyxin sulfadiazine agar (SPSA) was used to determine the number of sulfide reducing anaerobic bacteria (SRAB). Violet Red Bile Agar medium was used for coliform microorganism. Typical colonies resulting from 24-h incubation at 30°C were counted (ICMSF, 1982). Baird Parker agar medium was used for *Staphylococcus/Micrococcus* count after incubation at 37°C for 2 days (ICMSF, 1982). Rose Bengal Chloramphenicol Agar medium was used for enumeration of yeasts and molds which were incubated for 5 days at 25°C (Mislivec et al., 1992). SPSA was used to determine the number of SRAB. After sowing using roll-tube technique, incubation was performed at 37°C for 24 h and irregular black colonies formed in tubes were evaluated (Harrigan, 1998). Each experiment was repeated three times.

Results and Discussion

Two different drying techniques were applied for date palm drying process. Thermogravimetric method (Androutsopoulos, 2001) and drying in hot air in an oven (Kayacan et al., 2020) were applied as drying techniques.

The drying temperatures were stable during the drying process. Since the endothermic behavior of water content of palm fruit to be vaporized, at 90°C the temperature reaches the target temperature after 35 min and 70 min duration time is sufficient for drying. At the other temperatures, the endothermic peak spreads over time and the drying temperatures were 30 min, 50 min, 90 min, and 145 min for 110°C, 90°C, 70°C, and 50°C, respectively. The mathematical model of the drying temperature depending on drying time is calculated as $DT = -37,58\ln(t) + 237,74$ with a regression coefficient of $R^2 = 1,00$. The drying time and temperature relation are shown in Figure 1a and the thermogravimetric changes during the drying process via TG-DTA are exhibited in the following figure Figure 1b.

The drying process was repeated with oven at 70°C, 90°C, and 110°C temperatures and sample weight-time figures are exhibited in Figure 2a–c, respectively. The date palm was dried without chopping or pretreatment in a tempreature controlled oven.

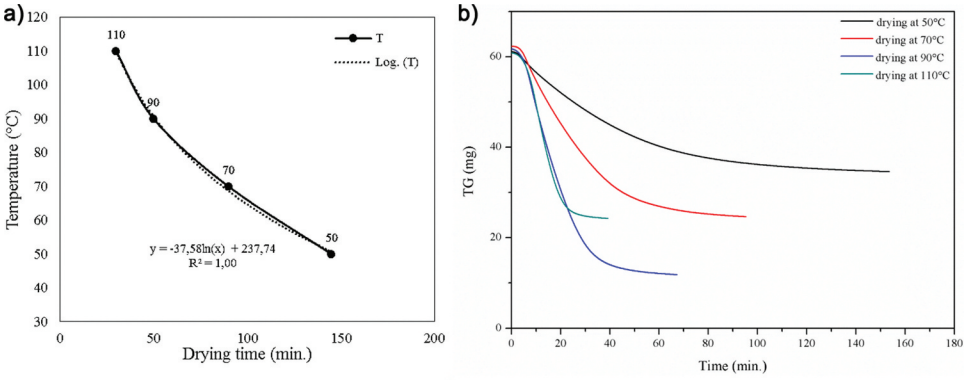

Figure 1. Drying with TG-DTA (a) mathematical model of isothermal drying time of palm chips according to drying temperature using thermogravimetric device (R^2 = 1,00) and (b) TG-DTA weight change data during drying processes.

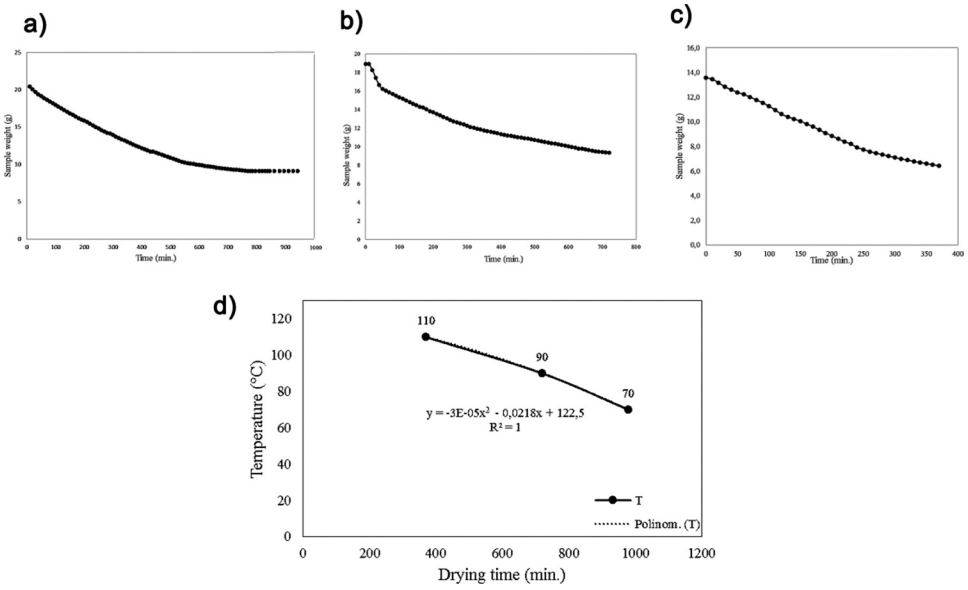

Figure 2. Sample weight vs. time graph of drying process in oven (a) at 70°C, (b) at 90°C, and (c) at 110°C and (d) mathematical model of drying time of palm dates according to drying temperature using oven (R^2 = 1,00).

The palm fruit shell was thick and brittle after it had been dried. It was observed that the thickness of palm shell was very effective on the drying time. When the palm dried with its shell as a complete fruit, the drying time at 110°C was 360 min while it took only 30 min when it was chopped and dried at the same temperature. Many researchers have found that pretreatment before drying is necessary to shorten the drying time and preserve the beneficial content of food (Ni et al., 2020; Nyangena et al., 2019). Total drying time vs. drying temperature relationship with oven drying is shown in Figure 2d.

When the relationship between drying time and drying temperature was investigated, a mathematical model of drying temperature dependent on drying time was obtained as $DT = -3 \times 10^{-5}(t^2) - 0,0218t + 122,5$ with a regression coefficient of $R^2 = 1,00$ for drying process with oven.

After the drying process, the dried fruit samples were investigated with FTIR analysis to see is any change in the chemical structure after the drying processes at different temperatures (Figure 3).

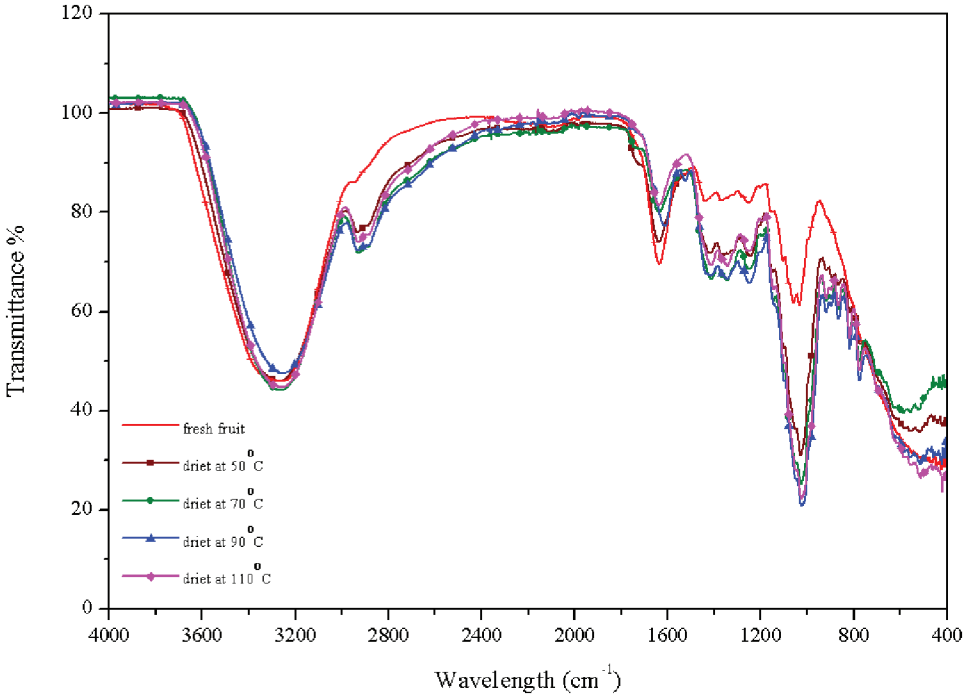

Figure 3. FTIR analysis of dried palm fruit at 70°C, 90°C, and 110°C.

The FTIR samples were collected from the flesh of palm fruit. FTIR results demonstrated that the chemical structure of the palm fruit was not affected by temperature even at 110°C. However, transmittance of the peaks at 1022 cm^{-1}, 2881 cm^{-1}, and 2932 cm^{-1} wavelength decreased and sharper peaks were observed after drying processes. The chemical bonds in the date palm did not show a significant change with the increasing drying temperature. The chemical bonds observed within the date palm dried at 50°C were the same with the chemical bonds achieved with the date palm dried at 110°C.

The amount of ash is a measure of the amount of mineral matter present in foods. Mineral substances are essential elements of living metabolisms. In addition to acting as cofactors of enzymes, they form bone structure, contribute to the work of muscles and nerves, and even play a role in blood coagulation. The date palm fruit ash amount was calculated using TG-DTA analysis applied between 25°C and 500°C in air atmosphere (Figure 4). According to this analysis, the ash amount of the date palm fruit of fresh fruit weight was 8% of fresh fruit that is higher than most of the palm fruit species (İrtem, 2014). The calculated water content of the palm fruit was about 50–60% of fresh date palm fruit weight. It was observed that the color of dried fruit became darker as the drying temperature increased. The color difference is exhibited in Figure 5. Since the fruit has a high sugar content, the higher temperatures lead to darker color after the drying process. The fibrous structure image of the date palm was achieved with scanning electron microscope (SEM) as shown in Figure 5. This image was taken from the inner part surrounding the seed of the date palm. Nanofibrillated cellulose structures make the date palm fruit important for human health. Fibrous foods are essential for the healthy functioning of the human digestive system. Nowadays, they are widely used in weight control diets. Regular fiber consumption prevents excessive weight gain, constipation, development of digestive system cancers, diabetes, and heart diseases.

Microbiological investigation results are given in Table 1. TMAB contamination was 20% in dried date fruits and 40% in fresh date fruits. The highest TMAB number was found in dried date fruits as

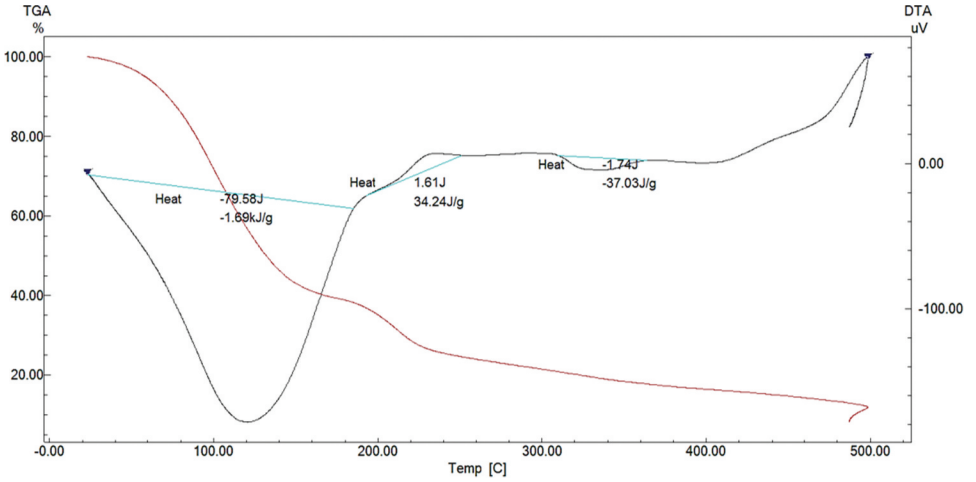

Figure 4. TG-DTA diagram of date palm between 25°C–500°C in air atmosphere.

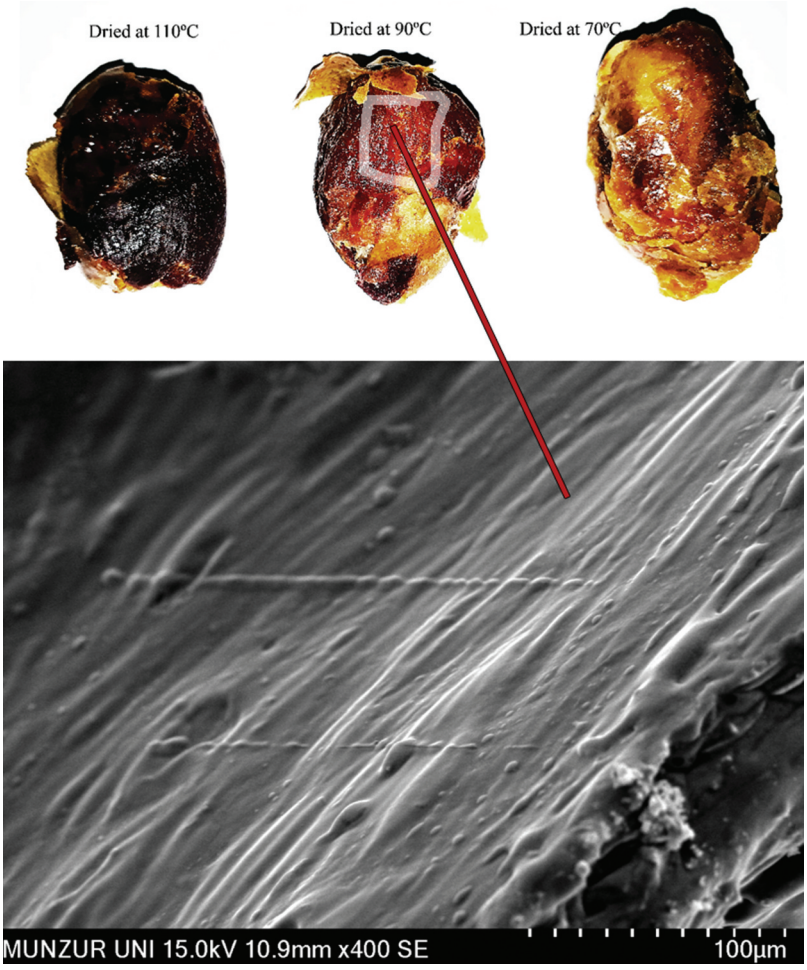

Figure 5. Color differences of dried palm fruits at different temperatures and SEM micrographs of palm fibers.

Table 1. Contamination percentage values (%) and microorganism number (cfu/g) in fresh and dried date palm samples.

	TMAB (%)	MO number (cfu/g)	Coliform (%)	MO number (cfu/g)	*S/M* spp.(%)	MO number (cfu/g)	Mold-yeast (%)	MO number (cfu/g)	SRAB (%)	MO number (cfu/g)
Fresh date palm	40	5.0×10^3	ND	ND	10%	8×10^2	10%	1.2×10^2	ND	ND
Dried date palm	20	3.3×10^2	ND	ND	ND	ND	ND	ND	ND	ND

MO: Microorganisms; ND: Not detected; TMAB: Total Mesophlic Aerobic Bacteria; *S/M* spp.: *Staphylococcus/Micrococcus* spp.; SRAB: Sulfite reducing anaerobic bacteria

3.3×10^2 cfu/g and 5.0×10^3 cfu/g in fresh date fruits. Coliform bacteria, *Staphylococcus/Micrococcus* spp. and mold-yeast presence was investigated in order to determine the hygienic quality of the analyzed food samples. In addition, analysis was performed for SRAB. Coliform contamination was not observed in dried date fruit and fresh date fruit. *Staphylococcus-Micrococcus* spp. was detected in 10% of fresh palm fruit samples, while none of the dried palm fruit samples were found to have *Staphylococcus-Micrococcus* spp. Yeast-mold contamination was found to be 10% in fresh palm fruit, whereas yeast-mold contamination was not found in dried palm. The number of yeast-molds was found as 1.2×10^2 cfu/g. SRAB were not found in any of the fresh and dried date fruits.

In dried fruits, only mold and yeast counts are required as criteria. Because dried fruits are susceptible to mold contamination during ripening, processing, drying, storage, and transportation. Some of these molds can produce toxigenic compounds (Alghalibi and Shater, 2004; Zain, 2011).

Dried fruit samples analyzed in this study were within acceptable limits according to Turkish Food Codex Regulation on Microbiological Criteria (Anonim, 2011) in terms of number of yeast and mold. In addition, the presence of coliform and *Staphylococcus/Micrococcus* spp., which was used to determine the microbiological hygienic quality of the dried fruits, indicates that the fruits do not have a health risk.

For fresh date fruit, coliform was not detected and the presence of *Staphylococcus/Micrococcus* spp. was as low as 10%. This situation indicates that the raw material was obtained from a very hygienic place. However, the low level of *Staphylococcus/Micrococcus* spp., which is known as a hygiene indicator, indicates that the drying process should be performed more carefully and adequately in case of the possibility of causing food spoilage or health problems. In this study, the absence of microorganisms, which are considered as hygiene indicators, after drying showed that the drying process was sufficient.

Conclusions

Drying the date palm as a whole fruit without any pretreatment lead a long drying time because of the thick shell of the date fruit. This situation leads to a high cost and time-consuming drying process. Thus, some pretreatment techniques that provide faster drying may be applied on the palm fruit before the drying process.

In the TG-DTA drying experiments, the mathematical model of the drying temperature depending on drying time is calculated as $DT = -37,58\ln(t) + 237,74$ with a regression coefficient of $R^2 = 1,00$ and as $DT = -3 \times 10^{-5}(t^2) - 0,0218t + 122,5$ with a regression coefficient of $R^2 = 1,00$ for drying process with oven. Since the drying time is important economically, drying time and drying temperature model will be useful for process design.

According to the results of microbiological examination, it was determined that dried fruit samples did not pose a risk to public health and it was observed that drying could increase the economic contribution of the fruit while increasing the storage or shelf life time.

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