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Surface temperature a critical parameter to control peanut quality during far infrared pretreatment process

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Abstract

Far infrared (FIR) radiation was used for surface decontamination of peanuts at varying exposure temperatures between 150-300°C. Depending on the holding time, FIR heating resulted in complete inactivation of total mold and yeast population. 5 log reduction in total mold and yeast population was observed when surface temperature of the peanuts reached 70°C. Besides the microbial reduction and changes on quality characteristics, the effect of infrared heating on physical quality was also investigated during FIR heating process. As a result, the surface temperature was considerable in relation to both microbiological and physical quality characteristics and the measurement of the surface temperature can be suggested as an effective and rapid method to control majority of quality parameters of peanut samples during the FIR heating treatment which could also find commercial use as an effective postharvest process for nuts considering the final microbiological and physical quality.

Introduction

Peanut *(Arachis hypogaea)* is a leguminous herb native to South America and one of the most important oilseed crops with high nutritional value. It is used to obtain oil, peanut butter and largely consumed as a snack in the food industry (Friedman, 1996; Duranti, 1997; Hammond, 1997; Atif *et al*, 2000; He *et al*, 2005; Kornsteiner, 2006). However, peanut is one of the most permissive host crops to molds that can cause the formation of aflatoxins (Guo *et al*., 2009). Contamination of peanuts with aflatoxins, caused mainly by *Aspergillus flavus* and *Aspergillus parasticus* (Diener *et al*., 1987) emerges as a worldwide problem (Marasas *et al*., 2008). Elimination of molds before the toxins are produced must be the primary objective rather than the removal of toxins once occurred. Therefore, there is a great interest to develop novel, practical, and cost effective post-harvest methods or processes to reduce or eliminate fungus before aflatoxins are produced during storage (Basaran *et al.* 2008).

Far infrared (FIR) treatment with low penetration power may be a preferable technique for decontamination processes of food without causing quality damages. Infrared waves are described as short (near), medium (middle), and long (far). Food components and the microorganisms absorb the infrared radiation especially in the far infrared region. Due to the short wavelength of infrared (0.75 to 3000 μm), penetration ability to the interior parts of foods is weak. In the literature, infrared heating was recommended as an advantageous method for surface decontamination while protecting the nutritional value and improving the final quality of the food products. (Sakai and Mao, 2006). Surface microbial load is reduced substantially and nutritional quality attributes are protected since infrared (IR) cause a rapid increase in surface temperature (Huang, 2004).

Several researchers have studied the efficiency of infrared pasteurization for various food samples. Bingöl *et al.* (2011) studied the reducing effect of infrared rays on Pediococcus level in raw almond samples contaminated with Pediococcus to a load of 10^8 CFU / g. Initially, the surface temperatures of the samples were rapidly increased to 100, 110 and 120ºC then hold at 70, 80 and 90ºC for 5 to 60 minutes. Depending on temperature - time combinations, a significant microbial reduction was achieved while the color parameters were not affected significantly. Similarly, Yang *et al*. (2010) used IR rays to roast almonds to investigate pasteurization efficiency. Samples inoculated with the initial load of 108.55 CFU / g Enterococcus faecium reduced significantly upon IR pasteurization. Erdoğdu and Ekiz (2011, 2013) investigated the effect of far infrared (FIR) rays on total mesophilic-aerobic bacterial and total mold yeast load of cumin and black pepper seeds. In both studies, the microbial load of cumin and black pepper samples were reduced to the target level within short treatment times without causing any changes in the volatile oil content and the color

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of the samples. Staack *et al.* (2008) also studied on IR heating to decontaminate paprika powder and obtained a reduction greater than 6 $\log_{10}$ CFU/g for *B. cereus* at 0.96 aw.

IR radiation has poor penetration capacity. However, the surface temperature of food materials increases rapidly during IR processing of foods leading to quality destructions due to overheating. Therefore, surface temperature should be raised to a level that the target microorganisms can be inactivated without increasing the interior temperature. In this study, surface temperature of peanut samples was measured during decontamination process and correlated with the microbial survival (TMY) and quality attributes (moisture content, color and texture).

Materials and Methods

Peanuts

Unshelled peanuts with reddish-brown skin were provided from a peanut storage and processing facility in Osmaniye, Turkey (Virginia type, NC 7 cultivar). Raw peanuts were kept in cold storage at 4°C until the analysis.

FIR heating process

A custom designed continuous system FIR heating equipment was used to determine the effect of infrared rays on the microbial load and the quality characteristics of peanut samples. As a source of FIR light, 48 ceramic lamps were utilized. Lamps, with maximum 39 kW/m^2 heat flux and 650 W power were adjusted up to a maximum surface temperature of 553°C. Lamps were mounted on the side walls of the tunnel oven. Interior walls of the tunnel were covered with aluminum to reflect the infrared energy. The technical properties of the infrared equipment have been reported in detail in a doctoral study by Erdoğdu (2011) previously. Experiments were conducted after the uniform temperature distribution and steady-state condition inside the tunnel were ensured by reading the value from the control panel connected to internal thermocouples of the tunnel.

Peanuts (15 ± 1g; 15-20 kernels) were spread into a single layer on a wire mesh and fed into the FIR tunnel oven at setting temperatures ranging between 150°C to 300°C for different holding times. Peanut kernels were aseptically placed in sterile petri dishes at the end of the heating process. Since prolonged holding times causes color change (darkening) detectable by human eye, the holding time which does not impair to the color characteristics of the sample has chosen as the maximum.

Surface temperature determination

Peanut samples were placed in petri dishes and fed into tunnel. Surface temperatures of the peanut samples were determined by using an infrared camera (FLIR I50, Boston, MA, USA). Temperature distributions at the surface of the peanut samples for each setting temperature were determined by analysis of the thermal images which were taken, from a small opening in the upper part and near the exit of the infrared tunnel. In order to obtain correct surface temperature; the image analysis software (FLIR Quick Report, Flir Instruments) expects from user to enter the atmospheric temperature, relative humidity, the temperature reflected to the sample surface, emissivity coefficient and distance values. Temperatures adjusted from the control panel of the tunnel were used as ambient temperature. These values were obtained from thermocouples that were placed near the surface of the ceramic infrared light in the tunnel. Infrared lamps were placed on the side walls of the tunnel and interior walls were covered with aluminum to reflect the infrared energy on both top and bottom surfaces of the food material. In that case, the reflected temperatures to the sample surface in the tunnel were higher than the temperature set because of the reflected energy by aluminum coated walls inside the tunnel. For each adjusted temperature conditions, reflected temperature values to the sample surface were determined with the use of a high temperature resistant and black painted copper disc (thickness 1,14 cm, diameter 4,93 cm). The disc was placed inside the tunnel prior to capturing the thermal images by infrared camera at different times for each FIR setting temperature (150, 200, 250 and 300°C). The disc has a thermocouple at the geometric center. The high thermal conductivity of copper (400 W/mK) allowed the application of lumped system analysis and the temperature difference between center and the surface was assumed to be negligible. In this context, thermal images of the copper disk obtained. After entering the ambient temperature (150, 200, 250 and 300°C), relative humidity (%1), reflected temperature (higher than the setting temperature) and emissivity coefficient (0.9), surface temperature of the disc was determined. At the point when temperature values obtained from thermal camera and thermocouple were equal, reflected temperature values of the copper disc were recorded. This temperature also shows the reflected temperature to the peanut samples. All the required data were entered to the image analysis software, and surface temperatures of the peanut samples were determined at all FIR setting temperatures and exposure times for each thermal image.

Determination of microbial load

Total mold and yeast (TMY) content of the peanut kernels were tested to determine the influence of FIR heating on microbial reductions. Following the process approximately 10 g of FIR treated samples were weighed in a sterile petri dish and transferred into a 250 ml volumetric flask containing 90 ml of sterile peptone water (0.1% w/V). Then the flask was vortexed (IKA, Germany) at 1400 RPM for 1 min. After performing serial dilutions, 0.1 ml of each, was transferred onto sterile Potato Dextrose Agar (PDA) for determining total mold and yeast count with at least three parallels and three replications. Sterile tartaric acid (10%) was added to obtain pH of PDA medium to 3.5 ± 0.1 for inhibiting bacterial growth. Petri dishes were incubated at 30°C for a period of four days in a thermostat incubator (Velp, Italy). Colonies were counted and the numbers of microorganisms in the samples were determined.

Color measurements

Color changes of the peanut samples were measured by using the Color Quest XE Colorimeter (Hunter Lab, U.S.A.). L^*, a^*, b^* values of samples were determined. Color readings were taken from the middle portion of both sides of Hunter Lab cuvettes. Peanuts randomly selected and a total of ten readings were averaged for each treatment condition.

Moisture content determination

Moisture content of peanut samples was determined by oven drying method (TS 3075). This method is based on the measurement of the amount of water removed from the sample by heating at 105°C. Experiments were performed in three parallels and three replications for each FIR setting temperature.

Texture analysis

Texture measurements were performed using a Texture Analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, UK). Tests were carried out at ambient temperature. Cylinder probe with the diameter of twenty five millimeters was used for the compression tests. Each peanut kernel was compressed to 5 mm after the probe touching the sample at a test speed of 5 mm/s. Twenty replications were performed for each FIR treated sample. The fracture force (maximum force at the first point fracture) was considered as the primary parameter to evaluate textural properties of peanut samples.

Statistical analysis

Changes of color and texture properties were analyzed statistically with IBM SPSS Statistics 20 software. Tukey's test was used to adjust for multiple comparisons. Results were shown in Table 1 and 2. Different letters within the same column indicate significant ($P<0.05$) differences.

Results and Discussion

FIR heating was used to reduce the number of microorganisms of peanut samples. Furthermore, the quality parameters of peanuts were evaluated before and after FIR treatment. Changes in quality attributes and microbial reduction have been correlated with surface temperature.

Efficacy of pasteurization

Microbial load of the untreated raw peanut samples were analyzed according to processed peanut standard (TS 13232) which is published by Turkish Standards Instution. In this standard, maximum permitted limit for total mold and yeast (TMY) content is stated as 10^3 CFU/g. Our samples has higher microbial load compared with the limit given in standard. Peanut samples having different initial microbial loads were used to investigate the detrimental effects of FIR rays on microorganisms. The reductions in TMY population on peanut samples during FIR heating are given in Figure 1. Peanut samples were fed into the tunnel and microbial load was reduced to 1×10^3 CFU /g level at FIR tunnel setting temperatures of 150, 200, 250 and 300°C for 300, 200, 90 and 80 seconds respectively. Complete elimination (< 1 log cfu/ml) was observed for all treatment temperatures except 150°C. Sterilization was provided at tunnel temperatures of 200, 250 and 300°C for 300, 125 and 125 seconds, respectively.

Erdoğdu and Ekiz (2011) previously observed 2 log units reductions in total mesopilic aerobic bacteria (TMAB) counts of cumin seed after 2.5 min. processing at 300°C by using the same FIR heating equipment. Erdoğdu and Ekiz researched in 2013 effect of far infrared heating for surface pasteurization of black pepper and they reduced the TMAB counts of samples approximately 7 log units after 4 minutes at 350°C. Additionally Erdoğdu (2011) reported in her doctorate thesis, cumin samples were sterilized in terms of total mold and yeast by using industrial scale FIR heating equipment. Initial microbial load of cumin was 103,6 cfu/g. After heating 1.5 min. at 200°C in this equipment mold and yeast free cumin samples were obtained. When these results were compared by taking processing temperatures and durations into consideration, significant reduction was achieved for peanuts in short processing durations. The different size and form of particles, microstructure, surface and

Table 1. a* value of peanut kernels treated under various IR heating conditions

150°C		200°C		250°C		300°C	
FIR treatment time (s)	a*	FIR treatment time (s)	a*	FIR treatment time (s)	a*	FIR treatment time (s)	a*
0	$9.11^{a}\pm0.68$	0	$9,11^{a}\pm0.68$	0	$9,11^{a}\pm0.68$	0	$9.11^{a}\pm0.68$
60	$9.70^{ab}\pm0.37$	50	$9.14^{a}\pm0.34$	40	$8.923^{a}\pm0.46$	30	$9.12^{a}\pm0.54$
120	$9.31^{b}\pm0.39$	100	$9.57^{abc}\pm0.30$	80	$9.39^{ab}\pm0.84$	60	$9.49^{ab}\pm0.35$
180	$9.57a^{b}\pm0.35$	150	$9.45^{ab}\pm0.47$	120	$10.28^{c}\pm0.31$	90	$9.85^{abc}\pm0.41$
240	$9.58^{ab}\pm0.48$	200	$9.91^{bcd}\pm0.31$	160	$10.03^{bc}\pm0.24$	120	$10.03^{bcd}\pm0.38$
300	$9.42^{ab}\pm0.81$	250	$9.90^{bcd}\pm0.17$	200	$9.89^{bc}\pm0.75$	150	$10.55^{bcd}\pm0.26$
360	$9.80^{ab}\pm0.48$	300	$10.14^{cde}\pm0.42$	240	$10.61^{c}\pm0.50$	180	$10.71^{de}\pm0.78$
420	$9.64^{ab}\pm0.39$	350	$10.46^{de}\pm0.58$	280	$10.62^{c}\pm0.54$	210	$10.84^{e}\pm0.53$
480	$9.89^{ab}\pm0.38$	400	$10.78^{d}\pm0.73$	320	$10.59^{c}\pm0.60$	240	$10.28^{cde}\pm0.36$
540	$9.93^{ab}\pm0.29$	450	$10.67^{d}\pm0.26$	360	$10.10^{bc}\pm0.61$	270	$10.14^{bcde}\pm0.90$

The values of the a* value shown in different letters are significantly different ($P < 0.05$).

Table 2. Fracture force of peanut kernels treated under various IR heating conditions

150°C		200°C		250°C		300°C	
FIR treatment time (s)	Fracture Force (N)	FIR treatment time (s)	Fracture Force (N)	FIR treatment time (s)	Fracture Force (N)	FIR treatment time (s)	Fracture Force (N)
0	$54.43^{b}\pm14.23$	0	$53.60^{c}\pm13.44$	0	$52.49^{b}\pm9.59$	0	$49.27^{c}\pm5.84$
60	$41.17^{a}\pm10.45$	50	$43.43^{abc}\pm9.70$	40	$40.18^{a}\pm10.33$	30	$34.76^{ab}\pm11.50$
120	$43.99^{a}\pm9.04$	100	$43.72^{abc}\pm13.95$	80	$37.80^{a}\pm10.01$	60	$41.72^{bc}\pm9.37$
180	$42.61^{a}\pm13.17$	150	$50.50^{bc}\pm10.69$	120	$38.55^{a}\pm11.39$	90	$35.84^{ab}\pm10.17$
240	$44.14^{a}\pm7.69$	200	$36.24^{a}\pm8.94$	160	$32.65^{a}\pm12.85$	120	$34.69^{ab}\pm8.94$
300	$44.72^{ab}\pm10.69$	250	$33.31^{a}\pm12.21$	200	$33.75^{a}\pm8.83$	150	$32.75^{a}\pm7.79$
360	$42.81^{a}\pm8.92$	300	$37.02^{a}\pm12.87$				
420	$38.03^{a}\pm7.04$	350	$39.73^{ab}\pm14.50$				
480	$40.26^{a}\pm8.44$						
540	$37.08^{a}\pm12.95$						

The values of the fracture force shown in different letters are significantly different ($P < 0.05$).

optical properties of the samples might have led to unequal microbial reductions for cumin and peanut.

Surface temperature profiles of peanuts and relation of temperature with microbial reduction

Surface temperature measurements were done by using an IR camera at 150, 200, 250 and 300°C FIR tunnel setting temperatures for different exposure times. The effect of heater setting temperature on surface temperature distributions was examined. It was found that the higher the heater temperature, the higher the surface temperature of the peanut samples [Figure 2-A].

The relationship between the surface temperature and the microbial load regardless of treatment temperature and holding time was shown in Figure 2-B. Surface temperature raised to 60°C and microbial load was reduced to targeted level of 1×10^{3} CFU /g at FIR tunnel setting temperatures of 150, 200, 250 and 300°C for 300, 200, 90 and 80 seconds respectively. Total elimination of microorganisms was achieved when the surface temperature reached to 70°C. This relation between surface temperature and microbial reduction led to a suggestion of a new infrared system including an infrared camera to follow the predictable microbial reduction simultaneously. Moreover, the surface temperature is to be estimated instead of microbial load during heating process. Previously, several researches on the efficiency of IR treatment for the reduction of different microorganisms were reported in the literature. *Listeria monocytogenes* load (analyzed under the zero tolerance policy) on turkey frankfurters was reduced from the approximate initial level of 106.5 to 10^{2} CFU/cm^{2} level by Huang (2004). Complete elimination could not be achieved at the final surface temperatures of 70, 75 and

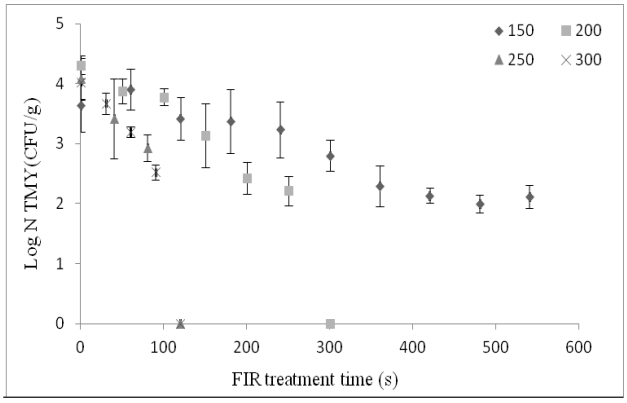

Figure 1. Effect of FIR surface pasteurization on survival of mold and yeasts

80°C. Bingöl *et al.* (2011) observed that holding the almonds at 90°C for 10–15 min in an infrared heating equipment reduced the Pediococcus population size by more than 5-log and holding at 80°C for longer than 22 min provided greated than 4-log reduction. Color values of almonds were affected significantly. This could be caused by the longer IR treatment time. Rosenthal *et al.* (1996) researched IR radiation (at 70°C for 5 min) for cottage cheese decontamination and they found that IR was efficacious in reducing the growth of yeasts and fungi on cheese surface without impairing the product quality, resulting in a shelf life of 3-4 weeks at 4°C. James *et al* (2002) were aimed to assess temperatures on the outside and interior of the shell to identify the highest temperatures that could be achieved on the outside of eggs without damaging the contents of the egg or the shell itself. The bacterial counts on the surface of the eggs were reduced by infrared radiation without significantly raising the interior temperature. Eggs were treated with IR radiation at 210°C for 30 seconds. Final surface temperature and interior temperature of eggs raised to 90°C and 50°C respectively. IR treatment was found capable to reduce Salmonella numbers on the exterior surface of an egg shell by 6 log while adversely protecting the interior contents.

Surface temperature is a practical parameter to measure and gives significant indications of the adequateness of the heating process. Therefore, the research was focused on the relations of surface temperature with quality characteristics of peanut samples during FIR treatment.

Multiple correlation of surface temperature and microbial reduction with quality characteristics

In this part, other than the relationship between peanut surface temperature and the microbial load; moisture content, texture and color parameters of peanuts related to the microbial load were investigated. Changes in moisture content, color, and

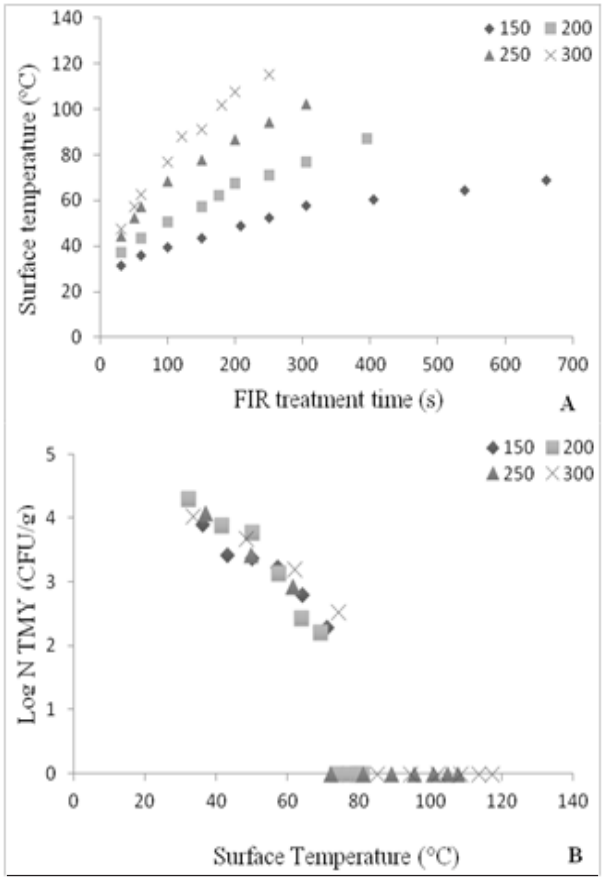

Figure 2. Surface temperatures of peanuts (A) and relationship between temperature and microbial survival (B) during FIR heating at different FIR tunnel setting temperatures (150, 200, 250 and 300°C)

texture of peanuts were in correlation with the survival of the microbial load and the surface temperature of samples. During the treatment of raw peanut samples with infrared rays for reducing microbial load, a minimal decrease in moisture content, slight increase in redness and fracturability were observed (Figure 3. A-B and C). Due to the relations between surface temperature and both microbiological and physical quality characteristics, measurement of surface temperature suggested as a prominent way to follow quality parameters of peanut samples simultaneously during the FIR heating process.

The moisture content

The initial moisture content of peanuts was 7,076±0,268 % on wet basis. Slight decreases on moisture content of samples with increasing treatment times and temperatures during FIR heating were observed. Figure 3-A., shows the surface temperature and moisture content for the target microbial reduction level. When the microbial load was reduced to the level of 1×10^3 CFU/g, the surface temperature was detected as approximately 60°C and moisture content (w/w) observed as 6%. Furthermore,

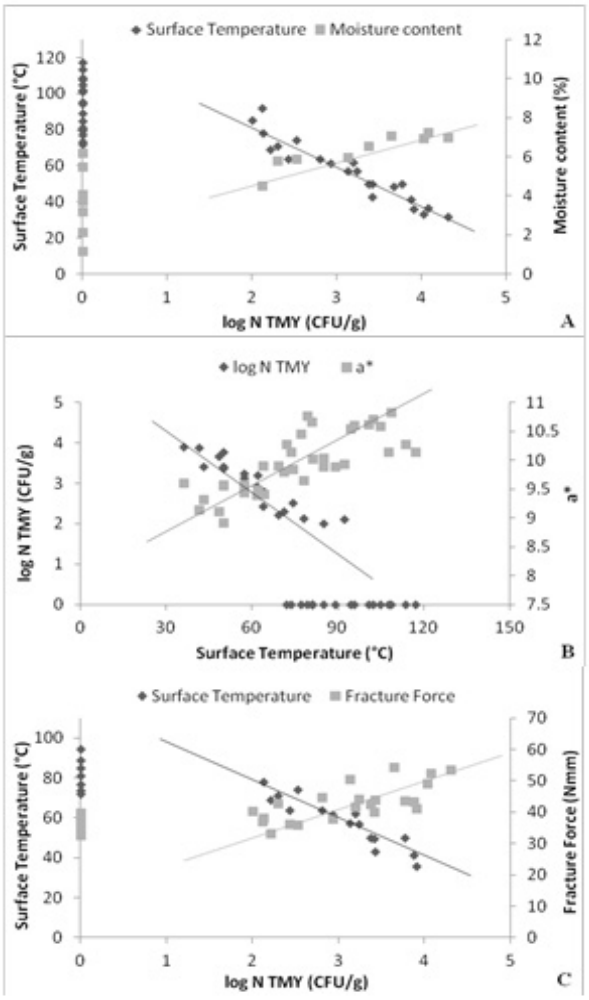

Figure3. Effects of FIR treatment on moisture content (A), redness (B) and fracture force (C) and relations with microbial survival and surface temperature during the FIR heating

at 70°C surface temperature, the moisture content of the peanut samples was reduced approximately to 4%. Under the given moisture content levels; physical, chemical and microbiological quality of peanuts can be protected during storage.

The color and texture profiles

L^*, a^* and b^* parameters of peanut samples were measured. The initial L^*, a^*, and b^* color parameters of samples were 54.79, 9.12, and 14.47, respectively. L^* (lightness) and b^* (yellowness) were not affected. Nevertheless, FIR treatment of raw peanut samples caused a slight increase in a^* (redness) (Eser, 2012). Therefore, in this study only result of redness was taken into consideration. Microbial reductions was correlated with a^* and surface temperature (Fig. 3-B). The a^* values of the samples were determined as approximately 9.5 and 10 at 60°C and 70°C respectively. Additionally Table 1 shows that at the end of the infrared heating process, there was no significant difference ($P > 0.05$) between a^* values of treated and untreated whole kernels. Therefore, it can be concluded that neither holding time and temperature nor infrared heating temperature had significant effect on color values of whole kernels. Any difference in appearance between infrared pasteurized and untreated peanuts was observed. This is in accord with Bingöl *et al.* (2011) for almond and Özdemir and Devres (2000) for hazelnut who did not observe any significant change in whole-kernel color values even when the kernels were exposed to roasting temperatures of up to 120°C. Effect of infrared heating on color parameters of peanut samples is comparable to other studies in the literature. Erdoğdu and Ekiz (2011 and 2013) used FIR heating for spice decontamination and reported that FIR treatment did not cause any significant changes in lightness and yellowness but an increase was observed in redness of the cumin and black pepper seeds with increasing treatment time. Similarly color parameteres were not affected by the infrared processing in previous studies conducted by Huang (2004) for frankfurters and Eliasson (2014) for oregano.

The force required to break nuts depends upon its moisture content. Reduction in the moisture content during heating imparts brittleness to the samples, requiring minimum energy breakage. The maximum force at the first fracture point named as fracture force was used to evaluate the textural properties of peanut. As FIR heating duration is increased, the force needed to break a peanut kernel decreased (Figure 3-C). The changes on peanut texture, microbial load and surface temperature should be evaluated together. Fracture force reduced from 55 N to approximately 45 N to reach the acceptable microbial quality level and at 70°C the reduction curve shows the point of 30N. The evaluation of texture of far infrared treated peanuts was done statistically and shown in Table 2. The table indicates that IR heating temperature and times did not effected texture of the samples. But untreated samples were found different from treated ones for all temperatures. Moisture loss in the samples is the major influencing factor of this difference during far infrared heating.

Texture has an utmost importance for nut processing. Hence it is essential to optimize the conditions for all processes (surface decontamination, drying, roasting etc.) to get products with desirable textural properties. As a result, it is possible to estimate the preferred physical and microbiological quality characteristics of peanut kernel controlling the surface temperature, practically. In previous studies, the decrease in hardness with the increase in processing time during pulsed infrared roasting of groundnut has been stated by Kumar *et al.* (2009).

Compressive strength reduced from approximately 80 N to 17 N. Saklar *et al* (1999) observed significant decrease in the first fracture point during roasting of hazelnuts. The effects of these roasting processes on textural properties were marginal, although this marginality resulted in nuts with better texture. The purpose was not to roast peanuts in our study. The microbial decontamination primarily aimed without compromising of physical quality of peanuts. Effects of FIR treatment on peanut texture were not comparable with the mentioned researches above.

This work potentially will lead to new studies that will be done with various food samples initially contain low and high levels of microorganisms. IR decontamination process parameters of food materials including treatment and surface temperature and duration of the treatment could be determined for each initial microbial condition by performing multiple experiments. Product temperature may be correlated with the microbial reduction to determine the pasteurization and sterilization points subsequently. In this regard, determining surface temperature of food samples at the end of the heating process may be an effective approach to predict majority of the quality parameters.

Conclusion

This study has shown that the infrared pasteurization was an effective method to reduce microbial load of raw peanut samples and caused slight changes on the physical quality characteristics of the samples. The most important finding of this study was the observation of the strong relationship between microbial load and surface temperature. Regardless of FIR tunnel setting temperatures and holding times, population of microorganisms of peanuts were reduced to the target levels at 60°C and total elimination of microorganisms were observed at 70°C. Therefore, we suggest that the temperature measurement apparatus should be used in order to determine the surface temperature for controlling the microbial load and physical properties during processing of food materials with this kind of heating systems.

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