ÇOMÜ Zir. Fak. Derg. (COMU J. Agric. Fac.)
2018: 6 (2): 83–91
ISSN: 2147–8384 / e-ISSN: 2564–6826

Araştırma Makalesi/Research Article

Effects Of Moisture Content And Temperature On The Emissivity Of Some Seeds

Haydar Arslanbay **Habib Kocabıyık***

Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Canakkale Onsekiz Mart University, Canakkale, Turkey
*corresponding author: kocabiyikh@comu.edu.tr

Geliş Tarihi: 04.04.2018 Kabul Tarihi: 27.09.2018

Abstract

The selected thermal radiative property, namely emissivity (ε) was aimed to determine for some seeds at different moisture content ranges. The emissivity values for the seeds were determined via direct measurement method using cavity model in dynamic temperature conditions. Seed emissivity values were determined to vary between 0.47 and 0.87 for sunflower, between 0.68 and 0.96 for pea, between 0.49 and 0.86 for paddy, between 0.46 and 0.83 for flax and between 0.63 and 0.96 for corn. The ε value of wheat seeds ranged between 0.50 to 0.96 for all tested varieties under conditions of varying moisture content and temperature. Emissivity values of all seeds were affected by temperature and moisture content. The emissivity values increased with increasing temperature.

Keywords: Thermal Radiation, Emissivity, Corn, Sunflower, Flax, Paddy.

Bazı Taneli Ürünlerin Emissivitesi Üzerine Sıcaklık ve Nem İçeriğinin Etkisi

Öz

Bazı taneli ürünler için termal ışınım özelliğinin yani emissivitenin (ε) farklı nem içeriği aralığında belirlenmesi amaçlanmıştır. Taneli ürünlerin emissivite değerleri, dinamik sıcaklık değişim koşullarında boşluk modeli kullanarak doğrudan ölçüm yöntemiyle belirlenmiştir. Emissivite değerleri, ayçiçeği için 0.47 ve 0.87, bezelye için 0.68 ve 0.96, çeltik için 0.49 ve 0.86, keten tohumu için 0.46 ve 0.83, mısır için 0.63 ve 0.96 arasında değişim göstermiştir. Test edilen tüm buğday çeşitlerinin ε değeri farklı nem içeriği ve sıcaklık koşullarında 0.50 ve 0.96 arasında değişmiştir. Tüm taneli ürünlerin emissivite değerleri nem içeriği ve sıcaktan etkilenmiştir ve sıcaklığın artmasıyla ε değerinde artış olmuştur.

Anahtar Kelimeler: Termal Işınım, Emissivite, Mısır, Ayçiçeği, Keten, Çeltik.

Introduction

Nowadays, agricultural and food products are processed and served to the consumers in numerous ways with the help of technological developments in food industry and postharvest stages. Thermal processes are widely applied on agricultural and food products to obtain high quality products and to sustain them for long periods of time (Kocabiyik et al., 2009).

Applications of infrared radiation in food processing have gained momentum in recent years. The intense thermal energy from infrared emitting sources has been used in the food industry for various purposes such as drying, blanching, curing, caramelisation, thawing, baking, frying, pasteurization, sterilization, roasting cooking and pathogen inactivation (Kocabiyik, 2012; Krishnamurthy et al., 2008). For example, Krishnamurthy et al. (2008) reported that infrared radiation can be effectively used for the inactivation of lipase and lipoxygenase enzymes in soybeans. It can also be used successfully for infrared irradiation as a stabilization method for rice bran (Tuncel et al., 2014; Yılmaz et al., 2014).

Agricultural and food products are perishable and heat sensitive materials. Properties of these materials vary drastically under various thermal conditions thus affecting their physical, chemical and nutritional properties. Particularly, products with high moisture content such as fruits, vegetables, some cereals, seafood and meat are highly affected by factors such as negative environmental conditions which in turn result in deterioration of materials. Improper process instruments and setting conditions for preservation also have significant impacts on these products. Therefore, the thermal properties of agricultural and food materials need to be known to better understand their nature, to be able to develop new technologies, to provide insight for the relation between product properties and engineering processes, to design new process operations and machines and to use energy more effectively. Some thermal properties (specific heat, thermal conductivity and thermal diffusivity) of various biological materials with related conduction and convections heat transfer conditions have been determined experimentally. Some mathematical models for predicting the thermal properties have also been reported (Kayisoglu et al., 2004; Kocabiyik et al., 2009).

It is desirable that the temperature of the product for process is obtained by way of experimental techniques and that the recommended temperature values are used for each product during the processing and storage of agricultural and food products. If the product temperature is above the desired values, the deterioration of the product due to change of chemical and physical properties accelerates resulting in loss of quality. For instance, storage temperature values below 18 ^{o}C for cereals prevent or completely stop the activity of many harmful insects. Drops of 5 ^{o}C in storage temperature extend the storage period by two times while an increase of 5 ^{o}C in temperature reduces the storage period thrice (Nithya et al., 2011). Therefore, product temperature must be constantly monitored and controlled during processing and storage. Contact thermometers with thermocouples or resistive sensors are generally used to determine the product temperature. However, non-contact temperature measurement systems have also gained attraction due to reasons such as late response time of the thermocouple or resistance-effect sensor, infectious effects, erroneous measurement as a result of physical adversities caused by contact with the product (Saunders, 2004). Non-contact temperature measurement can be carried out via infrared thermometers or thermal image sensors. The measurement accuracy with these equipment depends on two input parameters which are the measured emission value (emissivity) and the ambient temperature. Emissivity is a thermal property of the object, which indicates its ability to emit heat with radiation (Chen, 2015; Rakrueangdet et al., 2016). Emissivity plays a significant role in determining correct temperature of the object, and caution must be exercised to select an accurate value. In spite of the emissivity has a strong dependence of surface state, which is difficult to determine during heating process due to the occurrence of moisture loss and directional shrinkage, it directly affects the temperature captured by infrared thermography devices through changes in surface reflection (Llave et al., 2017).

The total amount of radiation released by the object per unit area per unit time is identified as its total emissive power and it depends on the temperature and surface properties of the object. This energy can emit in all directions and at all wavelengths. The emissivity property of food or non-food materials subjected to infrared radiation determines the absorption of incipient radiation. The characteristic of infrared source as well as properties of product play an important role in the selection of source wavelength and assisted dryer (Pawar and Pratape, 2017).

The number of studies in literature directly related with the thermal properties of agricultural and food materials interrelated with radiation heat transfer is not sufficient. Only one related study has been determined. In that study, Yu et al. (2015) investigated the emissivity of canola seeds as a function of temperature and moisture content and developed regression models for predicting it. In addition, emissivity values were determined for breaded chicken nugget and its meat (Zhang and Stewart, 2005) along with nine different plant leaves (López et al., 2012). However, the emissivity values of metals and non-metals excluding those for biological substances have been given provided as standard and references values in several sources involving books, research articles, manuals and the internet. Nevertheless, there are no standard or reference values for the emissivity of biological materials. Emissivity values of 0.93-0.95 have been recommended in some manuals for biological materials but the origin and source of the recommended emissivity values are unknown. Ilyasov and Kransikov (1991) stated that though emissivity data for biological materials are scarce, typical values of emissivity for agricultural crops may be optimistically assumed to vary from 0.7 to 0.9. Hellebrand et al. (2001) also proposed that emissivity should be determined via dynamic temperature measurements, and the change in emissivity with temperature should be carefully proven. The basic features related to the thermal radiation of products for temperature control and monitoring in product process automation are confronted as a missing subject.

Corn, wheat, sunflower, paddy, pea, flax are among the most highly produced grained products with the highest trade involved. These products are subject to long storage times due to economic reasons and they also undergo many different product processing stages such as mechanical, thermal, chemical etc. when they are transformed into final products for the consumers. Determining, monitoring and controlling the temperature properly are among significant criteria for the automation systems used during the processing of these products. Especially the correct measurement of temperature in contact free temperature measurement systems depends on the emissivity of the substance.

Therefore, the objective of this study was to determine the emissivity values for corn, wheat, sunflower, paddy, pea and flax seeds as a function of moisture content (MC) and temperature (T), and to investigate the correlations between the emissivity and colour properties of seeds.

Materials and Methods

Theoretical considerations

Emissivity is defined as the ratio of energy emitted from an object to that of a blackbody at the same temperature. Therefore, the blackbody, as the perfect absorber and emitter, serves as a standard against the radiative properties of actual surfaces.

Although closely approximated by some surfaces, it is important to note that no surface has precisely the properties of a blackbody. The closest approximation is achieved by a *cavity* with an inner surface at uniform temperature. If radiation enters the cavity through a small aperture, it is likely to experience many reflections before its re-emergence. Since some radiation is absorbed by the inner surface with each reflection, it is eventually almost entirely absorbed by the cavity, and thus blackbody behaviour is approximated. Blackbody radiation exists within the cavity irrespective of whether the cavity surface is highly reflecting or absorbing (Bergman et al., 2011).

Radiant energy (E) is the amount of energy leaving the target surface. This energy could be detected by way of infrared camera detectors mounted on a thermal imaging device and consequently converted into a real surface temperature reading value. For grey surfaces and opaque materials, this radiation includes the reflected portion of the irradiation or reflection which depend on its reflectivity (ρ) and surrounding temperature (T_{sur}), as well as the direct emission (E_o) from the object surface which in turn depends on its emissivity (ε_o) and surface temperature (T_o) (Rakrueangdet et al., 2016). Radiosity can be calculated using the following equation;

$$E = \varepsilon_o \sigma T_o^4 + \rho_{sur} \varepsilon_{sur} \sigma T_{sur}^4 \qquad (1)$$

Where σ is Stefan-Boltzmann constant (5.67×10^{-8} $Wm^{-2}K^{-4}$).

The radiation energy (E_c) detected by an infrared detector is calculated as;

$$E_c = \varepsilon T_c^4 \qquad (2)$$

Where ε is the set emissivity of the infrared detector, T_c denotes the detected temperature by the infrared detector.

The radiation energy (E_t) determined from the temperature detected by the contact-thermocouple can be defined as:

$$E_t = \varepsilon_r T_t^4 \qquad (3)$$

Where ε_r is real emissivity of object, T_t is the detected temperature by the contact thermocouple.

For the same object, the radiation energy (E_c) detected by infrared camera and the energy (E_t) generated from the temperature measured by thermocouple in Eqs. (2 and 3) must be equal. In addition, the temperature value detected by the infrared detector (T_c) and the temperature obtained via contact-thermocouple (T_t) must be equal. Equations (2) and (3) can be reorganized as follows;

If $E_c = E_t$ and $T_c = T_t$,

$$\varepsilon T_c^4 = \varepsilon_r T_t^4 \qquad (4)$$

$$T_c^4 = T_t^4 = \frac{E_c = E_t}{\varepsilon} = \frac{E_c = E_t}{\varepsilon_r} \text{ or} \qquad (5)$$

$$T_c^4 = \frac{\varepsilon_r T_t^4}{\varepsilon} \qquad (6)$$

Since $\varepsilon_r T_t^4$ is constant, the values of ε change.

Sample preparation

The seed samples (Corn, Sunflower, flax, paddy, pea and wheat) were obtained from the local market. The seeds were cleaned manually from foreign materials such as stone, sand, soil, broken seeds etc. The initial moisture content of seeds was determined by using the oven method at 105 °C for 24 h (ASABE, 2012). A predetermined quantity of distilled water was inserted by spraying to the known mass of the seeds at initial moisture content for increasing the moisture content of seeds. Afterwards, the samples were packed into sealed moisture resistant flexible bags. The flexible bags were constantly shaken and rotated while spraying with water. The flexible bags were then stored at +4 °C in a refrigerator for 48 h to achieve uniform moisture distribution. Seed samples were kept in the laboratory to reach room temperature and to release the surface moisture (surface dew) before starting the experiment. The moisture contents of the seeds are shown in Table 1. The colours of seeds were measured by Chroma meter (Konica Minolta CR-400), respectively. Some colour properties of seeds have been shown in Table 2.

Table 1. Moisture content of seeds used as experiment materials

Seed	**Moisture content levels (%)**					
	I	**II**	**III**	**IV**	**V**	**VI**
Corn	23.79	19.63	17.90	18.53	11.69	9.97
Sunflower	27.31	25.64	14.35	9.64	7.86	5.73
Flax	18.83	6.38	4.61			
Paddy	21.99	11.84	10.38			
Pea	77.92	57.92	58.07	31.26	21.15	
Wheat (Göksu)	32.04	30.53	25.93	24.71	15.26	
Wheat (Konya)	40.17	34.04	28.22	18.18	14.21	
Wheat (Kınacı)	34.32	33.69	27.10	16.65	12.47	
Wheat (Dağdaş)	39.29	36.37	27.94	19.98	13.00	

Table 2. Colour properties of seeds

Seed	**L***	**a***	**b***	**Chroma**	**Hue**	**R**
Corn	65.47±7.78	5.56±2.48	41.10±8.90	41.51±8.95	82.22±2.40	0.13±0.71
Paddy	54.97±3.05	7.77±0.86	32.50±1.74	33.43±1.84	76.56±1.08	0.23±0.02
Flax	29.53±2.50	8.18±0.94	14.07±1.06	16.28±1.28	59.86±2.14	0.58±0.04
Pea	42.21±5.51	-14.0±6.21	27.82±5.11	31.32±7.28	-64.55±6.39	-0.48±0.13
Sunflower	22.04±4.38	1.13±2.17	3.11±1.58	3.58±2.29	70.79±33.73	0.34±0.71
Wheat (Konya)	49.46±3.34	9.11±0.86	27.48±1.53	28.96±1.68	71.67±1.06	0.33±0.02
Wheat (Kınacı)	55.17±3.49	8.36±0.84	27.96±1.70	29.18±1.82	73.36±1.08	0.29±0.02
Wheat (Göksu)	58.18±3.88	5.78±0.81	27.84±2.22	28.44±2.28	78.28±1.21	0.20±0.00
Wheat (Dağdaş)	54.70±3.72	6.46±1.19	27.79±2.21	28.55±2.31	76.94±1.99	0.23±0.03

L*: Lightness/darkness, a*: redness/greenness, b*: yellowness/blueness, R: redness (a*/b*), $Chroma = (a^{*2} + b^{*2})^{1/2}$, Data represent means±SD (standart deviation)

Experimental setup

An experimental set up with the characteristics of an isothermal blackbody cavity was used in order to receive all the radiation emitted from the object by the detector for a proper determination of the emissivity of the samples (Fig. 1).

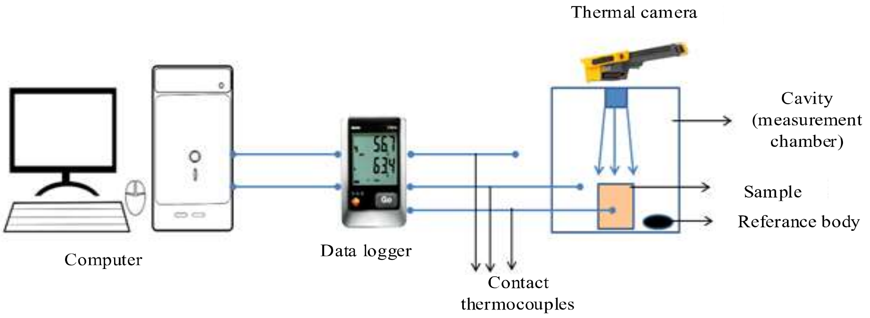


Figure 1. Experimental setup

The experimental set up consist of an environmental control chamber or measuring chamber, a thermal image camera, contact thermocouples, data loggers, reference materials (a black object and white paper) and a sample container.

A measuring chamber of 300 x 300 x 300 mm was made from Plexiglas sheet of 8 mm thickness. The inner sides of the measuring chamber were covered with aluminium foil due to its reflective properties. Similar to the blackbody cavity model, the energy that radiates from the sample surface is not absorbed by the surrounding surface and all energy is thus captured by the thermal camera detector. A rectangular opening that matches the camera measurement head on the top of the measuring chamber was opened to allow the radiant energy from the sample to reach the detector. The distance between the infrared camera detector and measuring surface was maintained at a constant value of 250 mm at viewing angles of normal direction (0°) throughout the experiments.

The reference method accepted as one of the most suitable methods for solid materials (Basterra and Casado, 2013; López et al., 2012; Nunak et al., 2015; Rakrueangdet et al., 2016; Zhang and Stewart, 2005), was used to determine the emissivity (ε) of seeds. This method is based on the radiation received by the camera detector which is equivalent to the radiation emitted from the object under isometric conditions.

The emissivity values of the seeds were determined via direct measurement method using Fluke Ti110 thermal image camera (Fluke Corporation, USA) operating in the spectral range of 7.5 to 14 µm. It can be adjusted for emissivity and has a thermal sensitivity of ≤ 0.10 °C at 30 °C with an accuracy of 2% in the measurement range of -20 - +250 °C. Infrared thermography recorded by the thermal camera was analysed using SmartView 4.1 software (Fluke Corporation, USA).

The temperature values for the sample, reference materials (black object and white paper), surrounding environment (interior temperature of the measuring chamber) along with the outside temperature of the chamber (laboratory temperature) were measured via K type thermocouples and recorded using data loggers (Testo 174 T4 and Testo 175 T3, Testo SE & Co. KGaA, Turkey).

A black rubber and a white paper with dimensions of 25 x 20 x 2 mm were used as reference materials. The emissivity of black rubber and white paper are 0.95. Calibration of the experimental set up was performed by using references materials after controlling test of their emissivity.

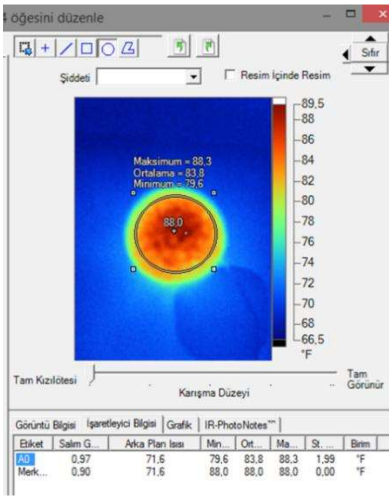
Emissivity measurement

Experiments were performed at 20 °C of constant temperature under laboratory conditions. Reference materials were first placed 50 mm away from the sample at the base of the measuring chamber prior to each test which were then contacted with K type thermocouples. A thermocouple was installed to measure the internal temperature of the test chamber. The seed was filled in a cylindrical container (Ø50 x 70 mm). Afterwards, the container was closed by a lid and the container was placed inside an oven preheated to 95 °C. The sample was then heated for 30 minutes in the oven after which the container was opened quickly only to be placed inside the test chamber. Meanwhile, a thermocouple was contacted with the sample surface.

The sample, reference and test chamber interior temperatures were recorded via data loggers at intervals of 5 minutes. Thermal images of the samples and references were taken simultaneously with the temperature measurement using a thermal camera with focal plane arrays of 160 x 120 resolution. An emissivity value of 0.95 was used for all images. After the equilibrium temperature was reached, meaning that there was no change in the temperature, the measurements and thermal image capturing process were stopped and the data were uploaded to the computer.

Finally, the inner temperatures of the test chamber for each recorded image were set in the SmartView 4.1 software as a background temperature. The sample surface which shows the infrared radiation emitted from the sample was selected and marked with a circular sketch about Ø25 mm on each image (Fig. 2). The temperature value measured via the contact-thermocouple was set as the virtual temperature. The emissivity value (ε) of the sample displayed on the software screen was obtained by adjusting and using the software until the temperature measured with the infrared camera was equal to that measured with the contact-thermocouple. It's the value was then recorded.

An analysis of variance (ANOVA) was performed to determine the significance ($p<0.05$) of the effects of moisture content (MC) and temperature (T) on the emissivity of seeds (wheat, sunflower, corn, flax, paddy and pea) with Minitab 17.0 Software (Minitab Inc., State Park, PA). It was also used to construct regression equations to predict the emissivity of seeds.



Maksimum = 88,3
Ortalama = 83,8
Minimum = 79,6

Etiket	Salım G...	Arka Plan Isısı	Min...	Ort...	Ma...	St. ...	Birim
A0	0,97	71,6	79,6	83,8	88,3	1,99	°F
Merk...	0,90	71,6	88,0	88,0	88,0	0,00	°F

Figure 2. Typical thermal image of seeds

Results and Discussions

The emissivity of seeds (ε) was determined to vary between 0.47-0.87 for sunflower, between 0.68-0.96 for pea, between 0.49-0.86 for paddy, between 0.46-0.83 for flax and between 0.63-0.96 for corn. The value of ε for wheat seeds ranged from 0.50 to 0.96 for all varieties. The emissivity values as a function of temperature and moisture content have been shown in Figure 3.

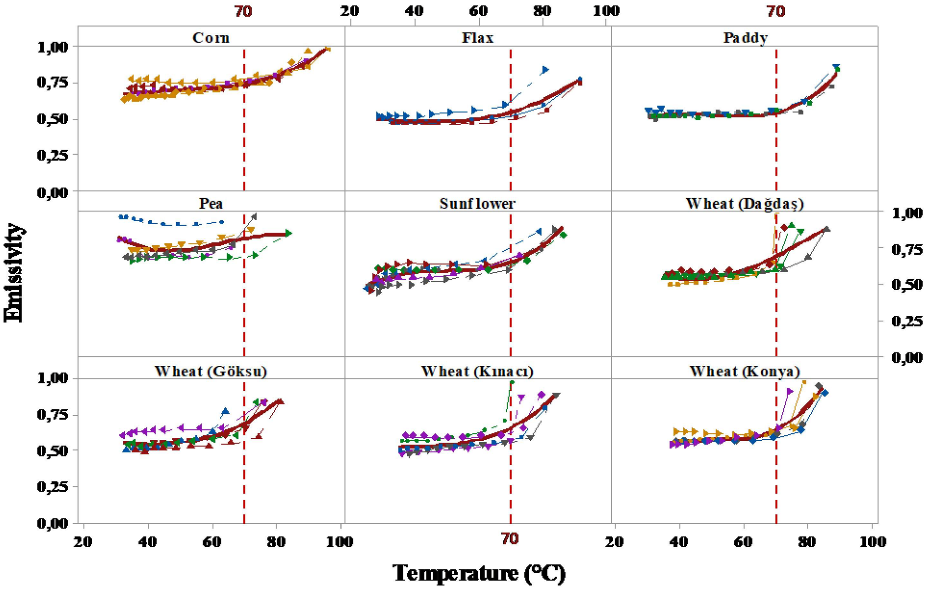


Figure 3. Variations in emissivity of seeds as functions of temperature and moisture content

Generally, ε was affected by temperature and moisture content. The emissivity values of the seeds remained constant for each moisture content until the product temperature reached about 70 °C, however, the emissivity values tended to increase rapidly after 70 °C thus reaching maximum value at about 80 °C. Temperature was more effective on the emissivity change in comparison with moisture content. Relations were found between the variables (moisture content and temperature) and ε of seeds. The equations related with the relationships between ε and the test variables (moisture content and temperature) have been shown in Table 3. It can be indicated that molecular activity increased with increasing product temperature resulting in greater thermal radiation emittance to the environment by the seeds or absorbing more thermal radiation from their environment. Water is a substance with a high emissivity value (about 0.94). Hence, an increase in emissivity was projected due to the changes in the moisture content of the seeds. However, emissivity did not have a significant relationship with moisture content due to the small changes in moisture content (Table 4). Similarly, Yu et al.(Yu et al., 2015) determined that the emissivity of canola seeds varied from 0.93-0.96 over the moisture content and temperature ranges of 5-11% (w.b.) and 40-90 °C, respectively. They also reported that there was a linear relationship for predicting ε of canola as function of temperature and moisture content. Pawar and Pratape (2017) stated all emitters used in the industry and laboratory equipment have emissivity greater than 0.9, and on the contrary, the emissivity of product being dried can be different and depends on its type and surface characteristics. Also, in food materials, it was indicated that the evaporating solvent is mostly water and hence the emissivity can be assumed equal or greater than 0.85.

Table 3. Regression equations for emissivity of seeds

Seed	Model	R^2
Sunflower	$\varepsilon = 0.5477 - 0.00217T + 0.000061T^2$	0.6808
Pea	$\varepsilon = 1.476 - 0.01659MC - 0.02092T + 0.000171MC^2 + 0.000185T^2 + 0.000075MC*T$	0.8758
Paddy	$\varepsilon = 0.8306 - 0.014012T + 0.000150T^2$	0.8169
Flax	$\varepsilon = 1.011 - 0.0529MC - 0.01558T + 0.001994MC^2 + 0.000151T^2 + 0.000222MC*T$	0.9368
Corn	$\varepsilon = 1.1501 - 0.0211MC - 0.01114T + 0.000280MC^2 + 0.000098T^2 + 0.000142MC*T$	0.8737
Wheat (Konya)	$\varepsilon = 1.715 - 0.02368MC - 0.03432T + 0.000237MC^2 + 0.000295T^2 + 0.000195MC*T$	0.7885
Wheat (Kınacı)	$\varepsilon = 1.081 - 0.00467MC - 0.01980T - 0.000223T^2$	0.7098
Wheat (Göksu)	$\varepsilon = 0.888 - 0.01627T + 0.000193T^2$	0.6185
Wheat (Dağdaş)	$\varepsilon = 1.450 - 0.01039MC - 0.03331T + 0.000295T^2 + 0.000223MC*T$	0.6600

MC: moisture content (%,w.b); T: Temperature (°C); R^2: coefficient of determination

Table 4. Results of correlations between emissivity and test variables and colour properties of the seeds

	MC	L^*	a^*	b^*	Chroma	Hue	R	T
L^*	0.063[$]							
	0.181[&]							
a^*	-0.638	0.290						
	0.000	0.000						
b^*	0.187	0.916	0.090					
	0.000	0.000	0.054					
Chroma	0.243	0.885	0.023	0.994				
	0.000	0.000	0.627	0.000				
Hue	-0.543	0.250	0.839	0.041	-0.036			
	0.000	0.000	0.000	0.386	0.441			
R	-0.647	-0.135	0.789	-0.304	-0.335	0.607		
	0.000	0.004	0.000	0.000	0.000	0.000		
T	-0.078	0.182	0.146	0.171	0.166	0.073	0.072	
	0.098	0.000	0.002	0.000	0.000	0.121	0.125	
ε	**0.309**	**0.224**	**-0.422**	**0.336**	**0.359**	**-0.354**	**-0.433**	**0.586**
	0.000	***0.000***	***0.000***	***0.000***	***0.000***	***0.000***	***0.000***	***0.000***

MC: moisture content (%,w.b); T: Temperature (°C); [$] coefficient of correlation; [&] p-values

For drying of thick moist materials such as foodstuff, the control strategies that depend on surface temperature of the food materials have to be considered to avoid extremely intense heating and thermal degradation. Moreover, it is required to develop a reliable model to predict the reduction in emissivity with respect to moisture content as drying proceeds to accurately predict the quality of dried product (Pawar and Pratape, 2017).

Zhang and Stewart (2005) observed an increase in the emissivity of breaded chicken nugget and its meat from 0.73 to 0.84 and 0.77 to 0.83 respectively during the cooling and cooking periods. They found that ε of the samples were lower at lower cooling and cooking temperatures. They also reported that ε of breaded chicken nugget and its meat increased with an increase in temperature in the range of 35-95 °C.

It has been reported by López et al. (2012) in another study that the average values of ε were close to 0.980 and ranged from 0.973 to 0.985 for nine different plant leaves. They also recommended that it was 0.980 as a reference emissivity value for the monitoring of temperature of horticultural crops leaves using infrared thermography within the spectral range 7.3-13 µm.

The observed ε values of different wood species ranged between 0.830 and 1.000 for the temperature range of -25 to +60 °C in another study. Furthermore, a negative linear relationship was found between emissivity and temperature (Basterra and Casado, 2013).

It is a known fact that the emissivity values of solid substances change depending on the physical (roughness etc.) and color characteristics. Hence, relationships between the emissivity values of seeds and color have been examined. The changes in colour properties (L*, a*, b*, Chroma, hue and R) of seeds and test variables (T and MC) had an impact on the emissivity values (Table 4). An increase in various colour parameters (L, b and Chroma) and test variables (T and MC) led to an increase in the ε values. Conversely, an increase in a*, hue and R colour parameters caused resulted in a decrease in the ε value. There was a strong positive relationship between ε and T. In addition, a moderate and positive correlation was determined between ε and various physical properties such as the colour parameter of seeds (b* and Chroma) and moisture content (MC). However, there were also moderate negative relationships between ε and the colour parameters of a*, hue and R.

Conclusion

The emissivity values of some seeds have been determined in this study. The emissivity of seeds (ε) ranged between 0.47-0.87 for sunflower, between 0.68-0.96 for pea, between 0.49-0.86 for paddy, between 0.46-0.83 for flax and between 0.63-0.96 for corn. The emissivity values of wheat seeds were ranged from 0.50 to 0.96 for all tested varieties. It was found that the emissivity of seeds is extremely dependent on temperature and moisture content of the seeds. Emissivity of seeds increased with increasing temperature. However, a moderate positive correlation was determined between the values of ε and various physical properties such as seed colour parameters (b* and Chroma) and moisture content. On the contrary, moderate negative relationships were determined between ε and colour parameters such as a*, hue and R. Further studies need to be carried out for determining the physical properties of seeds such as size, porosity, colour and temperature, moisture which play a role on emissivity values. The sensors should be calibrated while connected to the product in product processing facilities if contact-free temperature measurement and control setups will be installed.

Acknowledgment

The data used in this work comprise a part of the first author's master's thesis at the University of Canakkale Onsekiz Mart.

References

ASABE, 2012. Moisture measurement-unground grain and seeds. ASABE Stand. 1988, 2–4. doi:https://doi.org/10.13031/2013.24272

Basterra, G.L.L.A., Casado, L.A.M., 2013. Determination of the emissivity of wood for inspection by infrared thermography. J Nondestruct Eval. 32, 172–176. doi:10.1007/s10921-013-0170-3

Bergman, T.L., Lavine, A.S., Incropera, F.P., DeWitt, D.P., 2011. Fundamentals of heat and mass transfer, 7th Editio. ed. John Wiley & Sons, Inc., NewYork, USA.

Chen, C., 2015. Determining the leaf emissivity of three crops by infrared thermometry. Sensors. 15, 11387–11401. doi:10.3390/s150511387

Hellebrand, H.J., Beuche, H., Linke, M., 2001. Determination of thermal emissivity and surface temperature distribution of horticultural products, in: Sixth International Symposium on Fruit, Nut and Vegetable Production Engineering. Postdam, Germany, pp. 1–6.

Ilyasov, S.G., Kransikov, V.V., 1991. Physical principles of infrared irradiation of foodstuffs. Hemisphere Pub. Corp., NewYork, USA.

Kayisoglu, B., Kocabiyik, H., Akdemir, B., 2004. The effect of moisture content on the thermal conductivities of some cereal grains. J. Cereal Sci. 39. doi:10.1016/S0733-5210(03)00047-X

Kocabiyik, H., 2012. Biological Materials and Food-Drying Innovations, in: Rajeev, B., Alias, A.K., Paliyath, G. (Eds.), Progress in Food Preservation. Wiley-Blackwell, Oxford, UK, pp. 129–142. doi:10.1002/9781119962045.ch6

Kocabiyik, H., Kayisoglu, B., Tezer, D., 2009. Effect of Moisture Content on Thermal Properties of Pumpkin Seed. Int. J. Food Prop. 12, 277–285. doi:10.1080/10942910701673519

Krishnamurthy, K., Khurana, H.K., Soojin, J., Irudayaraj, J., Demirci, A., 2008. Infrared heating in food processing: An overview. Compr. Rev. Food Sci. Food Saf. 7, 2–13. doi:10.1111/j.1541-4337.2007.00024.x

Llave, Y., Takemori, K., Fukuoka, M., Takemori, T., Tomita, H., Sakai, N., 2017. Analysis of browning of broiled foods by noncontact techniques: A case study for japanese eggplant (Solanum Melongena). J. Food Process Eng. 40. doi:10.1111/jfpe.12347

López, A., Molina-Aiz, F.D., Valera, D.L., Peña, A., 2012. Determining the emissivity of the leaves of nine horticultural crops by means of infrared thermography. Sci. Hortic. (Amsterdam). 137, 49–58. doi:10.1016/j.scienta.2012.01.022

Nithya, U., Chelladurai, V., Jayas, D.S., White, N.D.G., 2011. Safe storage guidelines for durum wheat. J. Stored Prod. Res. 47, 328–333. doi:10.1016/j.jspr.2011.05.005

Nunak, T., Rakrueangdet, K., Nunak, N., Suesut, T., 2015. Thermal image resolution on angular emissivity measurements using infrared thermography. Proc. Int. MultiConference Eng. Comput. Sci. I.

Pawar, S.B., Pratape, V.M., 2017. Fundamentals of infrared heating and its application in drying of food materials: A Review. J. Food Process Eng. 40. doi:10.1111/jfpe.12308

Rakrueangdet, K., Nunak, N., Suesut, T., Sritham, E., 2016. Emissivity measurements of reflective materials using infrared thermography. Proc. Int. MultiConference Eng. Comput. Sci. I, 16–19.

Saunders, P., 2004. Reliable infrared temperature measurements of food products. Autom. Control April/May, 20.

Tuncel, N.B., Yilmaz, N., Kocabiyik, H., Uygur, A., 2014. The effect of infrared stabilized rice bran substitution on B vitamins, minerals and phytic acid content of pan breads: Part II. J. Cereal Sci. 59, 162–166. doi:10.1016/j.jcs.2013.12.005

Yılmaz, N., Tuncel, N.B., Kocabıyık, H., 2014. Infrared stabilization of rice bran and its effects on γ -oryzanol content, tocopherols and fatty acid composition. J Sci Food Agric. 94, 1568–1576. doi:10.1002/jsfa.6459

Yu, D.U., Shrestha, B.L., Baik, O.D., 2015. Thermal conductivity , specific heat , thermal diffusivity, and emissivity of stored canola seeds with their temperature and moisture content. J. Food Eng. J. 165, 156–165. doi:10.1016/j.jfoodeng.2015.05.012

Zhang, J., Stewart, J., 2005. Determination of emissivity for breaded chicken products in the far-infrared region, in: ASAE Annual International Meeting. 17 - 20 July 2005. Tampa, Florida.