Moisture content prediction of Iranian wheat using dielectric technique

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Abstract The moisture measurement is the most important criteria in harvesting and post harvesting processing of wheat. This paper investigates the moisture dependent dielectric constant and calibration equation of three most cultivated wheat varieties in Iran. An instrument with a cylindrical capacitive sensor was used to measure the dielectric constant of grain at different moisture contents. Samples were prepared at five levels of moisture content. To validate the proposed equations, the dried material dielectric constant was estimated and compared with the measured ones. Homographic regression models showed an acceptable prediction of dried wheat dielectric constant. Results showed that the calibration equation obtained for *Shahriar* variety was able to predict the moisture content of other varieties confidently. The lowest value of $R^2=0.985$ between predicted and reference moisture content for *Tajan* variety is still a good result.

Keywords Wheat · Dielectric constant · Moisture content · Instrument

Introduction

Wheat is the main food resource that is cultivated all over the world. As reported by FAO, about 676 and 14 million tons of wheat were harvested in the world (Anon 2011) and

Iran (Anon 2012) in 2011, respectively. This huge amount of wheat production needs proper harvesting, handling, storage and milling processes. The main factor that must be measured during these processes is the moisture content of grain. Because each of the mentioned operations invokes an individual optimum moisture content of grain.

Several methods and systems were proposed and applied to detect the moisture content of grain and cereals with the development of technology. The simplest method is the oven drying technique. Even though this technique is a precise one, it has defects that make it improper for fast and nondestructive detection. Nevertheless, the oven drying technique is a reference method of moisture content measurement that is used for the calibration of various species moisture meters. Distillation, infrared radiation, microwave radiation and resistance techniques are the other methods that are used for moisture content measurement. An interesting method of estimation of grain moisture content is based on capacitive properties of seeds. In this method, grain plays the role of the dielectric material in capacitive sensor and its dielectric characteristics are measured. The hypothesis in this field is that a correlation must exist between the moisture content and the dielectric properties of seed.

The dielectric property, or permittivity, indicates the interaction of material with electric fields. The dielectric properties of usual interest are the dielectric constant and the dielectric loss factor, the real and imaginary parts, respectively, of the relative complex permittivity, $\varepsilon = \varepsilon' - j\varepsilon'' = |\varepsilon|e^{-j\delta}$ where δ is the loss angle of the dielectric. “Permittivity” is understood to represent the relative complex permittivity. The permittivity relative to free space, or the absolute permittivity divided by the permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$ is called dielectric constant. Often, the loss tangent, $\tan\delta = \varepsilon''/\varepsilon'$, or dissipation factor, is also used as a descriptive dielectric parameter (Nelson and Trabelsi 2002). Different methods have been developed for dielectric measurement of agricultural products from direct current to microwaves. Some of the most used devices and

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Fig. 1 Block diagram of instrument for measuring the dielectric constant of seeds

instruments to measure dielectric properties of food materials are the parallel plate capacitor, coaxial probe, waveguide, resonant structure, inductance, capacitance-resistance meter (LCR meter), impedance analyzer, and scalar and vector network analyzer (Ragni et al. 2006).

Scientists have utilized the dielectric properties of agro-products and capacitive sensors for different purposes such as fruits and vegetables volume estimation, quality assessment, etc. The volume of watermelon, large cucumber, wax gourd and guava can be estimated by an electronic system based on capacitance measurement (Jarimopas et al. 2005). In quality assessment, the correlation between quality index (firmness, sugar content, pH, etc.) and dielectric properties of fruit or vegetables has been analyzed and modeled. For example, the relation between dielectric parameter and quality indices of banana fruit has been obtained and used for banana ripeness prediction during ripening treatment (Soltani et al. 2011). This method has also been used in watermelon sorting (Kato 1997) and determination of apple quality factors (Guo et al. 2007). Also Kumar et al. (2011) investigated the relationship between dielectric properties and quality factors of edible oils within the temperature range of 20–100 °C. They obtained a high correlation between viscosity and dielectric properties.

Some researches focused on the mass of agricultural products. For example Kumhála et al. (2007) designed a parallel plate capacitance sensor for forage mass determination. Kandala and Sundaram (2010) estimated mass ratio of the total kernels within a sample of in-shell peanuts using RF impedance method.

Correlation between moisture content and dielectric characteristics of material is an interesting branch in this area. A linear relationship has been reported between the dielectric constant

and loss factor when divided by the density of chickpea flour (Guo et al. 2008). Also as reported by Sacilik and Colak (2010) the dielectric constant, loss factor and loss tangent of corn seed increased with an increase in moisture content.

In Iran, no research has been conducted to study the dielectric properties of wheat; and moisture content of this product is measured by traditional methods or by imported instruments that are not proper for Iranian wheat. This paper aims to investigate the correlation between dielectric constant and moisture content of the three most cultivated varieties of wheat in Iran and compares the calibration equation of each variety and proposes the best relation for prediction of wheat moisture content by measuring dielectric constant.

Fig. 2 Variation of Dielectric constant with moisture content (in dry basis) at indicated frequency for three varieties of Iranian wheat

Table 1 Result of homographic regression for three varieties of wheat

Variety	Fitted Equation	R ²	RMSE
<i>Shahriar</i>	$\%MC_{db} = \frac{\varepsilon' - 3.772}{0.0161 \times \varepsilon' + 0.08971}$ (A)	0.999	0.2274
<i>Pishtaz</i>	$\%MC_{db} = \frac{\varepsilon' - 4.302}{0.02035 \times \varepsilon' + 0.01687}$ (B)	0.998	0.4355
<i>Tajan</i>	$\%MC_{db} = \frac{\varepsilon' - 4.282}{0.02283 \times \varepsilon' + 0.5456}$ (C)	0.989	0.7747

$\%MC_{db}$: Moisture content of wheat in dry basis, ε' : Dielectric constant of wheat

Materials and methods

Sample preparation

The three most cultivated varieties of wheat, *Shahriar*, *Pishtaz* and *Tajan* samples, have been obtained from Seed and Plant Improvement Institute located in *Alborz* province, Karaj city. Samples were manually cleaned in order to remove external materials and defected seeds and were prepared at five levels. The volume of sensor is approximately 100 ml. At each experiment, the sensor must be filled by seeds; therefore, a little more than 100 ml of seeds was separated for each level. The initial moisture content of seeds was determined by the oven method (level 3). To increase moisture content of samples and to prohibit gem-mating, the samples were exposed to saturated air in an isolated polystyrene box at 30 °C for 18 h (level 4) and 36 h (level 5), respectively. In order to decrease samples' moisture content, the oven method was used at 60 °C for 24 h (level 2) and 48 h (level 1). After preparation of samples, they were stored for 72 h so that the moisture content distribution is unified throughout the sample. At each level, the moisture content of these varieties was certainly not equal.

Instrumentation

An instrument with a cylindrical capacitive sensor designed by Soltani and Alimardani (2011a) was used to measure dielectric constant of grain at different moisture contents. The block diagram of the designed instrument is shown in Fig. 1. Additional information about the instrument and the method of dielectric constant calculation was presented at a previous research (Soltani and Alimardani 2011a).

Table 2 Comparison of measured and estimated value of ε'_d

Variety	Measured value of ε'_d	Estimated value of ε'_d	Percent of difference between measured and estimated value of ε'_d
<i>Shahriar</i>	3.899	3.772	3.26
<i>Pishtaz</i>	3.984	4.302	7.98
<i>Tajan</i>	4.222	4.282	1.42

ε'_d : Dielectric constant of dried material

Table 3 Result of paired *t*-test (P value) of obtained regression equation for prediction of each variety moisture content

Equation	<i>Shahriar</i>	<i>Pishtaz</i>	<i>Tajan</i>
(A)	*	0.593 ns	0.693 ns
(B)	0.368 ns	*	0.043**
(C)	0.967 ns	0.013**	*

ns: no significant at 5 % level of probability, **: significantly different at 5 % level of probability

Electrical experiments were carried out at room temperature (25 °C) and dielectric constant of prepared samples was obtained at each moisture content (Soltani and Alimardani 2011a). A 500 kHz sinusoidal signal was selected to feed into capacitor (Soltani and Alimardani 2011a) and then the moisture content of seeds was measured using oven drying method based on ASABE Standard (ASAE S352.2 DEC97 1999). The moisture content on dry basis ($\%MC_{db}$) was calculated on dry basis by Eq. 1.

$$\%MC_{db} = \frac{w_w}{w_d} \times 100 = \frac{(w_i - w_d)}{w_d} \times 100 \quad (1)$$

where w_i , w_w and w_d are the initial weight of sample, the weight of water in sample and the weight of dried sample, respectively.

Microsoft Excel 2007 and MATLAB 7.0.4 were used to analyze the obtained data and determine the regression models between moisture content and dielectric constant. The homographic regression was used to extract the best equation for the designed system (Soltani and Alimardani 2011b) and paired *t*-test was used to compare the predicted value of moisture content of each variety with the measured one.

Fig. 3 Correlation plot for moisture content of the dielectric predicted and the measured data for *Shahriar* variety ($\%MC_{db}$ is moisture content percent of wheat in dry basis)

Fig. 4 Predicted moisture content of *Pishtaz* variety versus measured moisture content with the line of equality (% MC_{db} is moisture content percent of wheat in dry basis)

Results and discussion

Results of the dielectric measurement are shown in Fig. 2. The results show that the ε' value of all varieties increased with increasing the moisture content. Also a similarity was observed among these varieties' behavior. A high correlation was observed between %MC and ε' for all varieties. The results are in agreement with other researches in this field. Lawrence et al. (1998) reported an increase in the hard red winter dielectric constant with increasing the moisture content at all frequencies in the range of 1 MHz to 350 MHz. Also Berbert et al. (2002) reported that permittivity increased with moisture content of common bean at every frequency where measurements were taken. Berbert et al. (2002) stated that this behavior is the result of the relatively high permittivity of water, which has a value of 80, compared with the permittivity of grain dry matter where the value of ε' is approximately 3 in the radio-frequency range. When the moisture content of wheat increases, the ratio of water to dry material increases too and as a result the dielectric constant increases as well.

In previous researches polynomial function has been proposed to describe the relationship between dielectric constant and moisture content (Sacilik and Colak 2010; Berbert et al. 2002). Soltani and Alimardani (2011b) proposed a homographic relation to correlate moisture content and ε' of grain. The equation is presented as following:

$$\varepsilon'_s = \frac{a MC_{db} + \varepsilon'_d}{b MC_{db} + 1} \quad (1)$$

where ε'_s is dielectric constant of grain at each moisture content, ε'_d is dried grain dielectric constant, MC_{db} is moisture content of grain in percent and a and b are

multiple regression of equation. By simplifying Eq. 1, the moisture content can be found as a function of ε'_s .

$$MC_{db} = \frac{\varepsilon'_s - \varepsilon'_d}{b \varepsilon'_s + a} \quad (2)$$

Table 1 shows that homographic regression is proper for extracting $MC_{db} - \varepsilon'_s$ calibration equation. The best result is obtained for *Shahriar* variety.

To validate the homographic regression after measuring the ε'_s of specimens at level 1, the samples were dried by oven method in order to measure the ε'_s at 0 % MC_{db} or ε'_d . Results are presented in Table 2. The estimated value of ε'_d for wheat varieties can be found in the related regression equation numerator (Table 1) and was represented in Table 2 to be compared with the measured values. Table 2 shows a good prediction of ε'_d by homographic regression.

It can be perceived from the results of paired *t*-test (Table 3) that the Eq. (A) (for *Shahriar* variety) can predict the moisture content of *Pishtaz* and *Tajan* varieties confidently, but the results of Eq. (B) and Eq. (C) prediction differ from the measured values of MC_{db} ($P < 0.05$). So Eq. (A) can be used for calibration of the designed system in order to estimate the moisture content of the three most cultivated wheat in Iran.

The plots of the moisture content as determined by dielectric prediction technique and oven method are shown in Figs. 3, 4 and 5. The lowest value of regression coefficient was obtained as 0.985 for *Tajan* variety. It means that dielectric method is sufficiently reliable to predict the moisture content of these varieties. Bansod and Thakur Ritula (2011) designed an instrument and calibrated it for the Indian wheat. They obtained a high degree of correlation between data obtained from the instrument and the oven drying technique ($R^2 = 0.995$).

Fig. 5 Comparison of measured moisture content of *Tajan* variety and predicted moisture content by dielectric method (% MC_{db} is moisture content percent of wheat in dry basis)

Conclusion

In this study, the moisture dependent dielectric constant of the three most cultivated varieties of wheat was investigated. Homographic regression can be used to correlate the dielectric constant and the moisture content reliably. It is concluded from this research that dielectric constant of wheat varieties are different as a result of the differences in the physical and chemical properties of each variety. Therefore, in order to calibrate an instrument for estimating the moisture content based on dielectric technique, an individual calibration equation must be extracted. Further works are needed to conduct researches on this method at higher frequencies and other electrical properties to develop a more reliable prediction of moisture content.

References

- Anon (2011) Global wheat production to increase in 2011. Food and Agriculture Organization of the United Nation. www.fao.org/news/story/en/item/53813/icode/ii21245. Accessed 23 March 2011
- Anon (2012) GIEWS Country Briefs, Iran (Islamic Republic of). Food and Agriculture Organization of the United Nation. www.fao.org/giews/countrybrief/country.jsp?code=IRN. Accessed 19 April 2012
- ASAE S352.2 DEC97. Moisture Measurement—Unground Grain and Seeds. ASAE standards 1999. 567
- Bansod BS, Thakur Ritula T (2011) Performance evaluation of digital grain moisture analyzer for Indian wheat. *J Sci Ind Res* 70:41–44
- Berbert PA, Queiroz DM, Melo EC (2002) Dielectric properties of common bean. *Biosyst Eng* 83(4):449–462
- Guo W, Nelson SO, Trabelsi S, Kays SJ (2007) 10–1800-MHz dielectric properties of fresh apples during storage. *J Food Eng* 83:562–569
- Guo W, Tiwari G, Tang J, Wang S (2008) Frequency, moisture and temperature-dependent dielectric properties of chickpea flour. *Biosyst Eng* 101:217–224
- Jarimopas B, Nunak T, Nunak N (2005) Electronic device for measuring volume of selected fruit and vegetables. *Postharvest Biol Technol* 35:25–31
- Kandala CV, Sundaram J (2010) Estimation of mass ratio of the total kernels within a sample of in-shell peanuts using RF impedance method. *J Electr Comput Eng* 2010:1–5. doi:10.1155/2010/375430
- Kato K (1997) Electrical density sorting and estimation of soluble solids content of watermelon. *J Agric Eng Res* 67:161–170
- Kumar D, Singh A, Tarsikka PS (2011) Interrelationship between viscosity and electrical properties for edible oils. *J Food Sci Technol*. doi:10.1007/s13197-011-0346-8
- Kumhála F, Kvíz Z, Kmoch J, Prošek V (2007) Dynamic laboratory measurement with dielectric sensor for forage mass flow determination. *Res Agr Eng* 53(4):149–154
- Lawrence KC, Nelson SO, Bartley PG (1998) Measuring dielectric properties of hard red winter wheat from 1 to 350 MHz with a flow-through coaxial sample holder. *Trans ASABE* 41(1):143–150
- Nelson SO, Trabelsi S (2002) Sensing grain moisture content through dielectric properties. *IEEE Sensors Applications Symposium Orlando; Florida, June 12–14*
- Ragni L, Gradari P, Berardinelli A, Giunchi A, Guarnieri A (2006) Predicting quality parameters of shell eggs using a simple technique based on the dielectric properties. *Biosystems Eng* 94(2):255–262
- Sacilik K, Colak A (2010) Determination of dielectric properties of corn seeds from 1 to 100 MHz. *Powder Technol* 203:365–370
- Soltani M, Alimardani R (2011a) Design, development and calibration of a portable capacitive moisture meter. *Sens Transducers J* 129(6):24–32
- Soltani M, Alimardani R (2011b) Prediction of corn and lentil moisture content using dielectric properties. *J Agric Technol* 7(5):1223–1232
- Soltani M, Alimardani R, Omid M (2011) Evaluating banana ripening status from measuring dielectric properties. *J Food Eng* 105:625–631