Moisture content determination of oilseeds based on dielectric measurement

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Abstract: Oilseeds have an important role in edible oil production. Moisture content measurement of oilseed is an inevitable operation in harvesting and almost all postharvest processing such as handling, storage, milling and oil extraction. In this paper, a cylindrical capacitive sensor was used to predict the moisture content of sesame, soybean and canola seed as a simple, low cost, rapid and reliable method. Two varieties of each oilseed were selected and extracted equation from a variety was evaluated for another variety. The hyperbolic regression and paired t-test were utilized to extract the calibration equations and perform a comparison between predicted moisture with actual values. The R^2 of calibration for *Dashtestan* and *Ultan* sesame were 0.998 and 0.999, respectively, for *L17* and *Sahar* soybean were 0.972 and 0.965, respectively and for *Okapi* and *Talaiyeh* canola were 0.993 and 0.994, respectively. The R^2 of prediction for *Dashtestan* and *Ultan* sesame were 0.966 and 0.932, respectively, for *L17* and *Sahar* soybean were 0.963 and 0.952, respectively and for *Okapi* and *Talaiyeh* canola were 0.993 and 0.994, respectively. Results of paired t-test confirmed that the measured and predicted moisture content of all oilseeds were not statistically different at the 5% level (p > 0.05). Based on obtained results the designed system using capacitive sensor is valid and reliable for moisture measurement of the studied oilseeds.

Keywords: oilseed, sesame, soybean, canola, moisture content, capacitive sensor

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1 Introduction

Oilseeds have an important role in edible oil production and trade. Edible plant oils are the main sources of energy and essential fatty acid for human body. Cultivated oilseeds in the world include sesame, soybean, canola, sunflower, safflower and mustard. Sesame seed, also known as beniseed (*Sesamum indicum* L.) is a rich source of oil (44%) and protein (19%–25%) (Tunde-Akintunde and Akintunde, 2004). Its protein has a high desirable amino-acid profile and is nutritionally as good as soya bean protein. The usual method of sesame seed oil extraction at the domestic level is by pounding the seeds in a mortar (Tunde-Akintunde and Akintunde, 2004). Soybean (*Glycine max* L.) is a species of legume native to Eastern Asia. Among the legumes, the soybean, is classified as an oilseed, is preeminent for its high protein content as well as its high oil content. Canola is a member of a large family of plants called crucifers. Canola seed contains approximately 40% oil and its meal consists of 35% - 40% protein (Razavi et al., 2003).

Moisture measurement of oilseed is an inevitable operation in harvesting and almost all postharvest processing such as handling, storage, milling and oil extraction. Many researches have been conducted investigating the moisture content effects on oilseed properties. Olayanju et al. (2006) surveyed the effect of moisture content on oil recovery from expelled sesame

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seed. It was reported that the moisture content affected the oil extraction operation. Low moisture caused brittleness and higher moisture content caused plasticising effects, which reduced the level of compression and given poor oil recovery. Akinoso et al. (2006) investigated the effect of moisture content on oil expression from sesame seed. They reported that moisture content had the highest influence on sesame seed oil yield. They achieved optimum condition at moisture content of 4.6% (wet basis). They used oven drying method for moisture content measurement of oilseed.

In view of the above mentioned applications, development of a simple, low cost, rapid and nondestructive method of oilseeds moisture content measurement seems to be an essential necessity. Various techniques have been developed for moisture content measurement. In drying method, the material is heated under specified conditions, and the weight loss is used to calculate the moisture content. This technique is a time-consuming method and destructs seeds. In chemical method, the material water is involved in a chemical reaction and the moisture content is estimated. This method is usable in laboratory. NMR (nuclear magnetic resonance) and NIR (near infrared) are other techniques that are used in moisture determination of seeds. NMR and NIR instruments are expensive electronic devices requiring calibration against standard procedures. Distillation, gas chromatographic and electrical measurement (electrical resistance, dielectric constant and microwave) techniques are other methods of moisture content measurement. Going through the above mentioned methods, electrical measurement is a low cost, rapid and effective technique and instruments based on this technique are subject to less errors that arise from non-uniform distribution of moisture and physical contact with the material under test (Rai et al., 2005). Among the electrical measurement methods, the dielectric method is widely used and developed for the determination of different properties of plant materials including moisture content. For instance, Kumar et al. (2011) investigated the interrelationship between viscosity and electrical properties for edible oils. They studied the dielectric constants, dielectric loss tangent and electrical conductivity of cottonseed, ground nut, mustard and sunflower oils in the temperature range of 20 to 100°C. They investigated the correlation between viscosity with dielectric loss tangent and viscosity with electrical conductivity and developed the related regression equations relating viscosity with loss tangent and electrical conductivity for all the four oils. Grossi et al. (2012) used impedance measurements in the frequency range 20 Hz to 10 kHz for automatic ice cream characterization. Yang et al. (2010) used dielectric technique in microwave range for moisture content prediction of milk powder. They established calibration models and then compared the obtained results predicted by the microwave technique with the results determined by standard methodology. They reported that the maximal measurement deviation was 0.2%, based on the microwave method. Sacilik et al. (2007) investigated the dielectric properties of safflower seed as a function of moisture content and bulk density.

The purpose of the present research was to develop a non-destructive, simple, rapid and low cost method for moisture content measurement of most cultivated varieties of oilseeds in Iran (sesame, soybean and canola) and investigate the effect of oilseeds variety on moisture content prediction accuracy based on the capacitance principle. In this paper nonlinear regression models were used and calibration equations were extracted for all oilseeds.

2 Materials and methods

An appropriate quantity (approximately 1 kg) of samples for sesame (*Oultan* & *Dashtestan* varieties), soybean (*Sahar* & *L17* varieties) and canola (*Okapi* & *Talaiyeh* varieties) were prepared to conduct dielectric studies at room temperature. In order to increase the moisture level of samples, and prohibit gemmating, the samples were exposed to saturated air in an isolated polystyrene box at 30˚C and to decrease the moisture content level, the oven method was used at 60˚C for a needed time (ASAE S352.2 DEC97). The prepared specimens were stored in sealed polyethylene bags at 4˚C in cold storage for 72 h before electrical measurements.

In preparing conditioned samples, a fixed quantity (100 cc, approximately the volume of sensor) of grain was taken and broken kernels along with foreign materials were removed manually.

An instrument was developed to measure the capacitance of the seed-filled sensor at different moisture contents. The instrument consists of a cylindrical capacitor with volume of 100 cc (approximately) as a standard hardware sensor (Figure 1). To measure the capacitance of sensor a voltage divider circuit (Figure 2) was used. An Atmega32 microcontroller and XR2206 IC have been used to measure the output voltage and generate the 500 kHz sinusoidal with 5V (p-p), respectively (Soltani and Alimardani, 2011). The developed electronic system was calibrated by accurate capacitors and finally, the capacitance of sensor was displayed on a LCD.

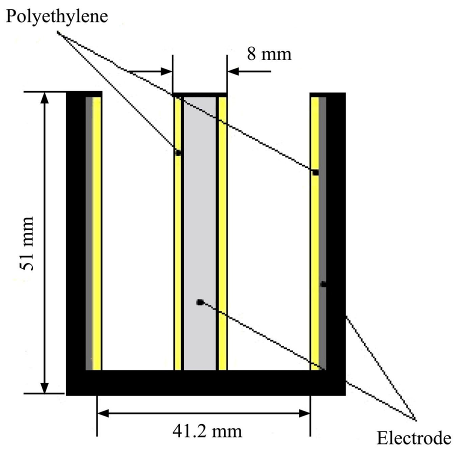

Figure 1 Schematic diagram of cylindrical capacitive sensor used for seed moisture content prediction

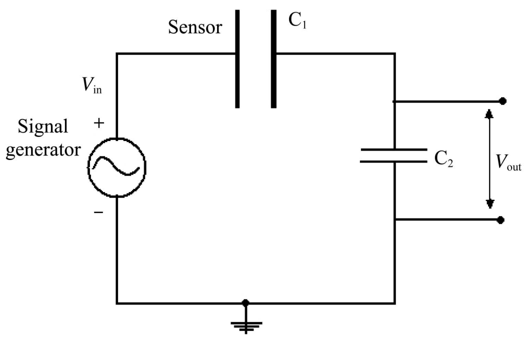

Figure 2 Voltage divider circuit used for capacitance measurement

After electrical measurements, the actual moisture contents of samples were obtained using oven drying technique as a standard method. The needed quantity of each sample was separated and was heated based on ASABE standard (1999).

MATLAB 7.6 (2009) and Microsoft Office Excel 2007 were used to establish the regression models between the studied attributes. The performance of the models was evaluated using Root Mean Square Error (RMSE) and coefficient of determination (R^2). The RMSE is a measure of accuracy and reliability to calibrate and test the data sets, respectively (Cihan et al., 2007).

3 Results and discussion

Plot of moisture content of oil seeds against capacitance of seed-filled sensor is shown in Figure 3, Figure 4 and Figure 5. In all studied oilseeds, a nonlinear and ascendant relationship was observed between moisture content and capacitance of seed-filled sensor. In addition, in each oilseed, the behavior of each variety was approximately the same. Also an increase occurred in capacitance with increasing of moisture content. This increase in the capacitance was due to an increase in dry basis moisture content (MC_{db}) ($MC_{db} = \frac{Mass\ of\ water\ in\ seed}{Mass\ of\ dry\ material}$).

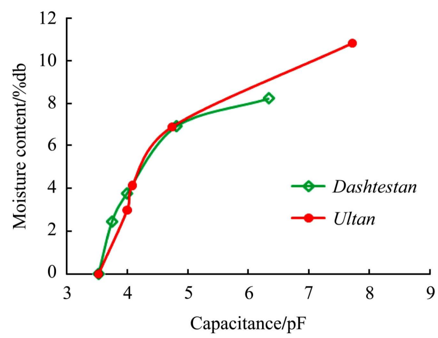

Figure 3 Relationship between capacitance and moisture content for sesame seed

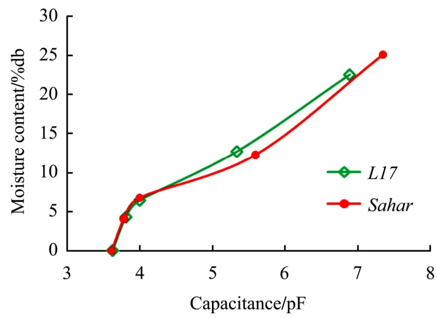

Figure 4 Seed moisture content versus capacitance of filled capacitive sensor with soybean

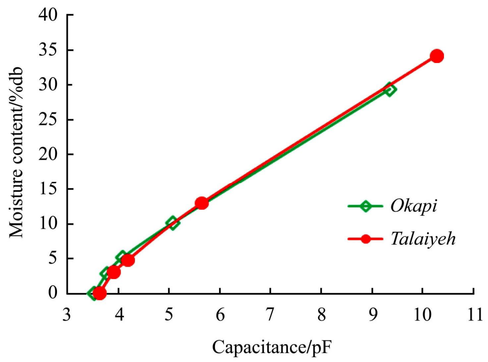

Figure 5 Moisture content as a function of capacitance for canola seed

Berbert et al. (2002) stated that this behavior is as a result of the relatively high dielectric constant of water, which has a value of 80, compared with the dielectric constant of grain dry matter where the value of dielectric constant is approximately 3 in the radio-frequency range.

When the moisture content of seed increases, the ratio of water to dry material increases and as a result the capacitance increases as well. Figure 3, Figure 4 and Figure 5 show a nonlinear and univocal relation in all oilseeds. Therefore, the linear regression is not proper to extract the related calibration equations. A hyperbolic model was used for moisture prediction of seed using dielectric technique. Therefore, the hyperbolic regression was developed in MATLAB (Curve Fitting toolbox) for extraction of needed equations. Equation 1 shows the developed hyperbolic regression.

$$\%MC_{db} = \frac{a.C_s + b}{c.C_s + d} \quad (1)$$

where, C_s is the capacitance of seed-filled sensor (pF); $\%MC_{db}$ is the moisture content of seed and a, b, c, d are constants.

The Levenberg-Marquardt method of curve fitting was used and the initial value of constants (a, b, c and d) was assumed as 1. Result of hyperbolic model for oilseed is presented in Table 1. The best and worst result was obtained for canola and soybean, respectively based on their R^2. Even though, the R^2 of calibration for soybean is the lowest value, it is an indication of high correlation between capacitance and moisture content. The coefficient of determination for *L17* and *Sahar* soybean were obtained as 0.972 and 0.965, respectively which were acceptable values.

The results were in agreement with the results of Sacilik et al. (2007). They reported the dielectric constant of safflower increased with the increasing moisture content. Also they developed second-degree polynomial relationships to correlate the dielectric constant and moisture content. But the quadratic function is not proper for moisture prediction, because calibration equation must be an injective function, while parabolic function may return two outputs for one input. Also Singh et al. (2006) reported an increasing relation between moisture content and dielectric constant of Indian oilseeds (namely *Brassica Compestrris* Yellow and Black). They stated that at higher moisture levels, more water dipoles contribute to the polarization, due to high water mobility, showing that the water dipoles easily follow the applied field vibrations. At low moisture content, because of strong bound water state (monolayer), the distance between the water molecule and cell wall is very small and attraction force is very large. Therefore, the dielectric properties of material are small. They observed an increasing relationship between moisture content and dielectric constant of oilseeds that declares indication of nonlinearity between mentioned variables. Also Berbert et al. (2001) investigated the dielectric properties of parchment coffee and performed several polynomial regressions between moisture and dielectric constant of coffee at different frequencies. They reported the best model yielded the R^2 of 0.998.

Table 1 Results of hyperbolic regression to extract the calibration equation for oilseeds

		$\frac{a.C_s + b}{c.C_s + d}$						
Oilseed	Variety	*a*	*b*	*C*	*d*	R^2	*SSE*	*RMSE*
Sesame	*Dashtestan*	1.437	-5.068	0.135	-0.37	0.997	0.156	0.395
	Ultan	1.22	-4.316	0.082	-0.167	0.994	0.392	0.626
Soybean	*L17*	1.931	-6.552	0.021	0.16	0.972	8.504	2.916
	Sahar	7.897	24.49	-0.081	1.94	0.965	13.32	3.469
Canola	*Okapi*	2.108	-7.236	0.023	0.214	0.998	1.224	1.106
	Talaiyeh	0.883	-3.117	0.007	0.099	0.999	0.915	0.957

To validate the obtained calibration equation, the moisture content of each variety was predicted by equation obtained from another variety of the same oilseed. To compare the predicted moisture content by capacitive sensor with the actual values, the "two-tailed" paired t-test (α = 0.05) was performed. The paired t-test is used for testing whether the difference between the two methods is significantly different. The important feature of this test is its ability to compare the measurements within each subject (Soltani et al., 2011).

The results of comparison between predicted and actual values of moisture content for sesame, soybean and canola and also the correction coefficient for each equation are presented in Figure 6, Figure 7 and Figure 8. The coefficient of determination for *Dashtestan* and *Ultan* sesame were 0.966 and 0.932, respectively, for *L17* and *Sahar* soybean were 0.963 and 0.952, respectively and for Okapi and *Talaiyeh* canola were 0.993 and 0.994, respectively. The R^2 parameter can be interpreted as the proportion of the variance in the predicted values attributable to the variance in the actual measurements. The higher the R^2 values, the closer the estimated results are to the actual results (Omid et al., 2010). Results of paired t-test analysis are presented in Table 2.

The paired t-test results showed that for all studied oilseeds in this research the measured moisture content was not significantly different from the predicted moisture with capacitive technique ($p > 0.05$).

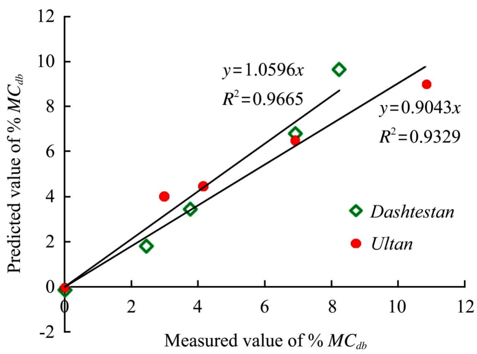

Figure 6 Comparison of predicted and measured moisture content of sesame with capacitance sensor and oven drying method

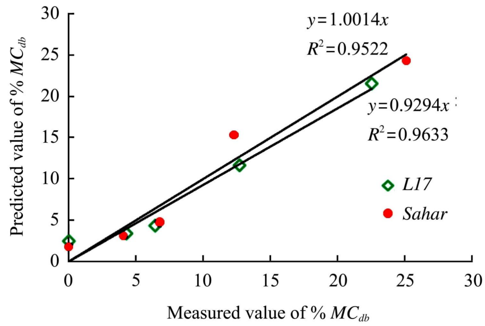

Figure 7 Soybean moisture measured using water oven technique and capacitive sensor method with the line of equality

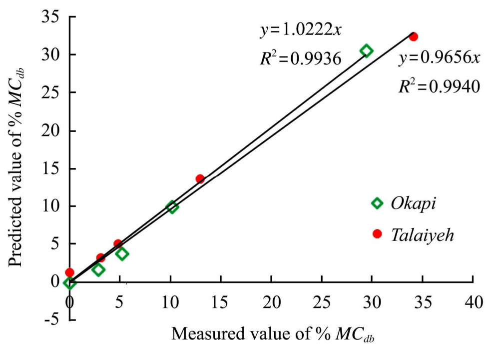

Figure 8 Correlation between experimental and estimated moisture values for canola seed

Table 2 Paired t-test analysis between capacitive sensor and oven drying methods

Oilseed	Variety	Paired t-test
Sesame	*Dashtestan*	0.91
	Ultan	0.72
Soybean	*L17*	0.56
	Sahar	0.82
Canola	*Okapi*	0.53
	Talaiyeh	0.74

4 Conclusions

In this paper, an electrical technique based on capacitive sensor was used to predict the moisture content of sesame, soybean and canola seed. Experiments indicated that the capacitive properties of studied oilseed in this research were found to be a function of moisture content. Hyperbolic regression was performed for calibration equation extraction that yielded high values for R^2. Result of paired t-test indicated established calibration formulas for a variety can be used for another studied variety. In summary, based on the obtained results from statistical analyses, the design and performance of this type of sensor is an appropriate technique for oilseed moisture prediction and the electrical measurement concurs with obtained values from oven drying method. Dielectric measurement is a powerful tool for determining the moisture content and more practical than time-consuming oven method.

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