Investigation of the Relationship between Moisture Content and Dielectric Constant of Wheat and Millet

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Moisture content has significant effects on most properties of agricultural products. One of these properties which are highly affected by moisture content is the dielectric constant of grains and seeds. Capacitive technique is a suitable method for moisture prediction of grains and seeds. In this study, a cylindrical capacitive sensor was used to determine the dielectric constant of Iranian wheat and millet. Results showed that dielectric constant of grains are highly dependent on the moisture content and frequency. Polynomial and hyperbolic regression models were developed between dielectric parameter and moisture content. Results showed that hyperbola model is more suitable and had higher value of R² and lower value of SSE and RMSE. The best results were obtained at 500 kHz frequency for wheat and millet with R² respectively equal to 0.9999 and 0.9982 in hyperbola regression.

Keywords: Dielectric constant, Moisture content, Capacitor, Wheat and millet.

Introduction

Capacitive technique is a simple, rapid and low cost method to determine the quality of food, fruits and vegetable, seeds and grains. Due to these advantages, this technique is widely used in agriculture. Ragni et al., (2008) predicted the quality indices of eggshell using dielectric technique. They used a parallel plate capacitor as a sensor. In their experiments, samples of eggs were submitted to dielectric measurements in the range of 50i 500MHz after 1, 2, 4, 8, and 15 days of storage at 20 °C. They reported that models obtained by PLS (partial least square) processing of dielectric spectra showed R² values up to 0.996 for the time of storage and 0.876 for the air cell height. Guo et al. (2011) determined chestnut and chestnut weevil as a function of temperature by an open-ended coaxial-line probe and network analyzer. According to their findings, a temperature between 20 and 60 °C had positive effect on dielectric constant of chestnut and chestnut weevil and loss factor of chestnut over the entire investigated frequency range. The loss factor of chestnut weevil was influenced by temperature positively below 1000 MHz and negatively above 1GHz. Sacilik et al. (2006) determined the dielectric properties of flaxseed in the ranges of 50 KHz to10MHz using a parallel-plate capacitor sample holder. They studied the effects of moisture content, bulk density and frequency on the dielectric properties and concluded that the relative permittivity, loss factor, loss tangent and conductivity were greatly influenced by the moisture content, bulk density and frequency. They also deduced that the moisture content was the most significant factor affecting the dielectric properties of flaxseeds. Bansod and 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 (R² = 0.995).

The dielectric properties include the dielectric constant (ε') and loss factor (ε''), real and imaginary parts of relative complex permittivity, \( \varepsilon = \varepsilon' - j\varepsilon'' \). The dielectric constant is associated with the ability of a material to store electrical energy in the presence of an external electric field, whereas the loss factor refers to the dissipation of energy in the form of losses (Guo et al., 2008). 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 (Nelson and Trabelsi 2002). The aim of this paper is to study the behavior of Iranian wheat and millet as dielectric material at different moisture content and

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frequency. Various models of regression analysis were
developed and the best model was used for moisture
content prediction of wheat and millet.

**Material and Methods**

Samples of wheat and millet were prepared in 5
levels of moisture content artificially investigate
relationship between moisture content and dielectric
constant of seeds at 1 kHz ÷ 1 MHz frequency band at
room temperature. In preparing conditioned samples, a
fixed quantity (100cc) of grain was taken and the broken
kernels and foreign materials were removed manually.
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 ºC. The
temperature of isolated box was fix with a controlled
heater. To decrease the moisture content level, the oven
method was used at 60ºC for 18 hour and 36 hour,
respectively. The prepared specimens were stored in
sealed polyethylene bag at 4 ºC in cold storage for at for
72 hour, before electrical measurement.

An instrument was designed and developed to
measure dielectric constant of seeds at various moisture
contents using capacitive sensor. A cylindrical capacitor
with internal volume of 100 cc was designed and the
instrument was calibrated by accurate capacitors. The
capacitance of filled capacitor was measured and the
dielectric constant of samples was calculated. More
explanation of instrument and dielectric calculation was
presented by Soltani et al. (2011). Dielectric
measurement of seeds was performed at 5 levels of
moisture content at 1 kHz, 10 kHz, 100 kHz, 500 kHz
and 1 MHz frequencies. All measurements were
performed in a laboratory with an average room
temperature of 25ºC. After electrical experiments, the
moisture content of samples was measured using the
oven drying method. The moisture content (%MC _db_)
was calculated on dry basis by following equation.

\[
\text{%MC}_{db} = \frac{w_w}{w_d} \times 100 = \left(\frac{w_i - w_d}{w_d}\right) \times 100 \quad \ldots \ (1)
\]

where \(w_i\) is the initial weight of sample, \(w_w\) is the weight
of water in sample and \(w_d\) is the weight of dried sample.

MATLAB 7.6 (2009) was used to extract the
regression models between the studied attributes. The
performance of the models was evaluated using root
mean square error (RMSE) and coefficient
determination (R²). The RMSE is a measure of accuracy
and reliability to calibrate and test the data sets,
respectively (Cihan et al., 2007).

**Results and Discussion**

The measured moisture content (%db) of wheat and
millet specimens is presented in Table 1. Acceptable
amplitude of variation is observed in the moisture content
of wheat and millet. Fig. 1 shows the relation between \(\varepsilon_s\)
and moisture content (%MC _db_) of wheat. A regular
correlation was observed between \(\varepsilon_s\) and %MC _db_ at all
frequencies. The same results were also obtained for
millet. Similarity between Fig. 1 and Fig. 2 reveals the
fact that the shape of correlation between %MC _db_ and
\(\varepsilon_s\) are approximately the same for millet and wheat.
When the frequency of the sine wave was increased, a decrease in $\varepsilon_s$ was observed. This decrease was more vivid at higher levels of moisture content. Also at higher frequencies, the curves were smoother. Soltani et al. (2011) proposed that homographic regression is more proper than polynomial regression for estimation of relation between dielectric constant and moisture of seed. In this paper two models of regression (polynomial and homographic) were used. Results of polynomial regression analysis are presented in Tables 2 and 3. The lowest value of the coefficient of determination was found at 10 kHz ($R^2 = 0.969$) for wheat which is an agreeable value. It means that the quadratic function can be fitted into relation of $\varepsilon_s$ - %MCdb as well.

Table 2δ: Polynomial regression analysis of $\varepsilon_s$ - %MCdb for wheat.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Equation</th>
<th>$R^2$</th>
<th>SSE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kHz</td>
<td>%MCdb = -0.097 $\varepsilon_s^2$ + 3.585 $\varepsilon_s$ -6.734</td>
<td>0.9813</td>
<td>2.751</td>
<td>1.173</td>
</tr>
<tr>
<td>10 kHz</td>
<td>%MCdb = -0.257 $\varepsilon_s^2$ + 6.065 $\varepsilon_s$ -14.10</td>
<td>0.9698</td>
<td>4.447</td>
<td>1.491</td>
</tr>
<tr>
<td>100 kHz</td>
<td>%MCdb = -0.606 $\varepsilon_s^2$ + 10.89 $\varepsilon_s$ -28.38</td>
<td>0.9883</td>
<td>1.722</td>
<td>0.928</td>
</tr>
<tr>
<td>500 kHz</td>
<td>%MCdb = -0.624 $\varepsilon_s^2$ + 11.77 $\varepsilon_s$ -31.12</td>
<td>0.9991</td>
<td>0.064</td>
<td>0.1784</td>
</tr>
<tr>
<td>1 MHz</td>
<td>%MCdb = -0.483 $\varepsilon_s^2$ + 10.50 $\varepsilon_s$ -28.63</td>
<td>0.9991</td>
<td>0.173</td>
<td>0.253</td>
</tr>
</tbody>
</table>

Table 3δ: Polynomial regression analysis on $\varepsilon_s$ - %MCdb for millet.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Equation</th>
<th>$R^2$</th>
<th>SSE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kHz</td>
<td>%MCdb = -0.018 $\varepsilon_s^2$ + 1.790 $\varepsilon_s$ -0.155</td>
<td>0.9776</td>
<td>2.532</td>
<td>1.125</td>
</tr>
<tr>
<td>10 kHz</td>
<td>%MCdb = -0.305 $\varepsilon_s^2$ + 6.124 $\varepsilon_s$ -13.03</td>
<td>0.9781</td>
<td>2.483</td>
<td>1.114</td>
</tr>
<tr>
<td>100 kHz</td>
<td>%MCdb = -0.572 $\varepsilon_s^2$ + 9.702 $\varepsilon_s$ -23.10</td>
<td>0.9874</td>
<td>1.422</td>
<td>0.843</td>
</tr>
<tr>
<td>500 kHz</td>
<td>%MCdb = -1.009 $\varepsilon_s^2$ + 14.63 $\varepsilon_s$ -35.03</td>
<td>0.9986</td>
<td>0.154</td>
<td>0.277</td>
</tr>
<tr>
<td>1 MHz</td>
<td>%MCdb = -0.738 $\varepsilon_s^2$ + 11.76 $\varepsilon_s$ -28.06</td>
<td>0.9972</td>
<td>0.322</td>
<td>0.401</td>
</tr>
</tbody>
</table>

Table 4δ: Homographic regression for wheat.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>$a$</th>
<th>$B$</th>
<th>$c$</th>
<th>$d$</th>
<th>$R^2$</th>
<th>SSE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kHz</td>
<td>1.834</td>
<td>-4.506</td>
<td>0.038</td>
<td>0.3363</td>
<td>0.9826</td>
<td>2.562</td>
<td>1.601</td>
</tr>
<tr>
<td>10 kHz</td>
<td>16.99</td>
<td>-56.69</td>
<td>0.551</td>
<td>0.007</td>
<td>0.9754</td>
<td>3.626</td>
<td>1.904</td>
</tr>
<tr>
<td>100 kHz</td>
<td>1.203</td>
<td>-4.334</td>
<td>0.04</td>
<td>-0.055</td>
<td>0.9948</td>
<td>0.7633</td>
<td>0.8736</td>
</tr>
<tr>
<td>500 kHz</td>
<td>1.053</td>
<td>-3.444</td>
<td>0.02</td>
<td>0.05</td>
<td>0.9999</td>
<td>0.01837</td>
<td>0.1355</td>
</tr>
<tr>
<td>1 MHz</td>
<td>1.319</td>
<td>-4.245</td>
<td>0.017</td>
<td>0.112</td>
<td>0.9988</td>
<td>0.0171</td>
<td>0.413</td>
</tr>
</tbody>
</table>

When the frequency of the sine wave was increased, a decrease in $\varepsilon_s$ was observed. This decrease was more vivid at higher levels of moisture content. Also at higher frequencies, the curves were smoother. Soltani et al. (2011) proposed that homographic regression is more proper than polynomial regression for estimation of relation between dielectric constant and moisture of seed. In this paper two models of regression (polynomial and homographic) were used. Results of polynomial regression analysis are presented in Tables 2 and 3. The lowest value of the coefficient of determination was found at 10 kHz ($R^2 = 0.969$) for wheat which is an agreeable value. It means that the quadratic function can be fitted into relation of $\varepsilon_s$ - %MCdb as well.

When the frequency of the sine wave was increased, a decrease was observed in $\varepsilon_s$. The result was in accordance with the findings of Guo et al. (2011). They similarly reported that the dielectric constant ($\varepsilon'$) of both chestnut and chestnut weevil decreased with increasing frequency of input signal.

The lowest value of $R^2$ for polynomial regression was found at 10 kHz as 0.969. Although this value was the lowest one from stand view of statistic, it is an indication of high correlation between $\varepsilon_s$ and %MC. The results were in agreement with the similar studies for corn, soybean, hard red winter wheat and chickpea flour (Guo et al., 2008). Sacilik and Colak (2010) proposed second and third-order polynomial equations to describe the existing relationship between the dielectric properties and the moisture content of corn seed. They obtained their best result at 1 MHz with $R^2$ of 0.998. Berbert et al. (2002) reported stated that the real component of the complex permittivity (dielectric constant) decreased as the frequency increased for soybean of all moisture contents. Also they proposed a polynomial relation between moisture content and the dielectric constant of bean with $R^2$ equal to 0.9928, 0.9951, 0.9953 and 0.9983 at 100 kHz, 500 kHz, 1 MHz and 5 MHz, respectively.

As reported by Lawrence et al. (1998), the dielectric constant of hard red winter wheat increased with moisture content and decreased with frequency. The same results were obtained by Das et al. (2010) and Guo et al. (2008) for soybean and chickpea flour.

Results of homographic regression analysis are presented in Tables 4 and 5. Comparing statistical indices ($R^2$ and RMSE) of polynomial and homographic
regression, it can be concluded that as a whole, homographic model is superior for prediction of wheat and millet moisture content. It should be noted that the parabolic function is not an injective function and may return two outputs for one input. However, being injective is a necessary condition for a calibration equation. Homographic regression satisfies this condition and is a more suitable regression for moisture content prediction. Among the considered frequencies, the results of the statistical analysis at 500 kHz are more satisfying. The $R^2$ for wheat and millet has the highest value and the RMSE has the lowest value at this frequency. So the 500 kHz sinusoidal was selected for calibration of the system.

### Conclusion

In this study, the dielectric constant of wheat and millet was investigated as a function of moisture content and frequency. Polynomial and homographic regression was used to analyze the relationship between $\varepsilon_s$ and %MC. Homographic model yielded better results. The dielectric constant increased homographically with increasing of moisture content. Through this method, the moisture content of wheat and millet can be predicted reliably. Further investigation of dielectric properties can be recommended at higher frequencies.

### References