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Evaluation of the accuracy of a capacitive moisture meter for corn

Y. Acun[1], S. Gürsoy[1]*

[1]Department of Department of Agricultural Machinery and Technology Engineering, Dicle University, 21280 Diyarbakır, Türkiye

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Abstract. *Accurate and rapid measurement of the moisture content of the grain is one of the most important factors for agricultural production and industry. Until today, many capacitance-based grain moisture meters have been commercially developed to measure grain moisture samples to an accuracy of ±0.1% w.b. However, several factors such as moisture content, bulk density, temperature, and varieties of grain samples significantly affect the accuracy and the precision of moisture meters. Therefore, a study was conducted to evaluate the effects of moisture content, temperature, variety of grain samples on the measurement accuracy of a capacitive moisture meter for corn. For this purpose, three experiments were carried out by considering different moisture content, temperature and varieties of grain corn. The results of the experiments showed that moisture content, temperature and variety of corn significantly affected the accuracy of the capacitive moisture meter. The difference between the moisture values determined by the meter and the oven was the lowest at the 23-24% moisture level of corn samples. The meter reading was progressively higher and lower than the oven at the lower and higher moisture content levels than 23-24%, respectively. The difference between the meter and the oven was the lowest at the 24-25°C temperature of corn samples. These results suggest that commercial moisture meters need to be optimized in the future to improve their accuracy by considering the grain variety, moisture content, bulk density, and temperature.*

Keywords: corn, moisture meter, capacitance, accuracy, regression, error

Introduction

Corn is one of the most important crops in most regions and countries of the world (Klopfenstein et al., 2013). The moisture content of corn during the processes of purchasing, processing, storing, and transporting is considered an important quality parameter because it affects decisions in harvesting, drying, storage, handling and marketing (Nelson et al., 2000; Rai et al., 2005). Accurate measurement of moisture content for corn is a very important issue at every point of harvest and postharvest handling. Small errors in measurement can cause significant wrong consequences during the determination of processes such as harvest time, the value of the crop to be sold, drying duration and storage duration (Nelson, 2000).

Moisture content of grain can be determined by using direct or indirect methods (Flor et al., 2022). Direct methods include oven drying method, distillation, drying with desiccants, etc. The oven drying method is the main known method for determining moisture of grains. It is highly accurate but has many steps and takes a lot of time. Therefore, it is generally used for calibrating other indirect method based moisture

*e-mail: songul.gursoy@dicle.edu.tr

meters. Indirect methods include methods such as capacitance, resistance, near infrared, microwave, a high-frequency impedance, acoustic, neutron, and nuclear magnetic resonance. These methods use other physical and chemical properties of the material that are related to moisture content (Nelson and Trabelsi, 2004; Kandala et al., 2007; Song et al., 2020; Flor et al., 2022). Among these measurement methods, the capacitance method is known as the most common method because it has advantages of low cost, small volume and fast detection, although it lacks high precision (Sadaka and Rosentrater, 2019). The capacitance method is based on the electrical capacitance of a material that in turn depends on the moisture and capacitance of the material. In other words, agricultural materials act as dielectric materials when placed between two plates or concentric metal cylinders which form a capacitor (Nelson and Trabelsi, 2004). The dielectric constants for the dry components of grains (oil, starch, protein) vary between 2 and 5 while "free" water has a dielectric constant of 80. Because of the significant difference between the dielectric constants for water and dry components, changes in the grain moisture content will change the capacitance reading on the meter. (Ahmed et al., 2015; Sadaka and Rosentrater, 2022). Nowadays, many capacitive moisture meters are commercially available to measure the moisture content of grain samples. These moisture meters are commonly used on the farm and in the grain trade, as well as for sensors of moisture-based dryer controllers, and can be operated over a wide moisture range (Young, 1991). Çelik et al. (2022) developed a laboratory scale dryer integrated with capacitive sensor modeled for shelled corn. They stated that the commercial development of grain capacitance moisture meters could be expected to increase their reliability and utility in the grain industries proposed to reveal the capacitance relationship of moisture meters integrated on the dryer at different operating temperatures.

Many factors such as moisture content, temperature, species and bulk density of grain can significantly affect the measurement accuracy and precision of a capacitive grain moisture meter. Several researchers (e.g. Hurburgh et al., 1985; Kraszewski and Nelson, 1992; Shande et al., 2000; Rai et al., 2005; Shi et al., 2015) demonstrated that the readings of capacitive moisture meters might depend upon the moisture content of grain, type of grain, year of harvesting, frequency characteristics of dielectric constant of grains, temperature and bulk density of grain, nature and degree of grain impurities, type of moisture (natural or added). For example, Hurburgh et al. (1985) demonstrated that both accuracy and precision of a capacitive moisture meter are functions of moisture content for corn. Also, in another study, Shande et al. (2000) observed that a capacitive moisture meter provided a rapid and accurate measure of seed moisture at lower moisture levels (< 29%), but was inaccurate at high moistures. The researchers stated that the accuracy of a moisture meter used in determining seed moisture could be influenced by sampling and handling procedures followed at each location. Jones et al. (2022) reported that grain permittivity measurements, the primary factor considered during dielectric measurement of agricultural grain moisture, are affected by their free and bound water contents, chemical composition, temperature, constituent shape, phase configuration and measurement frequency.

The performance of a moisture meter is mainly evaluated by its accuracy and precision. Both are important parameters in assessing the measurement results of a moisture meter. The accuracy of a moisture meter is a measure of the nearness of a reported moisture value to the correct or accurate value, namely reference value which is mostly determined using an oven method. On the other hand, the precision of a moisture meter refers to the repeatability of the moisture measurements which is the standard deviation of repeated measurements, with an "ideal" of zeroed although this is very difficult to achieve (Sadaka and Rosentrater, 2022). In a study conducted by Hossain et al. (2016) to examine the accuracy and precision of several moisture meters for rough rice, the deviations in the meter readings were found to be up to 13% compared to the oven method. Hurburgh et al. (1986) evaluated the performance of three commercial moisture meters that were commonly used on farms for both corn and soybeans. They found that precision was affected by the corn moisture content while there was no

effect due to moisture level for soybeans. Also, Hurburgh et al. (1985) evaluated 5 commercial grain moisture meters on 881 samples of corn and determined accuracy and precision levels for each comparing the official oven drying method. They found the change values ranging from 2.5% up to 4.5%, again, precision declining as moisture in the corn increased.

The objective of this study was to evaluate the effects of moisture content, temperature and varieties of corn on the accuracy of a commercial capacitive moisture meter when compared to the air-oven.

Material and methods

In order to evaluate the effects of moisture content, temperature, variety of grain samples on the measurement performance of a capacitive moisture meter for corn, three experimental studies were conducted at the research laboratories of Agriculture Faculty. In the first experiment, different moisture content levels of the corn variety "Pioneer 2105" were tested at 20-21°C, the second experiment at different sample temperatures of the corn variety "Pioneer 2105" at 16-17%, and the third experiment at different corn varieties at 11-12% moisture content and 20-21°C temperature.

The corn varieties used in the experiments were "Pioneer 2105", "KWS-KEFRANCOS", "Pioneer 0729", "DKC 5812", "Pioneer 3394", "DH690", "ADK 1432". While the variety "Pioneer 2105" from corn samples was obtained from the local market (Diyarbakır, Turkiye), the other corn varieties "KWS-KEFRANCOS", "Pioneer 0729", "DKC 5812", "Pioneer 3394", "DH690" "ADK 1432" were collected from test plots of GAP International Agricultural Research and Training Center. Some physical properties of corn varieties, for which the initial moisture content and temperature is 11-12% and 20-21°C, respectively, are given in Table 1. Also, different moisture content levels of corn seeds for the variety "Pioneer 2105" were prepared as 16-17%, 20-21%, 24-25%, 28-29% and 30-31% (wet basis) by adding a calculated amount of water and sealing them in separate polythene bags and storing in a refrigerator at 4°C for 2 weeks to attain the equilibrium predicted moisture levels.

Table 1. Some physical properties of the corn varieties used in the experiments

Variety	Seed size, mm			100 seed weight, g	Bulk density, g cm^{-3}
	Width	Thickness	Length		
Pioneer 2105	7.88±0.70	4.81±0.98	12.73±1.11	36.75±1.79	0.763±0.07
KWS-Kefrancos	8.79±0.34	4.56±0.78	10.54±0.42	32.21±2.21	0.706±0.02
Pioneer 0729	9.04±0.38	4.83±0.43	10.77±0.79	31.73±1.82	0.703±0.02
DKC 5812	9.02±0.76	5.04±0.43	10.20±1.15	32.17±0.83	0.731±0.02
Pioneer 3394	8.03±0.91	5.02±0.95	10.61±0.89	31.78±0.98	0.762±0.02
DH690	8.57±0.76	5.99±1.12	10.27±1.12	38.55±1,43	0.791±0.01
ADK 1432	7.55±0.94	5.18±0.72	10.62±0.70	31.60±0.34	0.753±0.01

The PM450 Portable Moisture Meter (Kett Co., Japan) and the Memmer model ULM 400 (Memmer Co., Germany) heated with forced-air circulation are used to determine the moisture content of the corn samples as capacitance and standard oven (reference) methods, respectively.

The standard oven (reference) method was performed according to the ASAE standard S352•1 (ASAE, 2001). In this purpose, the whole seeds of the 15 g corn samples (three replication) were completely dried out in an air-oven at a temperature of 103°C for 72 hours. After that, moisture content of corn samples was calculated on a wet basis by Eq. (1).

$$M_{wb} = \left(\frac{(W_i - W_f)}{W_i}\right) * 100 \quad (1)$$

Where:

M_{wb} is the wet-basis moisture content of the sample (% w.b.), W_i is the initial weight of the sample (g), W_f is the weight after oven-drying of the sample (g).

The operating procedures and some specifications of the PM450 moisture meter obtained from a local firm selling the model are given in Figures 1 and 2, respectively. The moisture meter was operated according to manufacturer's instructions.

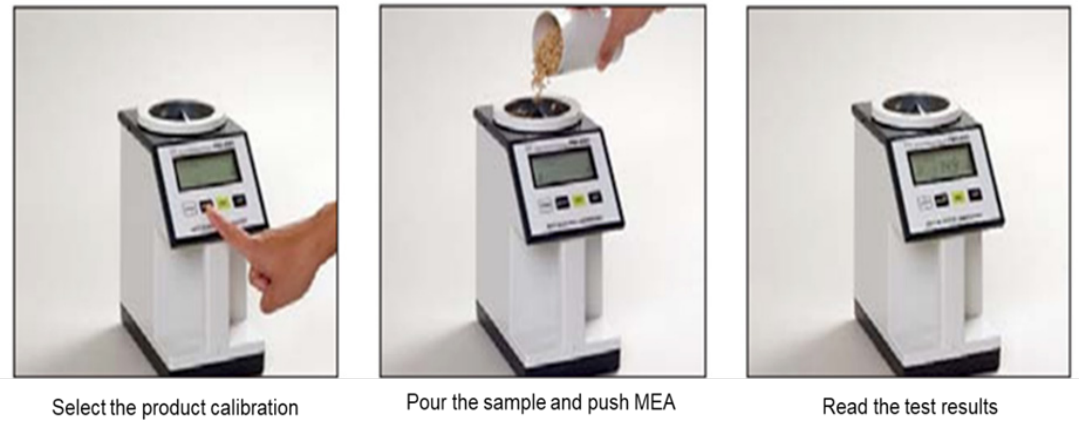

Figure 1. The operating procedures of the PM450 moisture meter used in the experiment

Table 2. Some specifications of the PM450 moisture meter

Model	**PM450**
Measurement principle	Capacitance (Di-electric) (50MHz)
Measurement range	Moisture 1-40% (product dependent)
Product calibration	A wide variety of seed and grains
Sample volume	Approximately 240 ml
Response time	Instant
Accuracy	±0.5% (under 20%)
Resolution	1%
Ambient temperature	0-40 °C
Ambient humidity	0-85% RH (non-condensing)
Features	Automatic density and temperature compensation, auto power of average.
Display type	Backlit LCD
Communications	
Power	4AA Batteries
Weight (kg) (Net/Shipment)	1.3/2.2
Dimensions (mm)	125Wx215Hx205D

The experiments were performed by Completely Random Design with four replications. Three experiments were conducted by considering the different moisture content, temperature and corn varieties. In the first experiment, the corn seed samples (variety: Pioneer 2105) were tested for six moisture contents (11-12%, 16-17%, 21-22%, 24-25%, 28-29%, 30-31% w.b.) at ≈20-21°C. In the second experiment, the corn seed samples (variety: Pioneer 2105) at 16-17% w.b. were tested for four grain temperature ranges (17-18°C, 20-21°C, 25-27°C, 32-33°C). In the third experiment, the six corn varieties (Pioneer 2105, KWS-KEFRANCOS, Pioneer 0729, DKC 5812, Pioneer 3394, DH690 and ADK 1432) were tested at 20-21°C and 11-12% w.b.

The accuracy of the moisture meter (DIFF_M) was determined as the difference between the moisture content values measured by a meter reading and reference (oven) method on a sample (Eq. 2). On the other hand, the percentage error (% error) as a function of accuracy was calculated using the Eq. (3) (Joaquin et al., 2019).

$$DIFF\_M = MC_{meter} - MC_{ref} \quad (2)$$

$$\%error = \left(\frac{\text{ABS}\left(MC_{meter} - MC_{ref}\right)}{MC_{ref}}\right) * 100 \quad (3)$$

Where;

DIFF_M, the difference between moisture content values determined by capacitive grain moisture meter and reference (oven drying) method (% w.b.)

MC_{meter}, moisture content value measured by the capacitive grain moisture meter (% w.b.)

MC_{ref}, moisture content value measured by the reference (oven drying) method (% w.b.)

% error, the percentage error as a function of accuracy (%)

The results obtained were subjected to analysis of variance (ANOVA) using the JMP statistical software (SAS Institute Inc., 2002) and analysis of regression using Microsoft Excel 2007 (Microsoft Corp., USA).

Results and discussion

The effect of the moisture content of corn samples on the accuracy of the moisture meter

Figure 2 shows the comparison of moisture content values of corn samples determined by the moisture meter and the oven drying (reference) method.

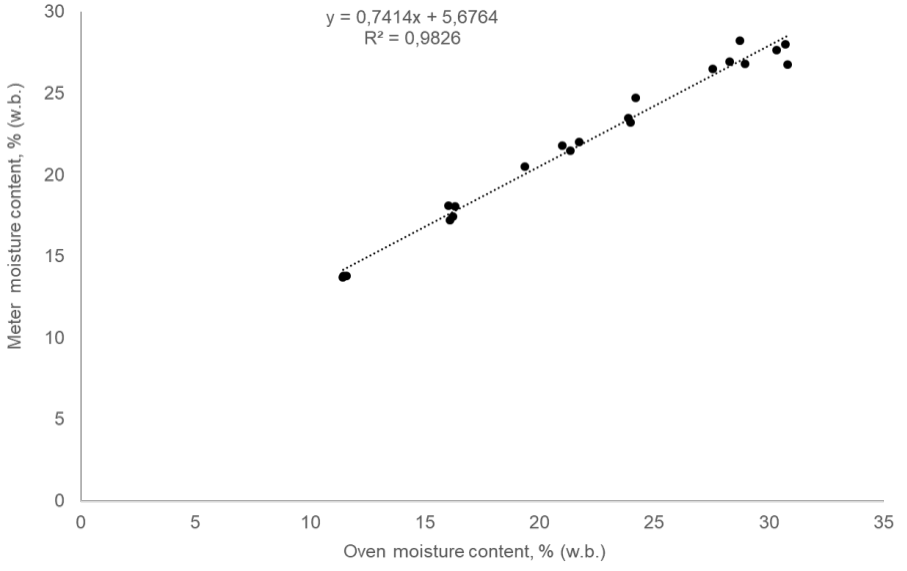

Figure 2. Comparison of corn moisture content readings between oven method and capacitive moisture meter.

A linear relationship was obtained between the moisture meter and the oven drying (reference) method as shown in Figure 2. This relationship means that the moisture content of this moisture meter can be estimated by the Eq.3 with relatively high correlation of determination (R2) of 0.98 within moisture content range of 11% to 31%.

$$MC_{meter} = 0.7414MC_{ref} + 5.6764 \quad (4)$$

Figure 3 shows how the accuracy (difference between moisture content values measured by the meter and oven method) and the percentage error (% error) of the capacitance moisture meter changed with the moisture content of corn samples determined by oven drying method. The variability in the comparison of meters with the oven increased both with an increase and a decrease in moisture content of corn samples from the optimum 20-24%. When the moisture content of corn samples was lower than 20%, the moisture meter readings were 1-2% points higher than the reference values. However, the moisture meter read lower than the reference values when the moisture content of corn samples was lower than 20%. Similarly, the percent error of meter was the lowest (about

2-3%) at the 20-24% moisture content of corn samples. The lower and higher moisture content than the 20-24% increased the percent error about 5-20%. The percent error of the moisture meter was 20-21%, 8-9%, 5-6%, 8-9% at the 11-12%, 16-17%, 28-29%, 30-31% moisture content of corn samples, respectively. Mustofah and Utami (2019) stated that the maximum percentage of moisture sensor error should be no more than 5%. The average percentage of errors obtained from the results of the analysis in this study, exceeded the maximum percentage of moisture sensor error during the measurement of corn samples at the lower and higher moisture content than the 20-24%. The moisture content measurement of grain materials with capacitive moisture meters is based on the significant difference between the dielectric constants for water and dry components of grain. Therefore, changes in the moisture content of grain affect the capacitance reading of the meter, which could be translated to grain moisture content (Hou and Su, 2005). The accuracy of a capacitive grain moisture meter is affected by several properties of grain such as temperature, size, variety, bulk density, porosity as well as grain moisture content (Nelson, 1982; Kandala et al., 2007).

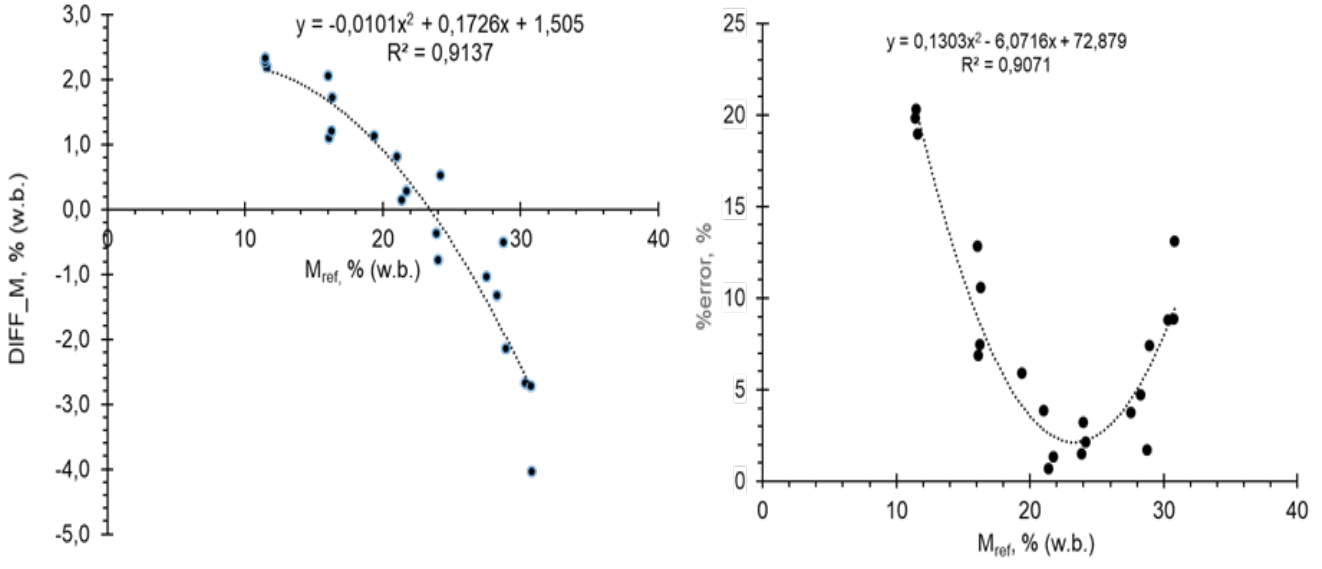

Figure 3. The accuracy and the percent error of a capacitive meter affected by the moisture content of corn samples

The effect of the temperature of corn samples on the accuracy of the moisture meter

The accuracy and the percent error of a capacitive meter affected by the temperature of corn samples are presented at Figure 4. There was a quadratic relationship between the accuracy of the moisture meter (DIFF_M) and the temperature of corn samples, also between the percent error of moisture meter and the temperature of corn samples. Both DIFF_M (the difference between the moisture content values determined by meter and oven method) and the percent error of moisture meter were the lowest at about 25°C temperature of corn samples. The higher and lower than 25°C increased the DIFF_M and the percent error of the moisture meter. Although the capacitance moisture meter used in this study includes an integrated scale and thermistor to automatically compensate for variation in both ensuring accurate moisture measurement each time, the difference in the comparison of the moisture meter with the oven and the percent error of the moisture meter increased both with an increase and a decrease in the temperature of corn samples from the optimum 25°C. The percent error of the moisture meter was higher than 5% at 17-18°C and 32-33°C of corn samples. In capacitance type moisture meters, higher or lower temperatures than calibrated temperature can make food and other materials slightly more or less conductive to electricity, meaning that moisture meters might return a reading that is higher or lower than the object's actual moisture content (Jha et al., 2011). It was observed that the temperatures of corn samples

between 20 and 29°C did not cause any significant changes in the reading of the moisture meter when considered the minimum DIFF_M (0.8%) and percent error values (5%) specified by National Institute for Standards and Technology (NIST Handbook 44, 2015). However, temperatures of corn samples lower than 20°C and higher than 29°C caused the DIFF_M and the percent error of the moisture meter to increase to higher than acceptable limits. Funk et al. (2007) emphasized that moisture meters based on capacitance moisture measurement required corrections for the influence of temperature and bulk density, applied through calibration charts or automatically built into the instruments. In this study, although there was a temperature thermistor providing automatic temperature compensation in the capacitance moisture meter used in the experiments, it was observed that there were still some errors with the accuracy of the moisture meter when the product temperature was outside the range of 20°C and 29°C.

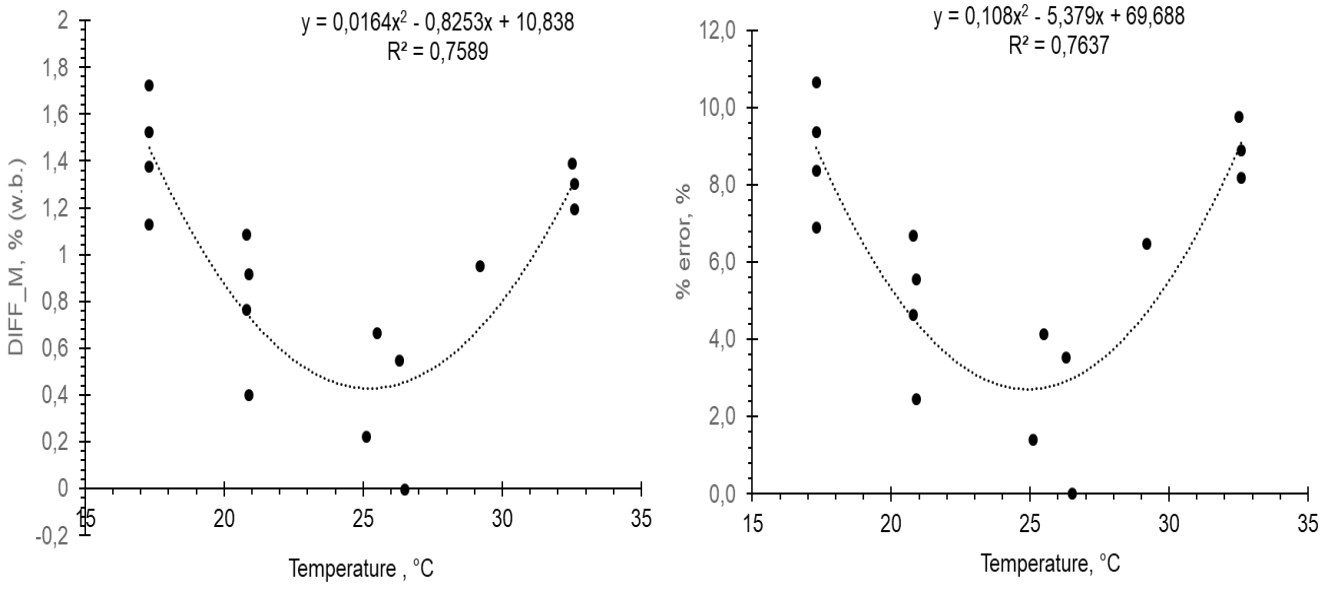

Figure 4. The accuracy and the percent error of a capacitive meter affected by the temperature of corn samples

The effect of the corn varieties on the accuracy of the moisture meter

The accuracy (DIFF_M) and the percent error of a capacitive moisture meter affected by corn varieties at 20-21°C and 11-12% (w.b.) is seen at Figure 5. The measurement results showed that the varieties had a significant effect on the accuracy (DIFF_M and the percent error) of the moisture meter. While the highest DIFF_M and the percent error was obtained from the Pioneer2105 and Pioneer3394 varieties, the lowest DIFF_M and the percent error was obtained during the measurement of the KWS-KEFRANCOS variety. In other words, it is understood that the measurement values of the moisture meter are more accurate in measurements made with the KWSKEFRANCES corn variety compared to other varieties. Similarly, it has been stated in the literature that the accuracy and precision of sensors and devices used in moisture measurement of grains and oil crops may vary depending on a number of grain characteristics such as particle shape, bulk density or porosity, temperature, chemical composition and purity, which are influenced by varieties of grain species and seasonal changes in climatic conditions (Soltani and Alimardani, 2011; Zhang et al., 2013; Singh et al., 2017).

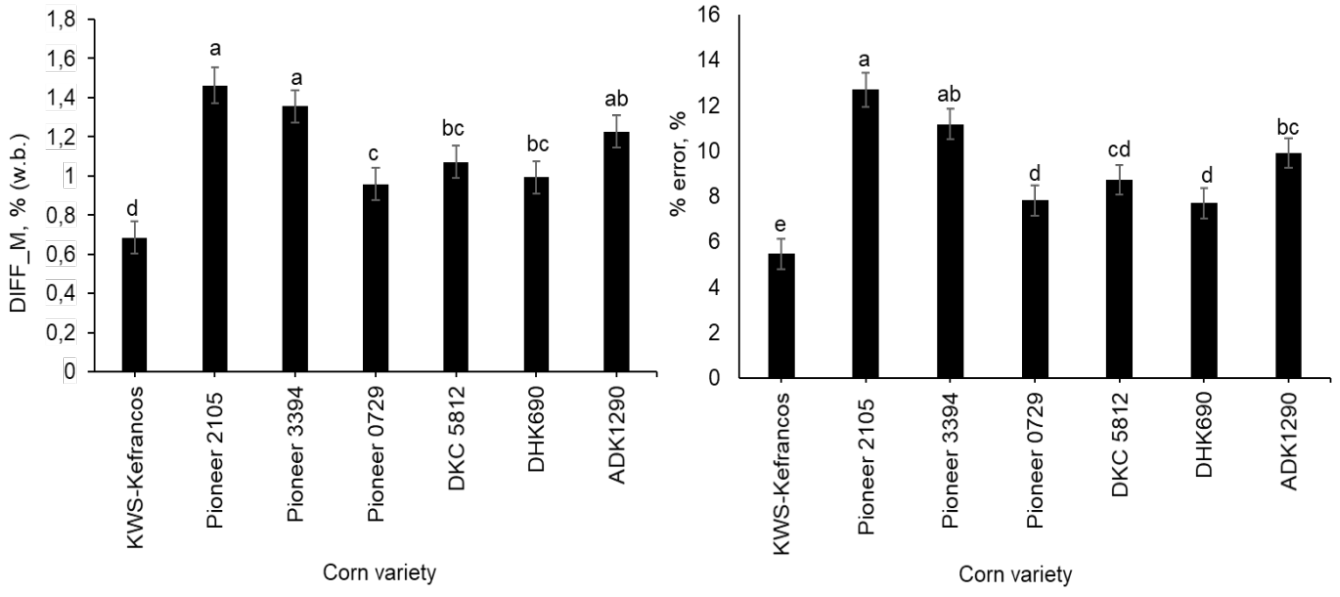

Figure 5. The accuracy and the percent error of a capacitive moisture meter affected by corn varieties

Conclusion

In this study, the effects of moisture content, temperature, variety of grain samples on the measurement accuracy of a capacitive moisture meter was evaluated for corn. The following conclusions were drawn from the study:

- The accuracy of the moisture meter decreased both with an increase and a decrease in moisture content of corn samples from the optimum 20-24% (w.b.).

- The error of the moisture meter was the lowest at about 25°C temperature of corn samples. The higher and lower than 25°C increased the measurement error of the moisture meter.

- The accuracy of the moisture meter was significantly affected by corn variety.

In summary, the accuracy and sensitivity of the portable type moisture meters used in the market are significantly affected by the moisture content, temperature and variety characteristics of the product, and it is of great importance to check the moisture meters by comparing them with the standard oven drying method at regular intervals after purchase and during their use in the field.

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