TECHNICAL NOTE:

A REDESIGNED DFA MOISTURE METER

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ABSTRACT. The DFA moisture meter has been internationally recognized as the standard for determining moisture content of dried fruit in general and is the AOAC Official Method 972.2 for measuring moisture in prunes and raisins since 1972. The device has remained virtually unchanged since its inception, with its operation based on conductance of a sample across an electrode pair that forms one branch of a Wheatstone bridge. In recent times, obtaining appropriate parts for the device has become problematic, as maintaining the original Wheatstone bridge design requires a precision potentiometer with nearly identical non-linear characteristics to the original. The design of the moisture meter has now been updated to use modern electronic components to, among other things, mimic the original potentiometer so that calibration charts, as well as AOAC certification, remain valid. The redesigned meter was compared to the original in moisture readings of raisins, prunes, and apricots. Scatter plot regression resulted in $R^2$ of 0.99999 and slope of 0.9902, indicating high correlation and identity between the original and modified meters. The updated device automates the time-consuming and error-prone steps currently performed manually and determines moisture content in 7 s.

Keywords. Moisture meter, Wheatstone bridge, DFA, Dried fruit, Potentiometer.

The DFA moisture meter has been internationally recognized as the standard for determining moisture content of dried fruit and is the AOAC Official Method 972.2 for measuring moisture in prunes and raisins. The instrument has remained virtually unchanged since its inception and continues to be referred to as the DFA moisture meter (fig. 1).

The underlying principle of the instrument’s operation correlates 60-Hz conductivity through a dried fruit sample when connected across an electrode pair ($R_2$ of fig. 2) of a Wheatstone bridge circuit to the moisture content. Specific details of the Wheatstone bridge circuit employed, including all resistance values, has been previously reported (AOAC, 1972). One branch of the Wheatstone bridge contains a non-linear wire-wound potentiometer ($R_1$) (10k Samarius p/n 55-140-020) in series with the fruit sample, while the other (reference) branch consists of a fixed resistor ($R_a$) and a switched tap resistance ($R_b$). The potentiometer is used as a variable resistor to obtain a null reading with respect to the reference branch. A microammeter measures the half-wave rectified current between the two branches and provides the operator a visual indication of the null condition. The seven position tap switch in the reference branch allows selection of various resistance values, depending on the type of sample being measured. For instance, for raisins with low moisture, a specific tap setting is indicated in the appropriate table (fig. 3). The sample is ground and packed into a cylinder which is inserted into the circuit ($R_2$). The potentiometer is adjusted until a null reading is obtained. Using the dial position on the potentiometer ($k$ value, 0 to 100) for the null reading, the selected tap position, and the sample temperature, the moisture content is obtained from the table (DFA of California, 2011).

Figure 1. DFA moisture meter including meter, sample holders, thermometer, calibration cylinders, and moisture tables.

Figure 2. When the voltage across two branches of a Wheatstone bridge is null, then $V_1 = V_2$ and $R_a/R_b = R_1/R_2$. For the configuration of the moisture meter, $R_a$ is fixed, $R_b$ is variable and is determined by the tap setting, $R_1$ is the potentiometer, and $R_2$ is the sample.
Twenty-four tables for various dried fruits are available. The values within each table are derived experimentally based on the dial reading of the specific non-linearity of the Samarius potentiometer. The meter's calibration is verified using cylinders of known resistance and required k null values for each tap position. While the device has proven to be extremely rugged and reliable over the years, in recent times obtaining appropriate parts for the device has become problematic, as maintaining the original Wheatstone bridge design requires a precision potentiometer with (nearly) identical non-linear characteristics to the original. In addition, manually referencing the moisture content from the tables can be time-consuming and introduces a potential source of error that could be eliminated with digital lookup tables. The objective here was to redesign the meter using modern electronic equipment without altering the underlying principles so that the AOAC accreditation would not be affected.

**METHODS AND MATERIALS**

Potentially time-consuming and error-prone operations of the original meter were eliminated by incorporating a programmable embedded controller with 512 K flash memory (Tern Model FB, Davis, Calif.) and a digital variable resistor. To maintain consistency with the published moisture tables it was necessary to determine the Samarius’ non-linear relationship and the null resistances. From the calibration cylinders, the relationship between the potentiometer k value and the null resistance was plotted (Fig. 4), and a regression formula was used to determine the required non-linearity of the potentiometer:

\[ R = 0.62295k^2 - 161.97052k + 9994.16511 \]  

with \( R^2 = 0.99995 \)

The same relationship was plotted in figure 3 for null resistance values measured on two DFA moisture meters (s/n A2021 and s/n A674) for comparison to equation 1, yielding after regression:

\[ R = 0.6758k^2 - 170.86k + 10382 \]

and

\[ R = 0.6678k^2 - 168.68k + 10244 \]

Equations 1-3 are consistent with the physical fabrication of the potentiometer: wire wrapped around a trapezoid form, itself wrapped around a cylinder. Correlation between the measured and computed values of \( R \) was evaluated and found to have almost perfect positive linearity. Of course, in order to replace the potentiometer with a digital equivalent it is necessary to derive the k values from the required null resistance, so that the inverse of equation 1 is required. The inverse for a quadratic equation is well known as a variation of the quadratic formula.

The digital variable resistor consisted of 11 individual serially connected resistors, each connected with a bypass reed relay (Coto 9001, North Kingstown, RI). Relay switching was directly controlled by the controller’s 11-bit digital output. Using standard 0.1% resistors with resistance values of 5120, 2560, 1280, ... 5 (\( \Omega \)) provided a maximum available resistance of 10.24K \( \Omega \) with 5-\( \Omega \) resolution. The controller’s software algorithm stepped through resistor null correction values based on proportional, integrative, and derivative null errors for a fixed time period, while saving “best” values of resistance in an array. The array of “best” null resistances was averaged to predict the most reliable null
RESULTS AND DISCUSSION

Of the 124 samples tested with A2021 and the new instrument, 83 yielded the same moisture content. For the remaining 41 samples, results differed between the new instrument and the old by either plus or minus 0.5%. The scatter plot and regression are shown in figure 5, with $R^2 = 0.9999$ and a slope of 0.9902, indicating high correlation and identity. The $k$ values used in the charts vary along a column of fixed temperature to a degree that is large compared to the percentage of error in predicting them, i.e., the change in $k$ value from one chart row to the next is large (fig. 3). At worst, the regression formula results in the selection of the $k$-value in an adjacent row to the true value, leading to a 0.5% disagreement in moisture content determination between the new meter and the old. The frequency with which this disagreement occurs is correlated with the error in matching the non-linearity curve of the potentiometer as described previously.

REFERENCES

