Influence of Moisture and Current Frequency on Electrical Potential of Sorghum Grains (Sorghum Bicolour (L.) Moench)

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Abstract
Non destructive quality parameter determination of agricultural produce is the latest technological trend in agricultural metrology. This study tends to establish the use of electrical potential values to determine moisture content of sorghum grains at certain current frequency range. Electrical potential values of sorghum grains at 10, 13, 16, 19 and 22% db were measured using a circuit arrangement consisting of functional generator, grain sample holder and oscilloscope. These measure grains were carried out at current frequencies of 1, 500, 1000, 1500 and 2000 kHz using three (white, red and yellow) varieties of sorghum. Measured values obtained across all varieties ranges from – 0.2 to -14.36 volts. Statistic analysis carried out on these data shows that moisture, current frequency and variety with their interactions has significant effect at p≤0.05 on electrical potential. The study also shows that behavioral trend between moisture and electrical potential are more visible at current frequency range of 1000 to 1500 kHz in all varieties. Regression equations were developed to predict moisture using electrical potential values.

Keywords: Moisture; Current frequency; Sorghum; Variety; Electrical potentials

Introduction
Sorghum (Sorghum bicolour (L.) Moench) is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic staple food for many rural communities. Sorghum belongs to the grass family Graminea [1]. According to Kimber [2], Sorghum is a cultivated tropical cereal grass. It is generally, although not universally, considered to have first been domesticated in North Africa, possibly in the Nile or Ethiopian regions as recently as 1000BC. Today, sorghum is cultivated across the world in the warmer climatic areas. It is quantitatively the world’s fifth largest most important cereal grain, after wheat, maize, rice and barley. World annual sorghum production is over 60 million tonnes, of which Africa produces about 20 million tonnes [3]. Adebayo & Ibraheem [4] reported that the highest producer of sorghum USA produces 10,400,000 metric tonnes alone while Nigeria produces 6,300,000 metric tonnes making it the highest in Africa and the third highest in the world.

Electrical properties of agricultural products are very important attributes of the products to be noted by Engineers, scientists and farmers in order to understand the behavior of these products around electrical field. These properties include: Electrical potential (Voltage), resistance, resistivity, conductance, conductivity, capacitance, dielectric constant, Permittivity, impedance, capacitance reactant etc. These properties can also be used to predict, determine, measure and preserve the quality of agricultural products and its environments. Other importance of electrical properties to agricultural products includes: drying, ohmic heating, bio-sensing (in instrumentation, processing, harvesting, grading, storage and environmental control), automation and robotization of agricultural operations [5-8].

Electrical potential (Voltage) is measures in Joules/Coulomb, or Volts. It is the energy per unit charge required to transport any electric charge in the electric field from one sport to another. It is a scalar quantity with no direction and said to be a property of the source charges. Knowledge of electrical potentials is used in batteries and capacitors. Electrical potential can also be called electrical potential difference [9]. Electrical potential can also be related theoretically with electrical potential energy, electrical work done and electrical field (see equation 1-4).

\[ \Delta V = V_2 - V_1 \]  
\[ \Delta V = \frac{\Delta U}{q} \]
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$$\Delta V = -\frac{W}{q}$$ \hspace{1cm} (3)

$$\Delta V = \int E \cdot dS$$ \hspace{1cm} (4)

Where $\Delta V$ is electrical potential in volts, $V_2$ is voltage at point 2, $V_1$ is voltage at point 1, $\Delta U$ is electrical potential energy in Joules, $q$ is electric charge in coulomb, $W$ is electrical work done in joules, $E$ is the electric field in Newton/coulomb and $S$ is distance in meters.

Most researches that pass electrical current through agricultural seeds and measure the voltage used it to correlate with the seeds germinating power and plant growth. These researchers include: Nelson & Burr [10], Wheaton [11], Navid Taghizadeh Sedighi et al. [9], Kaya [12] & Porsev et al. [13]. This research wants to look at electrical voltage through sorghum in order to develop moisture content measuring equipment using electrical potential. Although other researchers have developed moisture meters using other electrical properties like resistance, conductance and dielectric properties. It is always cheaper to use direct voltage measurement.

The objective of this research is to study the effect of moisture and current frequency on electrical potential of some sorghum varieties, with and intend of using these information to develop a grain moisture meter. To also generate regression equations relating moisture content to electrical potential.

**Material and Method**

**Sample**

Sorghum (Sorghum bicolor (L.) Moench varieties that were considered in this study are; NGB 01907 (red sorghum), NGB 01589 (White sorghum), NGB 01227 (yellow sorghum). Samples were acquired at the National Center for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Nigeria. The samples were then conditioned as described by Sangamithra et al. [14] to 10, 13, 16, 19 and 22% db.

**Determination of electrical potential**

Grain samples were poured into constructed grain sample holder shown in Figure 1. Sample holder was connected to the complete circuit for the measurement as shown in figure 2. The circuit is made up of a functional generator, Digital Oscilloscope, sample holder and connecting wires. Input and output voltage readings from the oscilloscope were used to calculate the electrical potential using equation 5. Current frequency ranges used in this research were 1, 500, 1000, 1500 and 2000 kHz. All readings were replicated three times.

$$\Delta V = V_{\text{output}} - V_{\text{input}}$$ \hspace{1cm} (5)
Statistical analysis

A univariate analysis of variance (ANOVA) was done on the data collected from the experiment using SPSS software version 21. Means separation was carried out using Turkey HSD test. Regression equations were generated using Microsoft Excel software.

Results and Discussion

Table 1: Mean Results showing the effect of Moisture, current frequency and Variety on electrical potential.

| Varieties     | Moisture | 1 kHz  | 500 kHz | 1000 kHz | 1500 kHz | 2000 kHz | Total   |
|---------------|----------|--------|---------|----------|----------|----------|---------|
|               |          |        |         |          |          |          |         |
| NGB 01589a    | 10%      | -11.437| -13.187 | -12.75   | -12.613  | -10.213  | -12.04  |
|               | Std. Dev.| 2.284  | 0.012   | 0.052    | 0.115    | 0.115    | 1.415   |
|               | 13%      | -10.3  | -11.48  | -11.54   | -11.56   | -11.56   | -11.288 |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.512   |
|               | 16%      | -10    | -11.52  | -11.56   | -11.6    | -11.44   | -11.224 |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.636   |
|               | 19%      | -0.2   | -4.4    | -5.8     | -6.6     | -6.8     | -4.76   |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 2.516   |
|               | 22%      | -14.24 | -14.767 | -3.2     | -12.4    | -9.881   |
|               | Std. Dev.| 0      | 0.058   | 0        | 0        | 0        | 5.064   |
|               | Total    | -9.235 | -11.071 | -8.97    | -9.435   | -10.483  |
|               | Std. Dev.| 1.415  | 0.012   | 0.052    | 0.115    | 0.115    |
|               | 10%      | -10.84 | -11.317 | -11.28   | -12.08   | -11.447  |
|               | Std. Dev.| 0.016  | 0.006   | 0        | 0        | 0        | 0.436   |
|               | 13%      | -3.8   | -9.28   | -9.16    | -9.12    | -9.28    | -8.128  |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 2.241   |
|               | 16%      | -9.7   | -11.2   | -11.6    | -11.76   | -11.56   | -11.164 |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.781   |
|               | 19%      | -9.12  | -10.4   | -10.48   | -10.68   | -10.52   |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.587   |
|               | 22%      | -14.36 | -13.16  | -13.24   | -13.52   | -13.4    | -13.536 |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.446   |
|               | Total    | -9.564 | -11.071 | -11.152  | -11.36   | -11.368  | -10.903 |
|               | Std. Dev.| 1.317  | 1.388   | 1.495    |
|               |          | 1.446  | 2.082   |
|               | 10%      | -11.39 | -11.953 | -12.92   | -12.6    | -12.997  | -12.372 |
|               | Std. Dev.| 0.01   | 0.011   | 0.001    |
|               | 13%      | -10.16 | -10.98  | -11      | -1       | -11      | -10.828 |
|               | Std. Dev.| 0      | 0       | 0        | 0        | 0        | 0.346   |
|               | 16%      | -12    | -11.76  | -11.48   | -11.72   | -11.76   | -11.744 |
|               | Std. Dev.| 0    | 0.139  | 0.346    |
|               | 19%      | -8.36  | -9.88   | -10.24   | -10.48   | -10.36   | -9.864  |
|               | Std. Dev.| 0    | 0       | 0        | 0        | 0        | 0.806   |
|               | 22%      | -11.28 | -13.12  | -13.08   | -13.64   | -13.44   | -12.912 |
|               | Std. Dev.| 0    | 0       | 0        | 0        | 0        | 0.871   |
|               | Total    | -10.638| -11.539 | -11.744  | -11.888  | -11.911  | -11.544 |
|               | Std. Dev.| 1.33  | 1.115   | 1.146    | 1.169    | 1.205    |
|               | 10%      | -11.222| -12.152 | -12.317  | -12.311  | -11.763  | -11.953b|
|               | Std. Dev.| 1.178 | 0.823   | 0.781    | 0.447    |
|               | 13%      | -8.087 | -10.58  | -10.567  | -10.56   | -10.613  | -10.081d|
|               | Std. Dev.| 3.216 | 0.999   | 1.081    | 1.107    |

Overall Total

Std. Dev. 1.33 1.115 1.146 1.169 1.205 1.256
Mean values obtained for electrical potentials after experimentation are shown in table 1. These values are obtained at a current frequency range of 1-2000kHz. All electrical potential values obtained in this study had a negative sign. This shows that sorghum like other agricultural grains offer resistance to electrical currents. Similar observation had been reported by Burubai [15], Kardjilova et al. [16], Shyam et al. [17], Moisés & Marcos [18] and Hlaváčová Z [19].

For NGB 01589 variety electrical potential values obtained ranges from -0.2 to -14.767 volts. The electrical potential trend in this variety show, that it had low values at higher moisture content and high values at lower moisture content across all current frequencies. This occurrence may be due to the fact that water molecules form ions when electric current pass through it therefore carrying electric current faster between sorghum grain surfaces. The faster the electric current moves through the grains, the lower the electrical potentials. Also Physical examination of data from this variety show, that increasing current frequency within the frequency range of study does not increase or reduce the electrical potential. The trend has a sinusoidal behaviour. It shows that increasing the current frequency from 1 - 500kHz, produces almost the same electrical potential as increasing it from 1000-2000kHz. This Phenomenon could be because of the cellular structural arrangement or the present of colour pigment found in this variety. Low potential values are found within 13% moisture content. Below or above this moisture level the electrical potential value increases. This could be due to the fact that, this is the point where tightly held water molecule in the grains cells can be allowed to flow. Increase in current frequency increase the electrical potential of this variety. This occur because increase in current frequency the increases the excitements of water molecules causing to collusion among molecules therefore hinder current flow and reduce electrical potentials. For this variety any current frequency used produced similar behavioral trend on moisture.

Electrical potential values obtained in this study for NGB 01227 variety ranges from -8.36 to –13.64 volts. Data trend shows that increase in moisture show a wave like fluctuations along their paths. This behaviour could be because of the present of pigment found in this variety. Low potential values are found within 19% moisture content. This occurs due to the same reason as that of NGB 01907 too.

Electrical potential values obtained using electrical potential values for this variety [20-22].

Table 2: Analysis of variance (ANOVA) for electrical potential of sorghum.

| Source                        | Type III Sum of Squares | Df  | Mean Square | F     | Sig.     |
|-------------------------------|-------------------------|-----|-------------|-------|----------|
| Corrected Model               | 1542.845a               | 74  | 20.849      | 290.159 | 1.835 x 10-133* |
| Intercept                     | 26059.214               | 1   | 26059.214   | 36266.344 | 1.106 x 10-255* |
| Variety                       | 111291.04               | 2   | 55.645      | 774.418 | 8.821 x10-80*  |
| Moisture                      | 458990.04               | 4   | 114.726     | 1596.643 | 8.442 x10-122* |
| Current frequency             | 62857.04                | 4   | 15.714      | 218.696 | 1.669 x10-61*  |
| Variety vs. Moisture          | 381546.04               | 8   | 47.693      | 663.747 | 5.794 x10-113* |
| Variety vs. Current frequency | 36693.04                | 8   | 45.877      | 63.831  | 1.818 x10-44*  |
| Moisture vs. Current frequency| 176826.04               | 16  | 11.052      | 153.806 | 2.239 x10-84*  |
| Variety vs. Moisture vs. Current frequency | 314728.04 | 32  | 9.835       | 136.877 | 2.776 x10-95*  |

Different alphabets along row or column are statistically different from each other according to Tukey HSD (Ps0.05, Harmonic Mean Sample Size = 45.000, Mean Square (Error) = 0.072).
Analysis of variance done for data of electrical potential displayed in table 2 shows that the choice of analysis (corrected model) is significant at p≤0.05. This analysis also shows that all factors considered in this study and all its interactions were all significant at p≤0.05. Tukey HSD mean separation done shows that all levels of the three factors considered (Moisture, current frequency and variety) were statistical different from each others. This is an important factor to be considered when developing instrument that will be used to measure moisture level of sorghum grains use electrical potential values.

Regression analyses done for the three varieties are shown in Figure 3. The regression equations developed are:

For NGB 01589:
\[
M = -82.866 - 36.329(\Delta V) - 3.6326(\Delta V)^2 - 0.1043(\Delta V)^3 \quad [R^2 = 0.9616]
\]

For NGB 01907:
\[
M = -1348.6 - 393.93(\Delta V) - 37.226(\Delta V)^2 - 1.1527(\Delta V)^3 \quad [R^2 = 0.8885]
\]

For NGB 01227:
\[
M = -1910.4 - 547.9(\Delta V) - 51.477(\Delta V)^2 - 1.5975(\Delta V)^3 \quad [R^2 = 0.572]
\]

Figure 3: Graph of regression of moisture content on electrical potential.
An interaction graph between all factors and their interaction with the values of electrical potential are displayed in figure 4. It shows that for NGB 01589 variety interactions occur between almost all moisture levels except 19% which has interaction only between 22%. For NGB 01907 variety interaction took place only between 16 and 10%. Interactions in NGB 01227 variety take place only between 10, 16 and 22%.

**Conclusion**

The following conclusion were drawn from this study

a. Moisture, current frequency and variety with their interactions has significant effect at p≤0.05 on electrical potential of sorghum grains

b. Behavioral trend between moisture and electrical potential are more visible at current frequency range of 1000 to 1500 kHz in all varieties

c. Regressions equations developed shows that electrical potential values can be used to predict moisture of sorghum grains.

d. Moisture determination meter can be developed using electrical potential properties.

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