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ORIGINAL ARTICLE

Studies on electrical properties of wheat as a function of moisture content

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Keywords
electrical properties variation; moisture content (MC); moisture prediction model; partial least squares; principal component analysis (PCA); statistical analysis.

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Abstract

Introduction Moisture content of cereal grains is one of the most important characteristics for determining quality of grains. *Objectives* The electrical properties of Indian wheat with moisture content range of 14.3% to 29.38% were characterized to develop a moisture prediction model. *Methods* A specially designed coaxial cylindrical cell was used for the purpose and electrical properties characterization system was used to carry out measurements of these properties. The studies were conducted for frequency range of 100 kHz–10 MHz and a fixed frequency was selected based on best correlation basis. Principal Component Analysis (PCA) was used to study the moisture dependence of various electrical properties such as Capacitance (C), Conductance (G), Impedance (Z), Theta (θ) and Dissipation Factor (D) of Indian wheat. The various statistical studies were conducted using The Unscrambler Version X, a multivariate Statistical Analysis Software. *Results* It was observed that Conductance (G) and capacitance (C) show the maximum variation with moisture. Partial Least Square (PLS) Regression was then used to develop the moisture prediction model based on these two electrical properties. *Conclusion* The developed model is highly accurate with high correlation of 0.973.

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Introduction

Moisture content (MC) of cereal grains is one of the most important characteristics for determining the quality of grains. Measurement of moisture is an important aspect in harvesting, drying, storing and processing of agricultural products. Some of these products, when freshly harvested, may have a MC in the range of 20–40%. For trading, processing or storage, these moisture levels have to be decreased to a recommended level, that is up to 13%, 13.5% and 10.5% for shelled corn, soft red winter wheat and peanuts, respectively (Lower *et al.*, 1994). Interest in electrical properties of grains for moisture determination dates back more than 100 years; Briggs (1908) studied the direct current electrical resistance of grain for the purpose of rapidly determining its MC. Later on, studies on alternating current measurements were reported based on the changes in the capacitance of sample-holding capacitors, when wheat samples were introduced between the capacitor plates. This was correlated with grain MC and used for grain moisture measurement (Burton & Pitt, 1929). Dielectric properties of cereal grains are highly correlated with MC (Nelson, 1981, 1991). Therefore, the development of electrical grain moisture meter based on electrical properties has been reviewed by a number of authors (Hart & Golumbic, 1963; Nelson, 1973, 1977; Ban & Suzuki, 1977). The performance evaluation of digital grain moisture meter for Indian wheat using capacitance variation has also

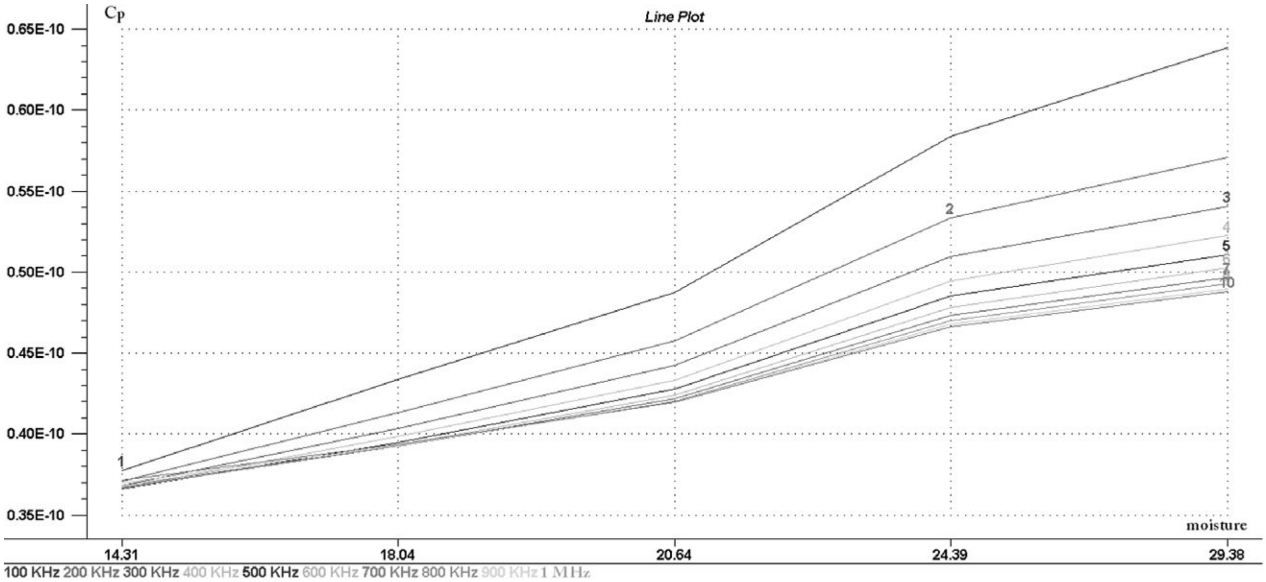

Figure 1 Moisture dependence of the capacitance of wheat grains at 100–1000 kHz frequency.

been reported recently (Babankumar & Ritula, 2011). Electrical impedance spectroscopy technique is a relatively powerful method of characterizing electrical properties of solid, liquid and combined solid–liquid materials (Li, 2003). It has been effectively used for moisture estimation in paper pulp (Sundara-Rajan *et al.*, 2004) and to measure moisture dynamics in cookies (Li, 2003). Bhatt & Nagaraju (2010) investigated the effect of MC and its migration on the electrical properties, mainly impedance, capacitance and resistance of wheat bread crust and crumb during storage for 120 h. Mizukami *et al.* (2006) developed a new method for the moisture measurement of tea leaves by using measurements obtained by electrical spectroscopy. The present paper reports the development of a moisture prediction model for *Triticum aestivum*, a cultivar of Indian wheat grain, based on the characterization of various electrical properties such as capacitance (C), conductance (G), impedance (Z), theta (θ) and dissipation factor (D) with MC range of 14.3–29.38%.

Materials and methods

Grain sample preparation

An appropriate number of samples for Indian short wheat grain were prepared artificially to conduct studies at 100 kHz–10 mHz frequency band at room temperature. In preparing conditioned samples, a fixed quantity (150 g) of grain was taken and weighed. The broken kernels and foreign materials were removed. Distilled water was added to the sample to raise its MC to predetermined calculated levels (14.3–29.38% w.b.). The sample was stirred during the addition of water and the conditioned samples were stored in the sealed jars at 2–4 °C in cold storage for at least 4–5 days, before its electrical properties were measured. During this conditioning period, the sealed jars were shaken periodically to aid the uniform distribution of moisture. The MC of each sample was determined by standard dry oven technique by grinding 5–10 g each samples and drying them for 2 h at 130 °C. Two hot-air dry ovens were used during the experimentation period to increase experimental throughput and avoid time lag. Refrigerated samples in sealed jars were permitted to reach room temperature (22 °C) before opening them for electrical measurements. Altogether, 19 samples covering the range of 14.3–29.38% (w.b.) moisture values were prepared for the room temperature studies.

Experimental setup

For the measurement of electrical properties, 100 g of each sample was used at room temperature. Various electrical properties such as C, G, Z, θ and D were measured using Keithley 4200 SCS model (Keithley Instruments, Inc., Cleveland, OH, USA). A specially designed concentric cylinder dielectric cell was used for the purpose. The outer cylinder is 58 mm long, with an internal diameter of 90 mm and has a wall with a thickness of 2 mm. The inner cylinder has outer

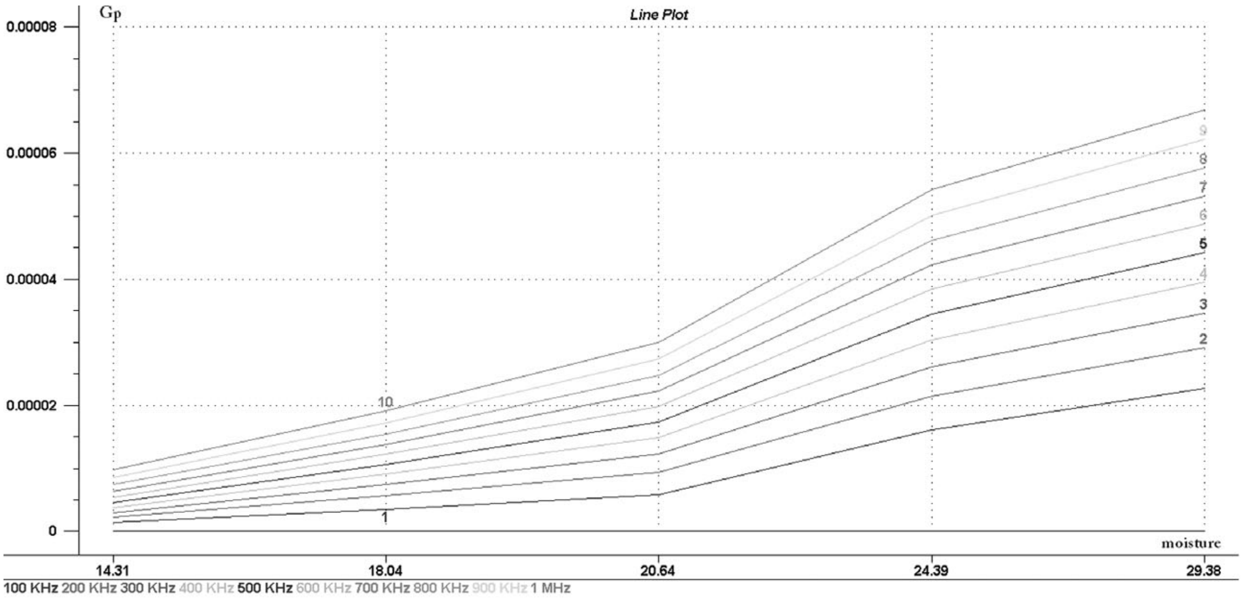

Figure 2 Moisture dependence of the conductance of wheat grains at 100–1000 kHz frequency.

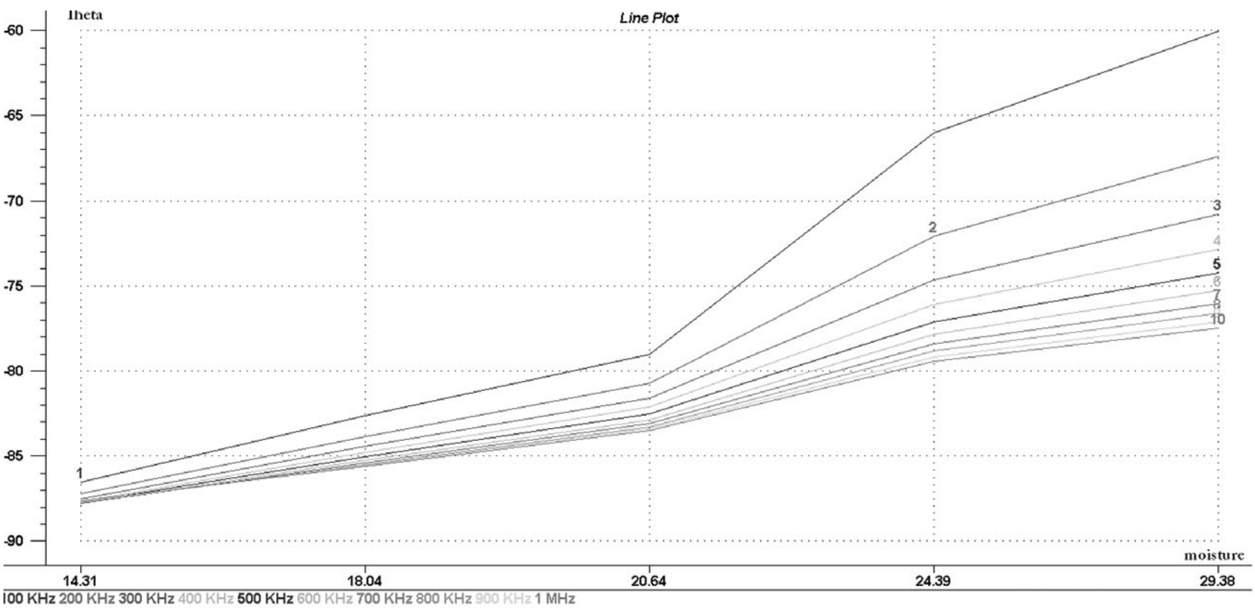

Figure 3 Moisture dependence of the Theta of wheat grains at 100–1000 kHz frequency.

diameter of 45 mm. These cylinders are joined on the single plate of Teflon. In order to improve the quality of the sensing cell, the cylinders are given an anodized and non-conducting material surface coating treatment on the walls to avoid capacitor leakage charging current. It forms a concentric cylindrical type dielectric cell, joined with shielded coaxial cable of low capacitance. These two leads from cylinder are connected to the two ports of Keithley characterization system. The measurement data were automatically transmitted from this system to a personal computer (PC) through an interface that connects the PC and the instrument serially. The calibration compensation was performed for the cylinder test leads before starting electrical measurements in order to avoid errors against terminal connections and residuals.

The studies were conducted for frequency range of 100 kHz–10 mHz and a fixed frequency was selected based

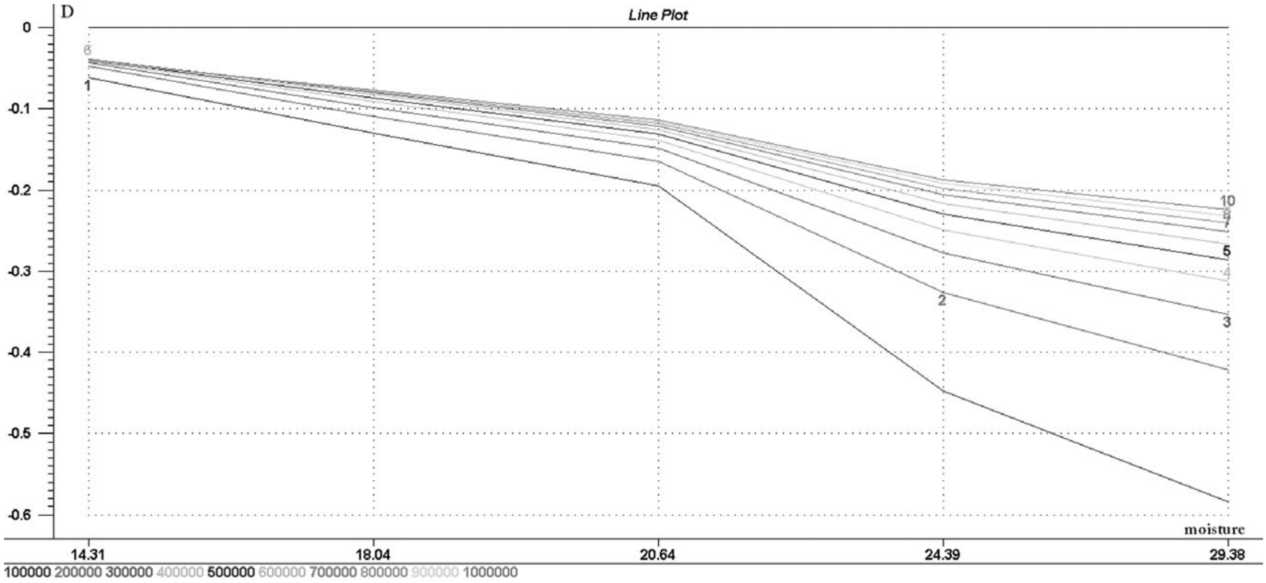

Figure 4 Moisture dependence of the impedance of wheat grains at 100–1000 kHz.

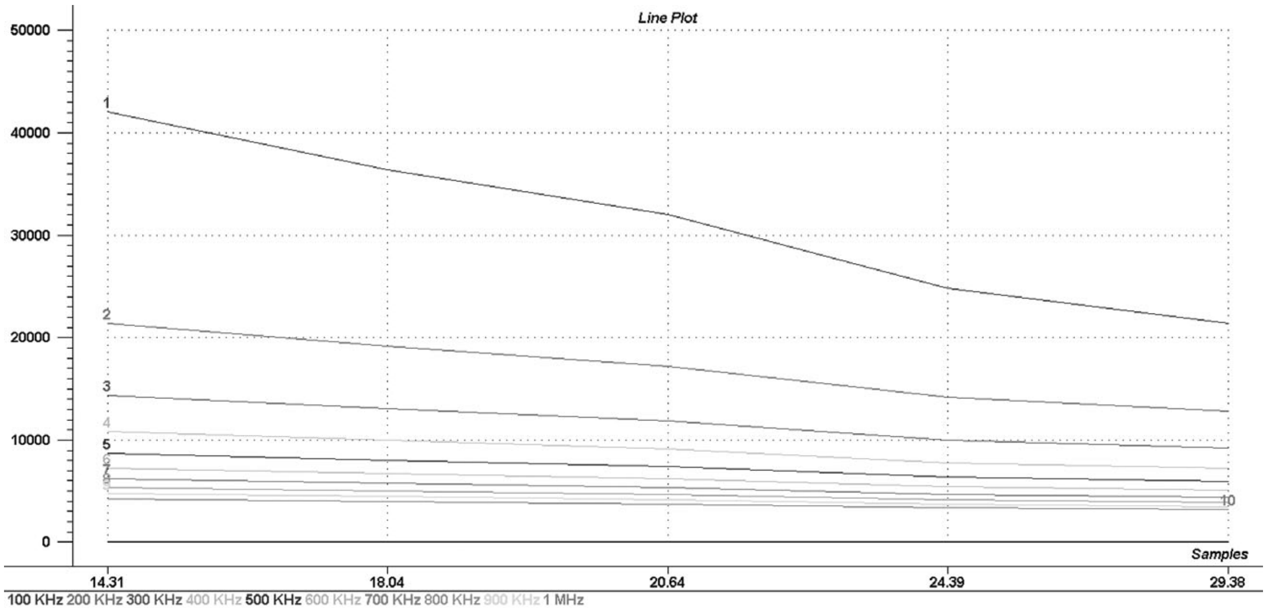

Figure 5 Moisture dependence of the dissipation of wheat grains at 100–1000 kHz.

on best correlation basis. Statistical analysis techniques such as principal component analysis (PCA) and partial least square (PLS) regression were applied using The Unscrambler Version X (CAMO Software AS., Oslo, Norway), a multivariate Statistical Analysis Software. PCA is a statistical technique used to identify patterns in data and then expressing the data in such a way as to highlight their similarities and differences. In the present work, it was used to show the dependency of electrical properties of wheat samples with moisture in a multivariate environment, and the plots generated were used to interpret differences and similarities among samples. G and C show the maximum variation with moisture and moisture prediction model was developed based on these electrical properties using PLS. It is a method for constructing predictive models when the factors are highly collinear. The accuracy of the developed moisture prediction model was studied using the plots generated by PLS.

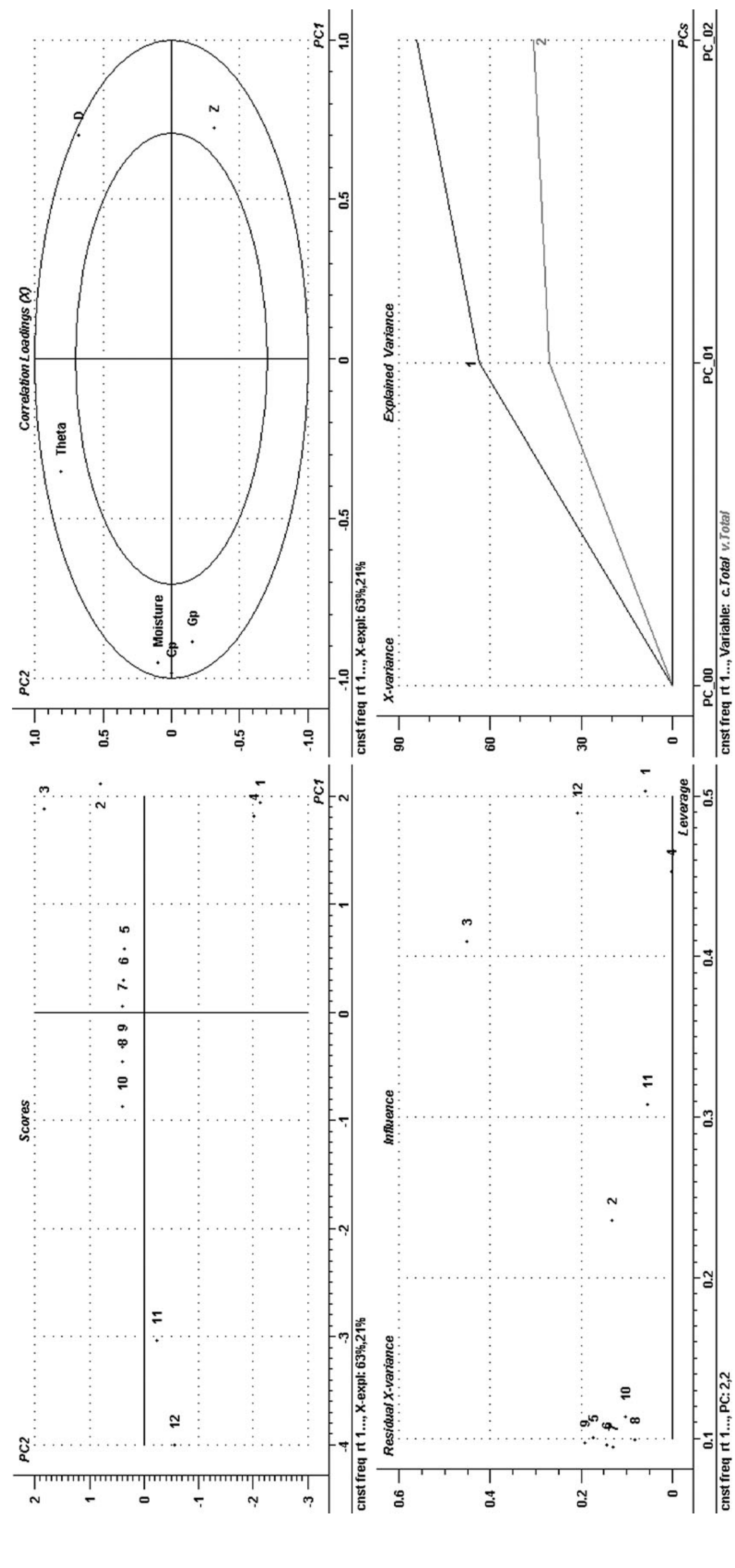

Figure 6 Principal component analysis of wheat grains samples at 100 kHz.

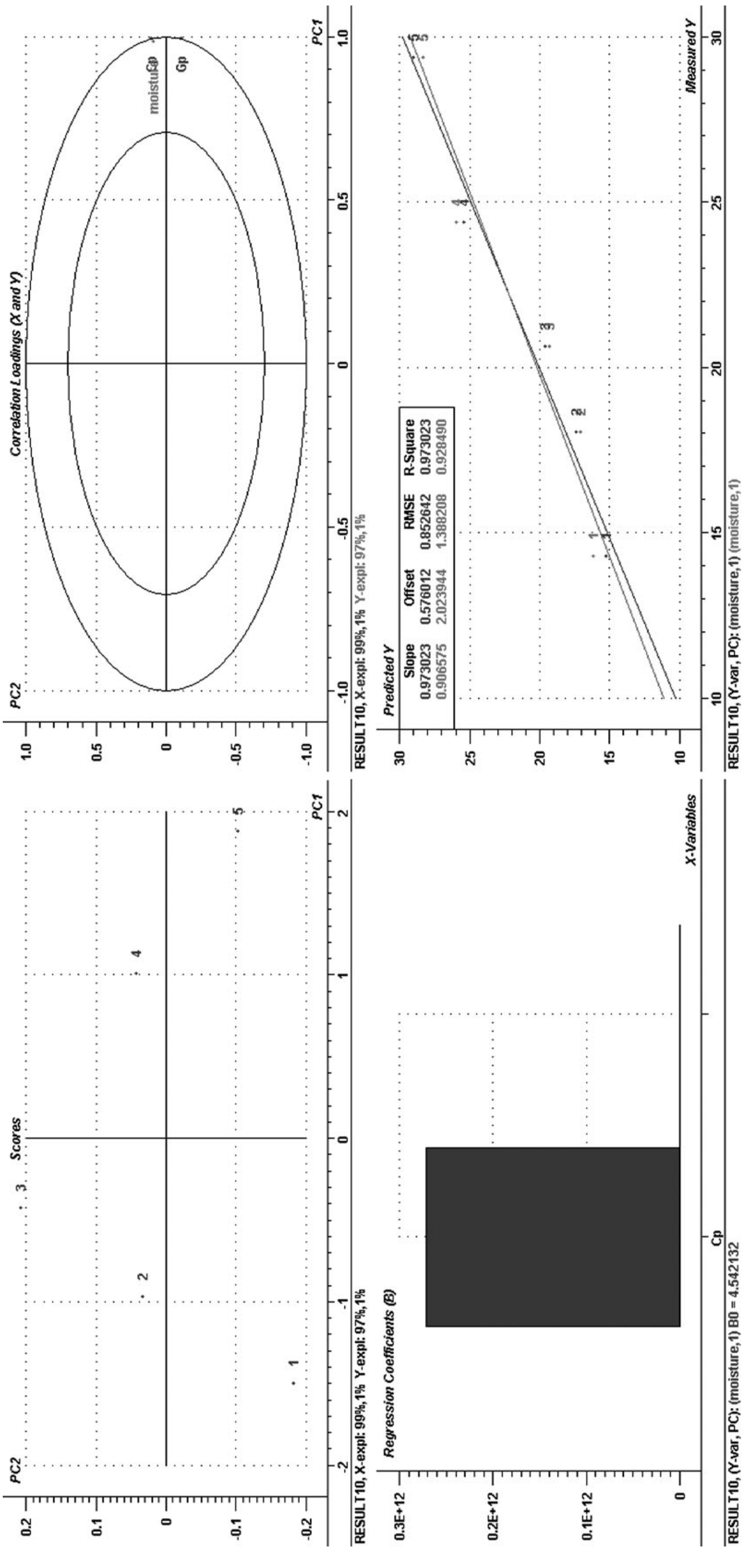

Figure 7 Partial least square regression analysis of grain samples at 100 kHz.

Results and discussion

Moisture dependence of electrical properties at various frequencies

Moisture dependence of various electrical properties such as C, G, Z, θ and D of Indian wheat was studied in the frequency range of 100 kHz–1 mHz and MC ranging from 14.3% to 29.38% as shown in Figures 1–5.

On the best correlation basis, it was found that all electrical properties have best correlation at 100 kHz frequency, So further studies were done at this frequency.

Moisture dependence of electrical properties at 100 kHz using PCA

PCA was used to show the dependency of electrical properties of wheat samples at a frequency of 100 khz (Figure 6).

These plots can be used to interpret differences and similarities among samples. As can be observed from correlations loading plot that G and C are very close to moisture and, hence show maximum variation with change in MC. These two values are further used to develop moisture prediction model using PLS regression. All statistical techniques were carried out using The Unscrambler version X statistical analysis software.

Moisture predicting model of wheat grains by using PLS regression analysis

After analysing data with PCA, it was found that G and C show largest variation with moisture. PLS regression technique was used to build moisture prediction model using these electrical properties (Figure 7).

The following is the moisture predicting equation:

$$M = 4.552e+11*Cp+1.569e+5*Gp+4.542132$$

A high correlation of 0.973 was achieved by comparing this prediction model with values obtained by dry oven technique. This shows that the developed prediction model is highly accurate.

Conclusion

The present paper deals with the development of moisture prediction model for Indian wheat using characterization of electrical properties with MC range of 14.3–29.38%. A Keithley 4200 SCS model (Keithley Instruments, Inc.) was used to carry out measurements of these properties: viz. C, G, Z, θ and D. The studies were conducted for a frequency range of 100 kHz–10 mHz and a fixed frequency was selected based on best correlation basis. PCA was used to study the moisture dependence of various electrical properties of Indian wheat. It was observed that G and C show the maximum variation with moisture. PLS regression was then used to develop the moisture prediction model based on these two electrical properties. The developed model is highly accurate with high correlation of 0.973.

References

Babankumar S.B., Ritula T. (2011) Performance evaluation of digital grain moisture meter analyzer for Indian wheat. *Journal of Scientific and Industrial Research*, **70**, 41–44.

Ban T., Suzuki M. (1977) Studies on electrical detection of grain moisture content in artificial drying, (Japanese). Techn. Rpt. No. 11. Institute of Agricultural Machinery, Omiya, Japan.

Bhatt C.M., Nagaraju J. (2010) Studies on electrical properties of wheat bread as a function of moisture content during storage. *Sensing and Instrumentation for Food Quality and Safety*, **4**, 61–66 DOI 10.1007/s11694-010-9095-z.

Briggs L.J. (1908) An electrical resistance method for the rapid determination of the moisture content of grain. Bureau of Plant Industry, Circular No. 20, U. S. Dept. Agriculture.

Burton E.F., Pitt A. (1929) A new method for the rapid estimation of moisture in wheat. *Canadian Journal of Research*, **1**, 155–162.

Hart J.R., Golumbic C. (1963) Methods of moisture determination in seeds. *Proceedings of International Seed Testing Association*, **28** (4), 911–933.

Li X. (2003) Impedance spectroscopy for manufacturing control of material physical properties. Masters Thesis, Department of Electrical Engineering, University of Washington.

Lower O.J., Bridges T.C., Bucklin R.A. (1994) *On-Farm Drying and Storage Systems*. American Society of Agricultural Engineers, St. Joseph, MI.

Mizukami Y., Sawai Y., Yamaguchi Y. (2006) Moisture content measurement of tea leaves by electrical impedance and capacitance. *Biosystems Engineering*, **93** (3), 293–299.

Nelson S.O. (1973) Electrical properties of agricultural products a critical review. *Transactions of ASAE*, **16** (2), 384–400.

Nelson S.O. (1977) Use of electrical properties for grain–moisture measurement. *Journal of Microwave Power*, **12** (1), 67–72.

Nelson S.O. (1981) Review of factors influencing the dielectric properties of cereal grains. *Cereal Chemistry*, **58** (6), 487–432.

Nelson S.O. (1991) Dielectric properties of agricultural products – measurements and applications. *IEEE Transactions on Electrical Insulation*, **26** (5), 845–869.

Sundara-Rajan K., Byre L., Mamishev A.V. (2004) Moisture content estimation in paper pulp using fringing filed impedance spectroscopy. *IEEE Sensors Journal*, **4** (3), 378–383.

