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Prediction of Robusta green bean coffee moisture content based on bioelectric properties with artificial neural network method

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KEYWORDS

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Bioelectric
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ABSTRACT

An artificial neural network (ANN) is presented for predicting the moisture content of Robusta green-bean coffee. Moisture content is measured based on bioelectric properties using a capacitance sensor, where coffee beans are considered capacitors. This research aimed to develop predictive models of the moisture content of Robusta green bean coffee using bioelectrical properties with the ANN method. Moisture content was affected by the bioelectrical properties, and the bioelectric model of green bean coffee moisture content became a resistor-inductance-capacitor (R-L-C) series. Moisture content is observed for 37.5 hours, with data collection time intervals every 2.5 hours. This research obtains 4800 data with eight samples at a frequency of 100 Hz, 1 kHz, and 10 kHz. The best ANN structure to predict moisture content based on the bioelectrical properties is 9-30-30-1. The selected ANN topology results in an R training correlation coefficient of 0.99123, an R validation correlation coefficient of 0.90343, a training MSE of 0.0099, and a validation MSE of 0.1047. ANN models based on the bioelectrical properties have been proposed to develop an accurate, simple, and reliable technique as a sensor for the detection of the moisture content of green bean coffee during the drying process.

Introduction

Robusta coffee is the type of coffee that is most in demand by the people of Indonesia, so it is widely cultivated in Indonesia. Drinks extracted from Robusta coffee beans have a strong taste and tend to be more bitter than Arabica (Farhaty and Muchtaridi, 2016; Chrismirina et al., 2016). Robusta coffee is easy to grow on marginal land, resistant to leaf rust disease and has higher productivity (about 74%) than Arabica and Liberica (Rosiana et al., 2018). Robusta coffee can grow better in areas with an altitude of 0-1000 mdpl, where the place is not suitable for Arabica coffee which requires an altitude of more than 1000 mdpl to avoid the pest attack *Hemileia vastatrix* (HV). This characteristic causes Robusta coffee to be more widely cultivated in Indonesia, where the area is dominated by lowlands (Rahardjo, 2012).

Most coffee products are exported to foreign countries, and the rest are marketed domestically. Around 67% of Indonesian coffee products are exported, with 90% of them being traded as green beans. However, the volume and value of these coffee exports still fluctuated from 2011 to 2019. This condition indicates that the competitiveness of Indonesian Robusta coffee in the world still needs to be improved. The grade of Indonesian coffee is still low for export quality compared to other major coffee-producing countries. Less progress in Indonesian coffee export may be caused by several factors, such as the productivity and quality of coffee. The amount of coffee exported will determine the competitiveness of Indonesian coffee in the international market. Increasing Indonesian coffee competitiveness in the international market requires steps to improve performance and a supportive export policy for coffee (Rosiana et al., 2018).

The quality of coffee can be maintained with a good drying process (Olguin, et al., 2017). Coffee beans produced from an improper drying will usually affect the taste and quality of the coffee beans. The drying process reduces the humidity content of the bean and impedes the microbial action that is responsible for spoilage during storage. Mould may multiply on the coffee beans

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due to the high humidity if it is not dry enough. The toxic mould growth on coffee beans can carry health risks if ingested. Substances such as aflatoxins and mycotoxins are common in under-dried coffee. These substances are known to be carcinogenic and have the potential to cause damage to internal organs, especially the kidneys and liver. Therefore, an important part of coffee processing is ensuring no mould growth. The drying process is to reduce the moisture content from 60-65% to 12% so that it is safe to be stored or packaged in sacks in tropical environmental conditions (Prastowo et al., 2010). The moisture content of coffee beans should be below 13%, and grain coffee should be below 12% during storage (Raharjo, 2017). Excessive drying can cause permanent damage to the coffee beans, such as decreased quality in terms of aroma and acidity, and reduced taste. In addition, coffee beans can become too brittle and break easily when ground. Excessive drying can also reduce the freshness and colour of the coffee beans, affecting the quality of the roasted beans and the selling price. This is why a gentle and slow drying process is required, while continuously monitoring the condition of the coffee beans. The moisture content in coffee beans must be continuously monitored.

Measurement of moisture content is important to do on coffee beans before the storage and packaging process. When the moisture content is outside the optimal range, these compounds are susceptible to release and decrease, especially if there is damage to the coffee beans during the drying process. It means that the quality of green coffee beans can decrease even when they are in storage. The gravimetric method is commonly used for measuring moisture content, but the weakness of the gravimetric method is a destructive method and takes a long time, and the data needs to be more accurate (Widyaningtyas, et al., 2018).

Another method to measure the water content of coffee beans is to pay attention to the bioelectrical properties of agricultural products. Bioelectrical properties of agricultural products have been proven as a reliable, simple, and non-destructive sensing technique (Nelson, 2015, Nelson et al., 2012). The method is based on the electrical properties of the material and describes the electric field or material interaction (Nelson, 2015; Sucipto et al., 2013). Naderi-Boldaji et al. (2015) revealed that the bioelectrical properties could be used as a parameter for the non-destructive measurement of sugar concentration in sugarcane. Sucipto et al. (2018) researched bioelectrical measurement using ANN for sugar recovery of sugarcane prediction. Meanwhile, this research uses the bioelectrical properties measurement at frequencies of 100 H, 1 kHz, and 10 kHz, to measure the moisture content of Robusta green bean coffee. Frequency is affected by the bioelectric properties of a material, because of the polarization from the dielectric of green beans and coffee due to an electric field. There has yet to be a robust model to predict the moisture content of green bean coffee. So, ANN method is used to build a robust predictive model. ANN modeling has been proven as a reliable predictive formulation in a variety of studies, such as the predicting water content of Sunagoke moss (Hendrawan and Murase, 2011), water status of plants (Hendrawan and Al Riza, 2016), and the detection of palm civet coffee adulteration (Widyaningtyas et al., 2018).

This research aimed to develop predictive models of the moisture content of Robusta green bean coffee using bioelectrical properties with the ANN method. The ANN model is expected to be able to predict the decrease in moisture content of Robusta green bean coffee during the drying process reliably and non-destructively so that it can support the development of rapid measurements.

Research Methods

Sample preparation

Robusta green bean coffee was taken from coffee plantations belonging to the Abadi Wonosantri Association, Bodean Krajan Hamlet RT 6 RW 1 Toyomarto Village, Kec. Singosari Malang Regency, East Java, Indonesia. Samples were prepared in 8 samples with 100 g of weight. The coffee sample was tested for water content with bioelectric properties and moisture content measurements.

Instrumentation setup and measurement of bioelectric properties

Each sample was put into a copper-based chamber. Then the chamber was connected to the LCR Meter APPA 703 to measure the bioelectrical properties of the sample (resistance, capacitance, and inductance) with frequencies of 100 Hz, 1 kHz, and 10 kHz. Combination of sample and air as the dielectric forming the capacitor. The conductive plate was made of copper material because of its consistency which is not easily ionized in measurements using capacitive properties. The instrumentation setup of bioelectric measurement for Robusta green bean coffee is shown in Figure 1. The measurement of bioelectrical properties, such as inductance (L), resistance (R), and capacitance (C), repeated eight times for each frequency. Moisture content was observed for 37.5 hours with data collection time intervals every 2.5 hours. This research obtained 4800 data with eight samples at a frequency of 100 Hz, 1 kHz, and 10 kHz. The primary point in measuring bioelectrical properties was the capacitance of the sample.

Laboratory Measurement of Moisture Content

The moisture content of green bean coffee used the gravimetric method, based on the Association of Official Analytical Chemists (AOAC). Calculation of moisture content using the following equation:

$$Mw(\%) = \frac{Ww}{Wt} x100 \text{...} (1)$$

where:

M_w = wet basis moisture content (%)

W_w = weight of water (g)

W_t = total weight of material (g)

ANN Modeling

ANN has been successful in predicting the level of some event outcomes (Basheer and Hajmeer, 2000). The ANN structure consists of 3 layers, namely input, hidden layer, and output. ANN topology optimization used Matlab R2014 software. The results of the acquisition of bioelectric data were 4800 data for each input parameter (L, C, R) and output moisture content. The data was divided using a percentage of 70% training with 3360 data and 30% with 1440 data. The best ANN topology design is through sensitivity analysis with variations in learning functions; activation function; learning rate and momentum (0.1, 0.5, 0.9); hidden layers (1, 2); hidden layer nodes (10, 20, 30, 40) with the lowest validation Mean Square Error (MSE) parameter. This study used 3 activation functions, namely linear function (purelin), sigmoid tan function (tansig), and sigmoid function (logsig).

Results and Discussion

Moisture content of Robusta green bean coffee during the drying process

The optimal moisture content of Robusta green bean coffee for the storage process ranges from 8-12%. Robusta green bean coffee has an initial moisture content of 53.1%. The drying process helps to reduce the moisture content of the material. The drying process is 37.5 hours with a drying temperature of 55 ^{o}C. Drying at temperatures below 45 °C, microbes and fungi are still alive, causing low product quality (Maheswari, et al., 2000). However, at drying air temperature above 75 °C, the chemical and physical structures are damaged because high temperatures and rapid air masses impact cell structure changes. (Akowuah, et al., 2018; Watkins, et al., 2001). The higher the temperature used for drying, the higher the energy supplied and the faster the drying rate. However, drying too fast can damage the material; the surface of the material dries too quickly, so it is not proportional to the speed of movement of water from the material to the surface. This causes surface hardening of the material. Furthermore, the water in the material can no longer evaporate because it is blocked. The use of temperatures that are too high can damage the physical of beans. At 30 hours of drying, the moisture content of coffee beans is about 11.01%, while at 37.5 hours, the moisture content reaches 7.63%. A moisture content of 12% with a tolerance of 1% is a limit that can ensure safety during storage. Beans with moisture content lower than 9% (too dry) will cause damage to taste and colour (Novita 2010).

Figure 1 Schematic illustration of bioelectric measurement of Robusta green bean coffee

Bioelectric characteristic of drying temperature and pH of the growing media

This study analyzes the relationship between bioelectric data and the frequency of the drying process of green bean coffee. The drying process is related to the decrease in the moisture content of the material due to the evaporation of water in the material. This process involves fluid flow with the liquid having to be transferred through the structure of the material during the drying process. Heat must be provided to evaporate the water and the water must diffuse through various resistances to escape from the material and form free water vapor. The time of the drying process depends on the material being dried and the heating method used. Several factors that affect the bioelectrical properties of materials are composition, density, temperature, impedance, and frequency. Bioelectric measurements in this research are related to inductance (L), capacitance (C), and resistance (R) data. The composition of the material affects the bioelectric properties because most of the content of agricultural and food ingredients is water content. This study uses three frequency treatments, namely 100 Hz, 1 kHz, and 10 kHz.

The analysis of this relationship is presented in the form of a graph where the x-axis is the frequency and the y-axis is the bioelectric data. Water is a current absorber due to the frequency when coffee is placed between parallel plate capacitors. The high water content in the material causes the electric current to be easily absorbed and its electrical properties measured. This is because water is polar (Vankantesh, 2004). Polar molecules can absorb electric current because they have a permanent dipole moment. The effect of temperature on the bioelectric properties of a material is due to the water and salt content and frequency in the material. Frequency affects the bioelectrical properties of a material because of the polarization arising from the orientation of the dielectric material due to the presence of an electric field (Nelson, 2012). When the frequency of the external voltage source is changed, the dielectric material inserted between the two plates will be disturbed resulting in a change in the direction of the electric dipole moment according to its frequency (Juansah, 2013). Analysis of frequency and bioelectric data are used to determine the effect of decreasing water content due to the drying process on bioelectric data.

Figure 2 shows the increased resistance in coffee beans during the drying process. The resistance value is influenced by the value of the water content in the material. Water is a conductor, so the lower the water content, the higher the resistance. The impedance value also affects the resistance value, where the impedance value is directly proportional to the resistance. This is in accordance with research conducted by Widyaningtyas et al. (2018), 100% water content of civet coffee has a lower resistance value than 0% civet coffee. According to Kertesz et al. (2015) impedance changes are influenced by the water content in the material. Moisture content is a parameter that is very influential on the bioelectric properties. The higher the impedance, the lower the conductivity of the material, and the lower the moisture content of the coffee bean. This is because water is a conductor. Fahrurozi's research (2011), in beef storage at a temperature of 28^{o}C for six days, found that the water content of the material decreased, which was accompanied by an increase in the resistance value. According to Tipler (2001), the resistance of a material is influenced by length, cross-sectional area, type of material, and temperature.

Figure 3 shows that the inductance value increases with the length of the drying process. The inductance value is related to the inductive reactance, where $X_L = 2\pi f L$, indicating that the reactance is directly proportional to the inductance. The inductive reactance value is the resistance value caused by the induced electromotive force of an inductor. The reactance value is directly proportional to the impedance value. When the moisture content of green beans decreases due to the drying process, the impedance and inductance increase. The higher the frequency value, the faster the inductance stability value is achieved. At a frequency of 100 Hz, the inductance value is stable at a drying time of 32.5 hours. At a frequency of 1000 Hz, the stability of the inductance value occurs at a drying time of 30 hours. While at a frequency of 10000 Hz, the stability of the inductance value is achieved at a drying time of 22.5 hours.

In coffee beans, the density and water content affect the dielectric properties. Coffee beans are a dielectric material that has low water content. In general, the higher the moisture content in the food, the higher the dielectric constant (Komarov et al., 2005). The internal properties of the material are influenced by the structure of the material itself. The interaction between microwaves and materials depends on their dielectric properties, which determine the degree of heating of the material when subjected to an electric field (Juansah et al., 2012).

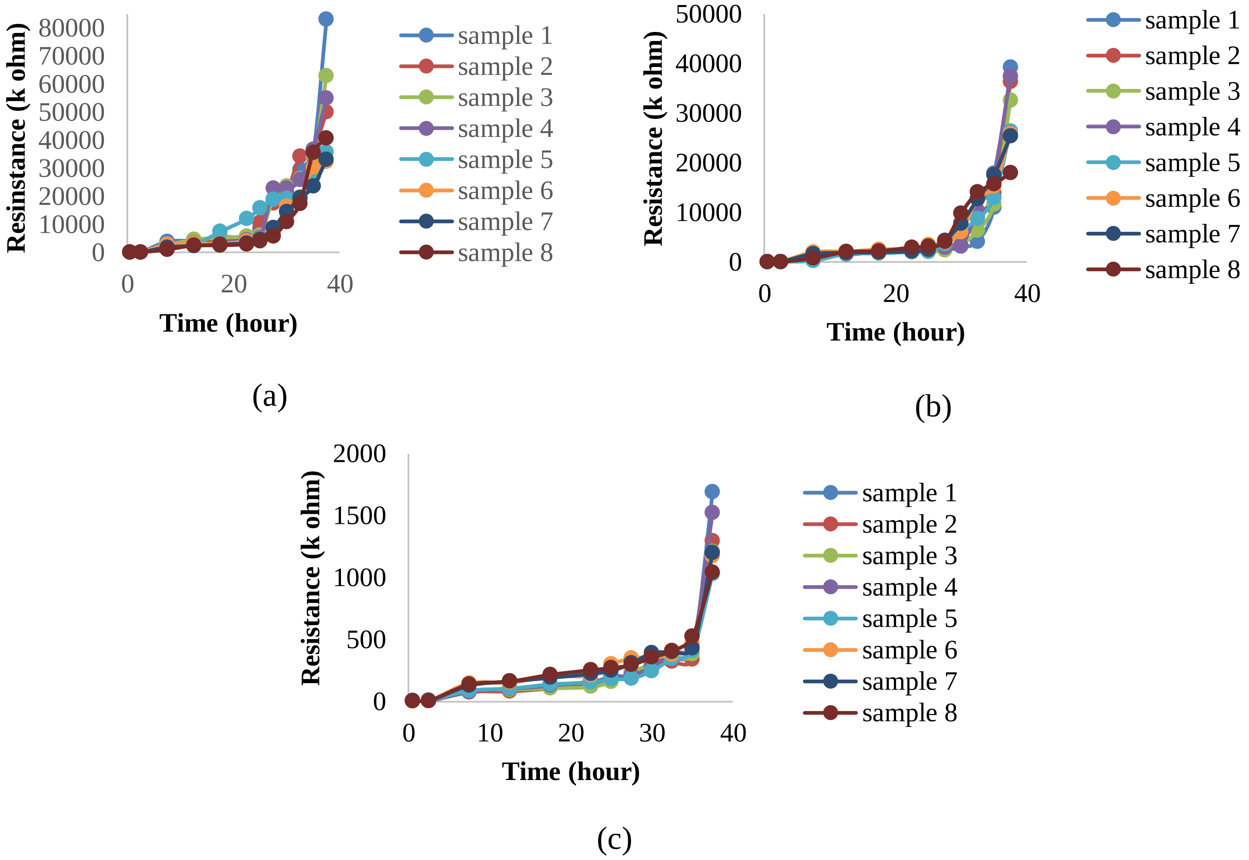


Figure 2 Material resistance during drying time with frequency variations; a) 100 Hz, b) 1 kHz, c) 10 kHz

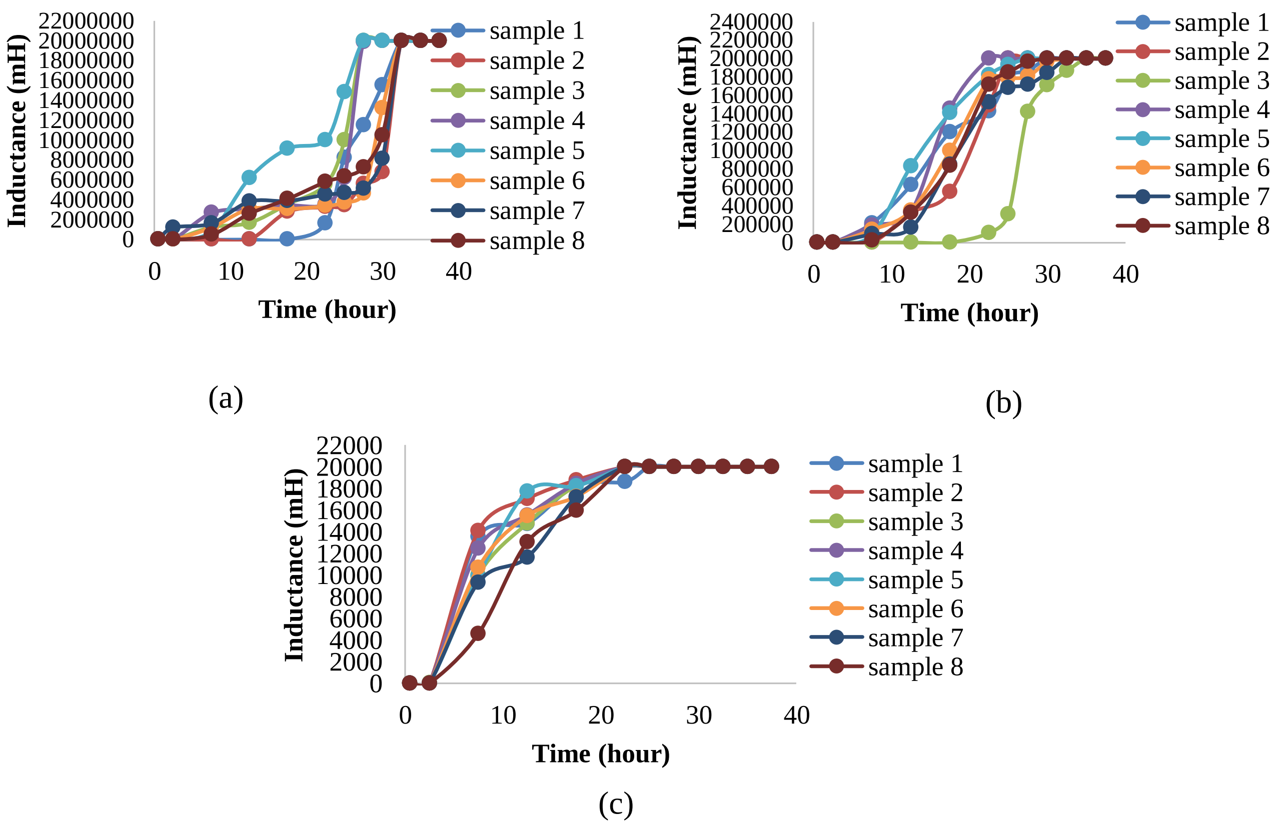


Figure 3 Material inductance during drying time with frequency variations; a) 100 Hz, b) 1 kHz, c) 10 kHz

Capacitance is the ratio of the charge on each conductor to the potential difference between the conductors in the capacitor. Capacitance depends on the size and shape of the conductor and the nature of the insulating material. Enhancement of the capacitance in the capacitor will increase the amount of energy stored. (Young and Freedman, 2003). According to Saleh et al. (2013), the bioelectric properties of food products are strongly influenced by water content. The value of the bioelectric properties is directly proportional to the water content of the material. The increase in the moisture content of the material causes a higher dielectric constant value and the dielectric loss factor. Figure 4 shows that the capacitance value decreases with the length of the drying process. Based on the relationship between reactance impedance and capacitance, $X_C = \frac{1}{2\pi f C}$, indicating that impedance or resistance reactance is inversely proportional to the capacitance. When the water content decreases due to the drying process, the capacitance value of the material decreases.

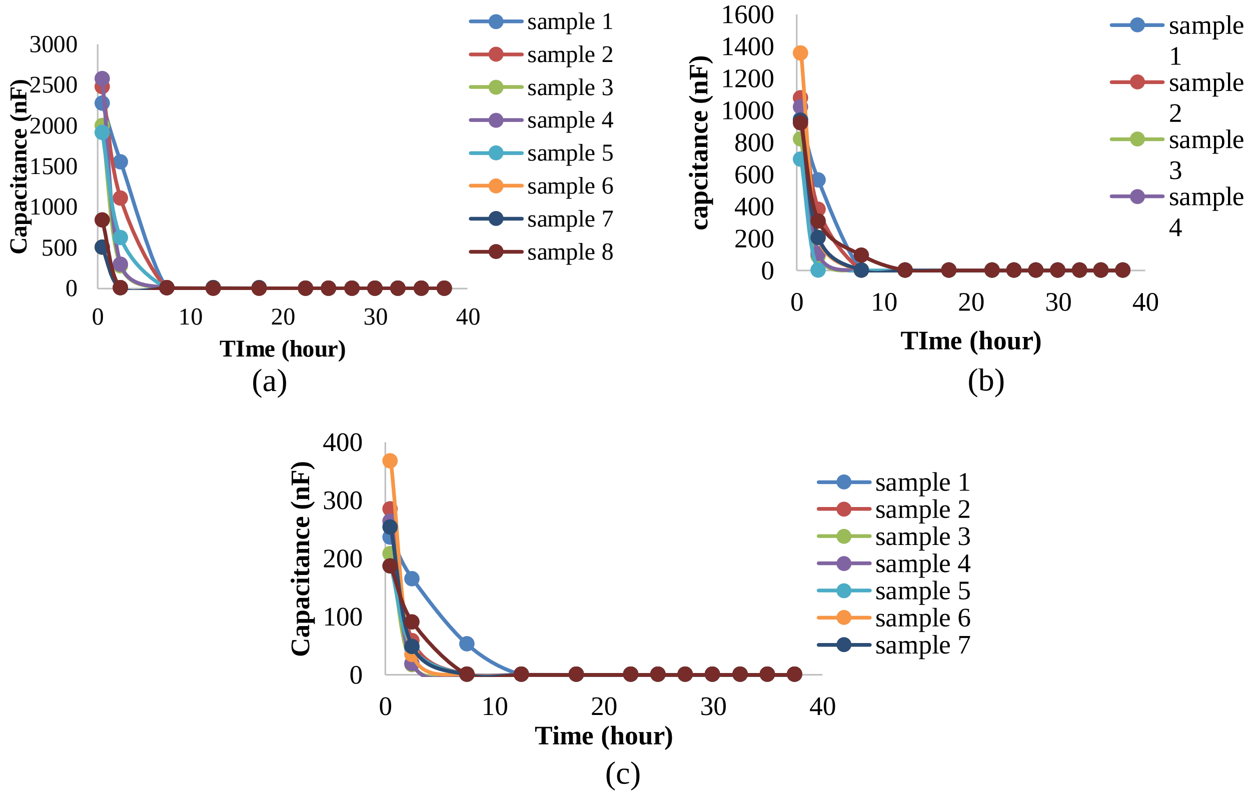


Figure 4 Material capacitance during drying time with frequency variations; a) 100 Hz, b) 1 kHz, c) 10 kHz

Artificial Neural Network Prediction Model

This research uses 4800 data with eight replications at a frequency of 100 Hz, 1 kHz, and 10 kHz. The normalized dataset uses to determine an optimal proportion of data training (70%) and data validation (30%). Before the training is carried out, the training function is modified so that it is optimal in training and the training results are good. During data training, modeling parameters are adjusted to get the best output prediction. The parameter number of nodes in the hidden layer is determined during training. This research used 1 and 2 hidden layers. According to Karsoliya (2012), the accuracy will increase by increasing the number of hidden layers, but the training time will increase. If accuracy is the main criterion, then the hidden layer can be improved. These parameters affect the error value in the prediction. Another parameter in training is that the maximum number of iterations is set at 10000, the learning rate is 0.1, and the momentum is 0.9. These parameters are modeled with several treatments to find the best accuracy for prediction. The final result of the training stage is the ANN model with the best weight. After knowing the best ANN model, the model is tested using data testing to obtain the best accuracy value. The testing process is carried out by simulating data testing using the best model to produce output. The output is compared to the target data testing to get the correlation coefficient and accuracy. The correlation coefficient (R) and MSE values from training and validation data for different ANN topologies can be seen in Table 1. The best topology is generated from two hidden layers with 30 nodes of hidden layers 1 and 2, 0.1 learning rate, and 0.5 momentum Figure 5. At the training stage, the best ANN model is 9-30-30-1 (9 input nodes, namely 3 L-C-R data at 100 Hz, 1 kHz, and 10 kHz of frequency, 30 nodes in hidden layer 1 and 30 nodes in hidden layer 2, and 1 output node of moisture content).

Table 1 *Trial and error* ANN Topology

Learning Rate	Momentum	ANN Structure	R Training	R Validation	MSE Training	MSE Validation
0.1	0.5	9-30-1	0.99121	0.76576	0.0100	0.2682
		9-40-1	0.99115	0.84715	0.0100	0.2023
		9-30-30-1	**0.99123**	**0.90343**	**0.0099**	**0.1047**
		9-30-40-1	0.99101	0.83736	0.0100	0.1807
		9-40-40-1	0.99102	0.87385	0.0100	0.1452
	0.9	9-30-1	0.99119	0.84052	0.0100	0.1836
		9-40-1	0.99107	0.82593	0.0100	0.1959
		9-30-30-1	0.99104	0.84921	0.0100	0.1602
		9-30-40-1	0.99102	0.91039	0.0100	0.1057
		9-40-40-1	0.99102	0.86274	0.0100	0.1594

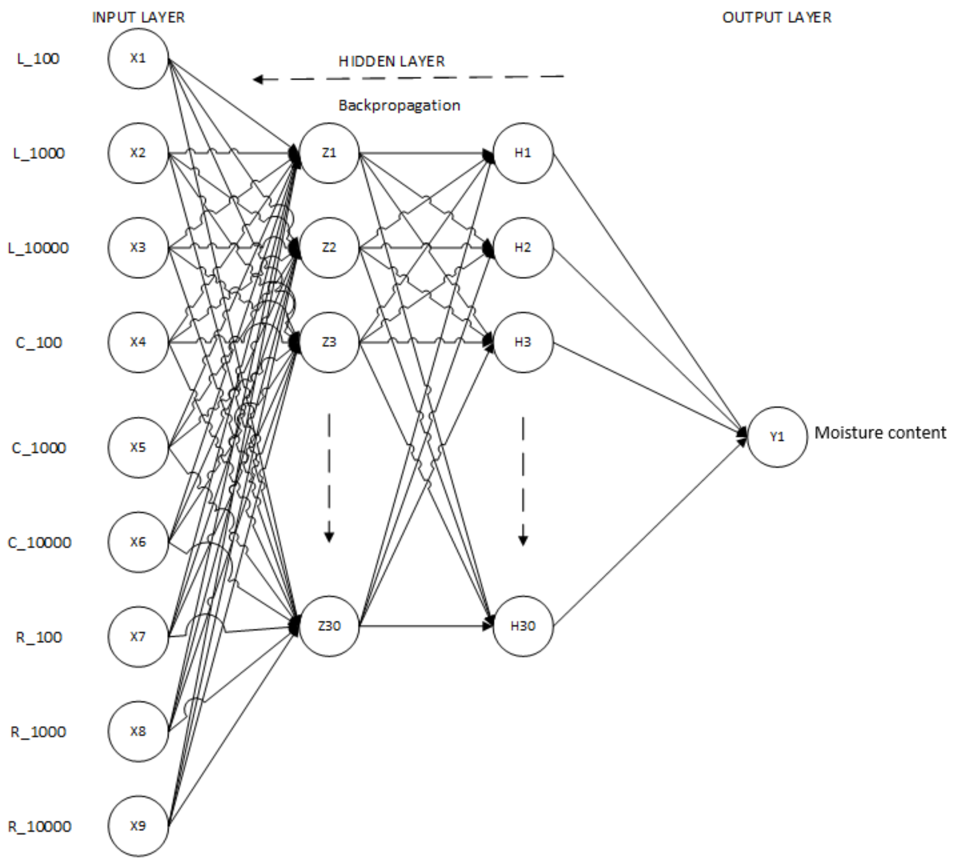
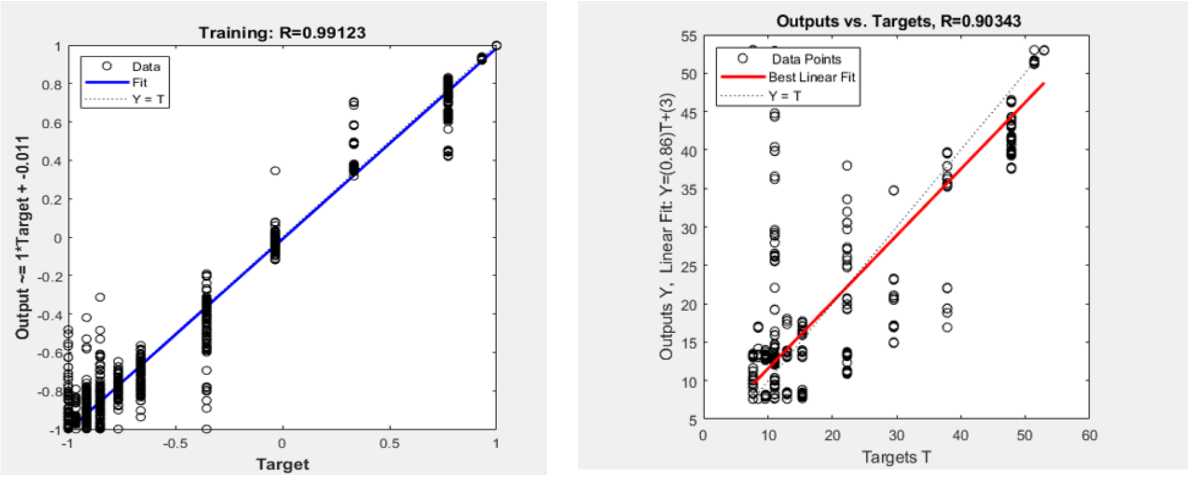


Figure 5 Selected ANN Model



(a) (b)

Figure 6 Simulation Regression Plots: (a) Training Data (b) Validation Data

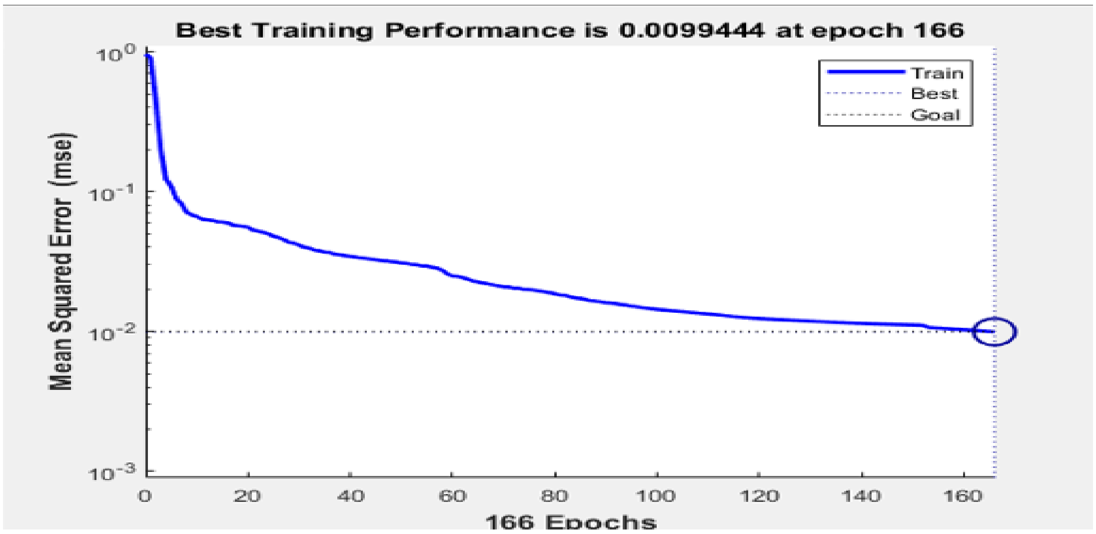


Figure 7 Generated error in selected ANN

Figure 6 shows the regression plots for the training and validation simulations. The data distribution is close to the linear conformity line and shows that the predicted results are close to one. The training correlation coefficient is 0.99123, while the validation correlation coefficient is 0.90343. Figure 6a shows that the output is the predicted yield value from the training data simulation, and Target T is the target of the training data, which is the moisture content value. The high accuracy value in training shows that the network model is feasible to use for testing. Figure 6b shows the value of the regression plot for the output of the testing data and the target of the testing data. Target T is the target value of the testing data in the form of the testing value and the output /prediction value from the testing data. The existence of data that deviates from the linear line causes a decrease in the value of the correlation coefficient. The correlation coefficient is interpreted as a measure of the linear dependence between x and y data (Suyono, 2015). If the correlation coefficient value is 80-95%, then the analysis is said to be good, while if the correlation coefficient value is 70-80%, then it can be said to be quite good (Lengkey et al., 2013). The result shows that a coefficient value close to 1 indicates a strong relationship between bioelectric properties and moisture content as output.

The maximum number of iterations is 10000 with a goal of 0.01. This means that training will stop at 10000 iterations or when the goal reaches 0.01. The number of iterations and goals are determined to avoid overfitting the model

(Hendrawan and Murase, 2011; Hendrawan and Al Riza, 2016). Overfitting occurs when the model recognizes the training data pattern so well that its generalization decreases. Figure 7 shows that the MSE value decreases with increasing iterations, indicating that the model is good. The final MSE reached the goal with a value of 0.01 in the 166th iteration.

Conclusion

The best ANN structure to predict moisture content based on the bioelectrical properties is 9-30-30-1. 9 node inputs are 3 L-C-R data at 100 Hz, 1000 Hz, and 10000 Hz of frequency. 30 nodes in hidden layer 1 and 30 nodes in hidden layer 2, and 1 output node of moisture content. The selected ANN topology results in an R training correlation coefficient of 0.99123, an R validation correlation coefficient of 0.90343, a training MSE of 0.0099, and a validation MSE of 0.1047. ANN models based on the bioelectrical properties have been proposed to develop an accurate, simple, and reliable technique as a sensor for the detection of the moisture content of green bean coffee during the drying process.

Declarations

Conflict of interests The authors declare no competing interests.

References

Akowuah, J. O., Maier, D., Opit, G., McNeill, S., Amstrong, P., Campabadal, C., Ambrose, K., and Obeng-Akrofi, G. (2018) ‘Drying temperature effect on kernel damage and viability of maize dried in a solar biomass hybrid dryer’, *Open Journal of Applied Science*, 8(11), pp. 506-517

Atmadji, E., Priyadi, U., and Achiria, S. (2019) `Vietnam and Indonesia coffee trade in the four main coffee export destinations: Application of the constant market share model’, *Jurnal Ilmu Ekonomi dan Pembangunan*, 19(1), pp 37-46

Basheer, I.A., and Hajmeer, M. (2000) `Artificial neural networks: fundamentals, computing, design, and application’. *Journal of Microbiological Methods*, 43(1), pp. 3-31

Chrismirina, S., and Afrina. Cut, M. S. (2016) ` Comparison of salivary flow rate before and after consumption of robusta coffee (Coffea cannephora)’, *Cakradonya Dental Journal*, 8(2), pp 88-91.

Farhaty, N., and Muchtaridi. (2016) ` Chemical review and pharmacological aspects of chlorogenic acid compounds in coffee beans : Review’, *Jurnal Farmaka*, 14(1), pp. 214-227

Hendrawan, Y., and Murase, H. (2011) `Neural-intelligent water drops algorithm to select relevant textural features for developing precision irrigation system using machine vision’, *Computers and Electronics in Agriculture*, 77(2), pp. 214-228

Hendrawan, Y., and Al Riza, D.F. (2016) ‘Machine vision optimization using nature-inspired algorithms to model sunagoke moss water status’, *International Journal on Advanced Science, Engineering and Information Technology,* 6(1), pp. 45-57

Maheswari, R., Bharadwaj, G., and Bhat, M. K. (2000) ‘Thermophilic fungi: their physiology and enzymes’, *Microbiology and Molecular Biology Review*, 64(3), pp. 461-488

Naderi-Boldaji, M., Fazeliyan-Dehkordi, M., and Mireei, S. A. (2015) ‘Dielectric power spectroscopy as a potential technique for the non-destructive measurement of sugar concentration in sugarcane’, *Biosystems Engineering*, 140, pp. 1- 10

Nelson, S. O. (2015) *Dielectric properties of agricultural materials and their applications*, London, UK: Elsevier Inc., pp. 292-292

Nelson, S.O., and Trabelsi, S. (2012) Factors influencing the dielectric properties of agricultural and food products’, *Journal of Microwave Power and Electromagnetic Energy*, 46(2), pp. 93- 107

Olguin, J. Q., and Durán, R. R. (2017) ‘Evaluación térmica y financiera del proceso de secado de grano de café en un secador solar activo tipo invernadero’, *Revista Mexicana de Ciencias Agrícolas*, 8(2), pp. 321–331

Prastowo, B., Karmawati, E., Rubiyo, Siswanto, Indrawanto, C., and Munarso, S. J. (2010) *Cultivation and postharvest coffee*, Bogor: Pusat Penelitian dan Pengembangan Perkebunan, pp. 62

Rahayu, A. Y., Okti, H., Ervina, M. D., and Rostaman, (2019) `Development of organic robusta coffee cultivation in Kelompok Tani Sido Makmur Desa Pesangkalan Kabupaten Banjarnegara', *Jurnal Pangabdhi*, 5(2), pp. 104-109

Rahardjo, P. (2012) *Arabica and Robusta Coffee Cultivation and Processing Guide*, Jakarta: Penebar Swadaya

Rosiana, N., Nurmalina, R., Winandi, R., and Rifin, A. (2018) 'Dynamics of Indonesian Robusta coffee competition among major competitor countries', *Jurnal Tanaman Industri dan Penyegar*, 5(1), pp. 1-10

Sucipto, S., Djatna, T., and Irzaman, I. (2013) `Application of electrical properties to differentiate lard from tallow and palm oil', *Media Peternak,* 36(1), pp. 32-39

Sucipto S, Widyaningtyas, S., Supriyanto, S., Arwani, M., Al Riza, D.F., Somantri, A. S., Hendrawan, Y., and Yuliatun, S. (2018) `Bioelectrical measurement for sugar recovery of sugarcane prediction using artificial neural network', *Proceeding of EECSI* 2018, Malang – Indonesia.

Watkins, A.E. and Maier, D.E. (2001) 'Thin-layer drying rates, stress cracking, and digestibility of selected high-oil corn hybrids' *Transactions of the ASAE*, 44, 617-622

Widyaningtyas, S., Sucipto, and Hendrawan, Y. (2018) `Detection of palm civet coffee adulteration using dielectric properties and artificial neural network'. *Jurnal Teknologi Pertanian*, 19(3), pp. 161-172