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Research Article

Utilization of Adaptive Neuro Fuzzy Inference System (ANFIS) for Prediction of Sacha Inchi Seed Weight Based on Fruit Morphology and Fertilizer Treatment

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Abstract

Background and Objective: The sacha inchi plant has seeds that are useful for various human needs from the health sector, food industry and cosmetics so that this plant has economic potential to be developed. This requires a study in increasing the weight of sacha inchi seeds as a basis for consideration for processing and sales. One of the supporters of the prediction of reference to increase the weight of the seeds of this plant through fertilization with organic materials. The purpose of the research was to predict efficient and effective fertilization treatment. **Materials and Methods:** The analysis of various fertilizer treatments from organic materials of chicken manure, goat, cow and sacha inchi waste on the weight of the seeds of this plant through fruit morphology so that an optimal model of the fertilizer treatment was formed. This fertilization activity is carried out by utilizing Internet of Things (IoT) technology automatically. The Adaptive Neuro-Fuzzy Inference System (ANFIS) method is the optimal fertilizer treatment model prediction method used in data analysis. **Results:** The analysis results of the research show that the application of organic fertilizer treatment from sacha inchi plant waste material shows optimal results on the weight of sacha inchi seeds seen from the length, width and thickness of the fruit with excellent prediction accuracy of 99.7%. **Conclusion:** The implications of the research results in management can develop the sustainability of product processing and sales by producing optimal seed weight and practically will increase the optimization and efficiency of production.

Key words: Sacha inchi, ANFIS, fertilizer treatment, seed weight, sacha inchi waste

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The sacha inchi plant is a family of Euphorbiaceae originating from the Peruvian Amazon forest¹. Sacha inchi plants around the Peruvian region include high potential plants of around 1200 tons per year so that Peru is the largest producer of sacha inchi plants followed by several other countries such as Latin America, namely Colombia, Brazil, Bolivia, Ecuador and Asian countries such as China, Cambodia, Laos and Thailand². The sacha inchi plant as a plant that contains a source of nutrients with oil (48-50%) and healthy protein (27-28%)^{3,7}. The seed oil of this plant also contains many valuable compounds in large quantities⁸. In addition, the sacha inchi plant has benefits for human health and is of high nutritional value^{9,10} and contains unsaturated fatty acids¹¹⁻¹⁵ also the sacha inchi plant has omega 3 and 6, essential fatty acids and omega 9¹⁶ and this is good for dietary supplements likewise, when viewed from its physical properties, this plant has high oil stability¹³.

The sacha inchi plant has several parts, namely seeds, seed coats, leaves that can be used for various needs both for health, food and cosmetic industries^{6,17} so that it can be used as a potential sustainable food industry⁶. Seeing this, the sacha inchi plant has the potential to be developed economically¹⁸. Seeing the economic and commercial potential of this plant, it is necessary to increase and sustain production in the development of this plant. One of the supports in increasing production, productivity and yields that will have an impact on the processing and sales process is through the fertilization process. The growth of sacha inchi plants is influenced by organic fertilizer materials and the addition of organic materials from several sources such as manure, compost of crop residues can increase soil organic matter and improve soil structure and can strengthen the soil base^{19,20}.

Fertilization of organic materials in this plant is very necessary in maintaining productivity and yields, especially in the weight of sacha inchi seeds as a basis for processing and sales considerations. This requires various references to the treatment of types of organic fertilizer materials in the fertilization process so that there is a need for research studies on this matter. The purpose of this study was to analyze various fertilizer treatments from organic materials of chicken, goat, cow manure and sacha inchi waste in seeing predictions of their influence on the weight of the seeds of this plant.

MATERIALS AND METHODS

Research location: The research location was carried out in the Cikadu Sindangkerta area of West Bandung, West Java with the consideration that around this area farmers have planted sacha inchi plants but have not been optimal in cultivating so that there is a need for studies, especially in increasing production. The tools and materials used in the research are sacha inchi plant cultivation tools and liquid organic fertilizer from chicken, goat, cow manure and sacha inchi waste which has been processed into liquid fertilizer ready for application. This study was carried out from June to October, 2023.

Research design: The fertilization process on sacha inchi plants was carried out through the treatment of liquid organic materials from chicken, goat, cow manure and sacha inchi waste. The dose applied at the research site was 150 mL/L of water. Fertilization is carried out every two weeks with the fertilization process carried out by flowing around the sacha inchi plant (on the disk) using an internet of things-based system as a supporter of this research so that it will facilitate and provide precise and fast monitoring in the fertilization process.

Plant samples and data analysis: The data used in this study are primary and secondary data. Primary data is obtained from plant samples of 200 trees that use chicken fertilizer, goat fertilizer, cow fertilizer and sacha inchi waste. The observed variables are the length, width and thickness of the fruit as an indicator of the morphology of this plant as an input variable and the weight of the sacha inchi fruit as an output variable. Secondary data consists of several literature reviews from various journal references and other supporters. Secondary data is needed to strengthen the results of the analysis carried out.

Analysis technique

Neuro-fuzzy ANFIS analysis method: Adaptive Neuro Fuzzy Inference System (ANFIS) is a network based on fuzzy inference system that has high-level reasoning capability based on the development of FIS²¹. In other words, by incorporating a FIS into an adaptive network framework, we get an ANFIS architecture^{22,23}. Due to the effective learning and reasoning competencies of the ANFIS model, it is gaining increasing interest from academics in various engineering and scientific fields. In the literature, different models apply different learning structures for many application developments, prediction systems and surveys^{24,25}.

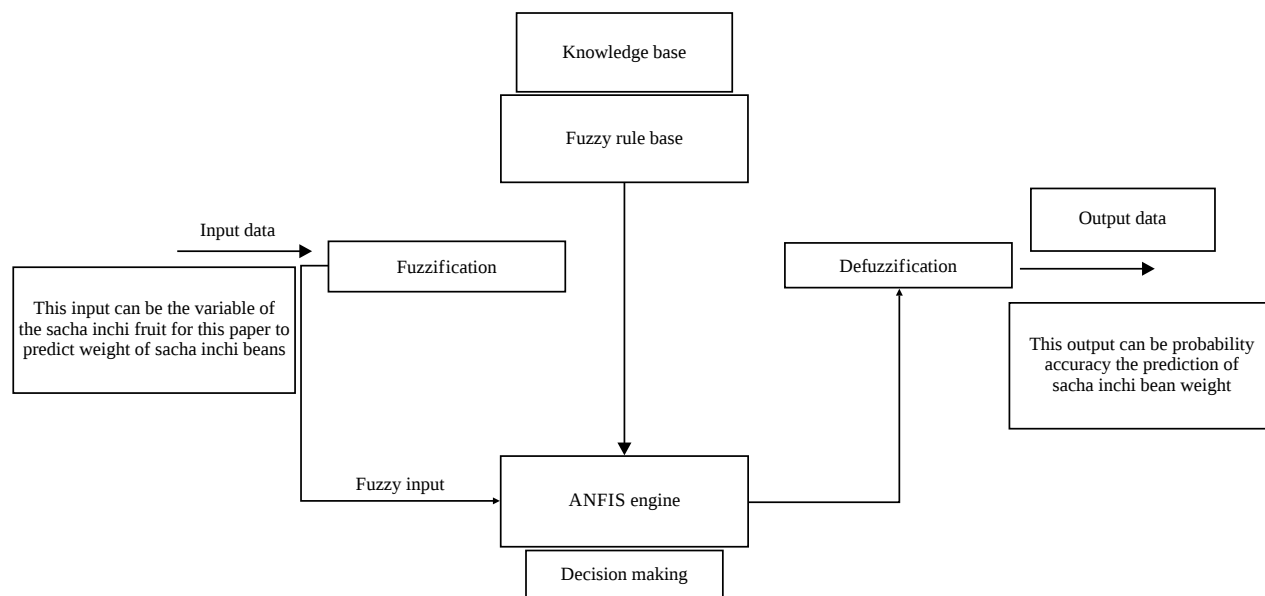


Fig. 1: Proposed Fuzzy logic inference system for predicting weight of sachu inchi

The ANFIS model is used in problems related to parameter identification and prediction. This is achieved through the incorporation of hybrid learning rules of back propagation, gradient descent and least squares methods. It is a multilayer feed-forward network that uses ANN and FLS to map inputs to outputs as shown in Fig. 1. Therefore, it is data implemented in an adaptive neural network structure. Furthermore, ANFIS can build the realization of IF/THEN rule network^{25,26}. The Adaptive Neuro-Fuzzy Inference System (ANFIS) used in this research is modeling with Sugeno fuzzy base structure, fuzzy rule base and artificial neural network (JST). The ANFIS architecture contains radial functions and some special constraints ANFIS allows conditions or rules to adapt²⁷.

Previous research in the literature is the identification of an agritourism development prediction model using the adaptive neuro-fuzzy inference system method²⁸. In addition, for prediction assessment, there is an analysis model for predicting sap production in *Arenga pinnata* using the adaptive neuro-fuzzy inference system method^{29,30}. The yield is anticipated through a versatile organize, which advances a multi-layer ANN with versatile hubs. Learning rules are characterized for the parameters of the versatile hubs and the alteration of the parameters depends on the blunder values³¹. In this work, ANFIS as an intelligent method or tool was used for prediction of weight of sachu inchi beans as it has been shown that the model can be used to assess predictions based on real data on observations processed by ANFIS computation^{22,27}.

In this study, the process in the ANFIS method consists of 5 main layers, namely the process of Layer 1 (fuzzification) which is the process of initial stage of ANFIS analysis, at this stage is the stage of the data input process in this study, which consists of the use of fertilizer with 4 treatments, fruit length, fruit width and fruit thickness, Layer 2 (fuzzy logic operation), Layer 3 (normalization of the degree of activation), Layer 4 (defuzzification) and Layer 5 (output). In addition, the hybrid algorithm is also used in ANFIS to set the parameters contained in the ANFIS method. The hybrid algorithm is divided into 2 learning, namely forward learning and backward learning. In forward learning the LSE recursive algorithm is used and in backward learning, the error backpropagation (EBP) algorithm is used. To determine the error rate of the resulting prediction, the error measurement is done using RMSE. This research method was in accordance with Fig. 2.

The next process generates a membership function (MF) for each input. There are basically several types of MFs in ANFIS, such as triangular MFs, generalized bell MFs and Gaussian MFs. In this research, the MF used is the triangular MF. Based on the fuzzy output clarification method used in the inference system is Sugeno type³². The ANFIS with Sugeno type inference system method is a hybrid method that utilizes parallel calculations and learning capabilities of Fuzzy Logic system features of artificial neural networks³³. In fuzzy identification, the Sugeno type fuzzy system is the most accurate MF for determining the relationship between input and output in the ANFIS model used. There are two algorithms

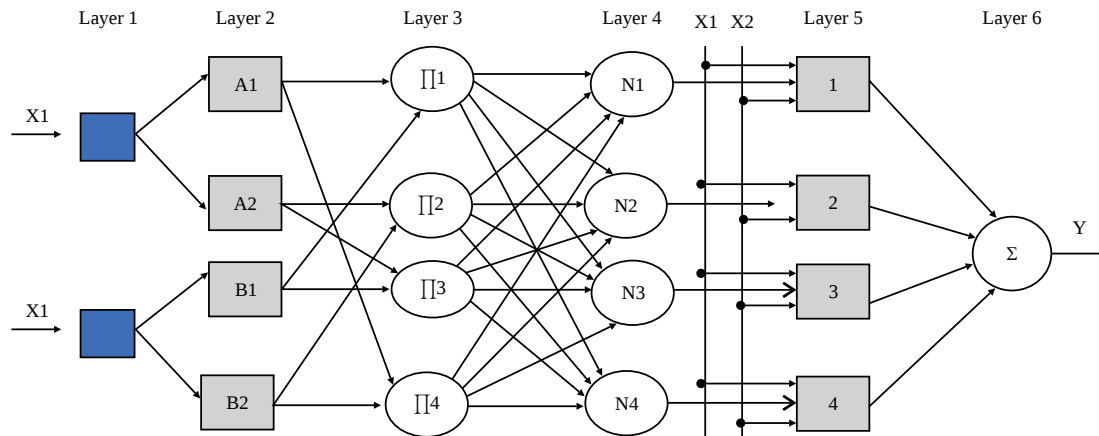


Fig. 2: ANFIS architecture

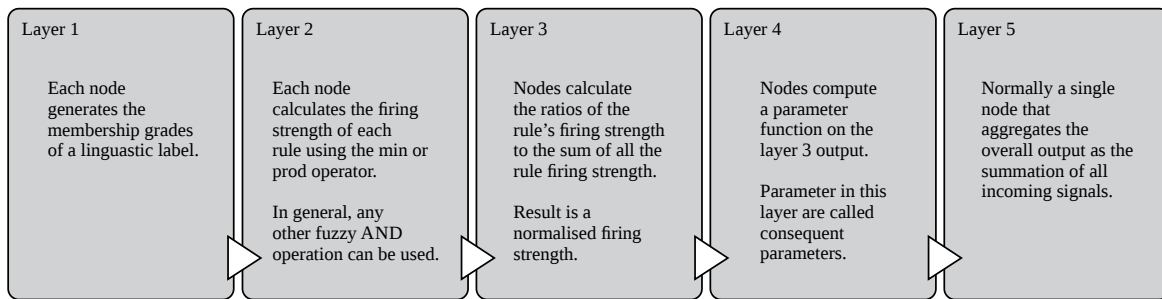


Fig. 3: ANFIS with 5 layers of neurons

in the ANFIS system, namely error backpropagation and hybrid learning. The ANFIS uses the learning capabilities of artificial neural networks to determine input and output spaces based on training data input to the ANFIS programming. In the Sugeno membership function, the fuzzy rule output is in the form of a linear function³⁴. In general, the prediction process using the Adaptive Neuro Fuzzy Inference System includes steps as in Fig. 3.

The first layer shows how much each numerical input corresponds to a different fuzzy set. Suppose MF from fuzzy set A_i , becomes B_i , then the output of this layer can be calculated by the next equation as follows³⁵:

$$O_i = \mu_{A_i}(x); i = 1, 2$$

$$O_i = \mu_{B_i}(y); i = 3, 4$$

With x and y are the inputs at the i -th node. While μ_{A_i} and μ_{B_i} are the membership functions of each node 1, functions to express a degree of membership of each input to the fuzzy sets A and B with 1, 2, 1, 2 are linguistic variables. The membership function used is the generalized bell membership function. The

generalized bell membership function can be written as follows^{36,37}:

$$\mu_A(x_i) = e^{-\frac{(x_i - c)^2}{2\sigma^2}}$$

$$f(x; a_i, b_i, c_i) = \frac{1}{1 + \frac{(x - c_i)^{2b_i}}{a_i}}$$

where, a_i, b_i, c_i are the set of parameters called premise parameters. By taking the value = 1, only the parameters and will change during the learning process. If the values of these parameters change, the generalized bell curve will also change.

Layer 2 (product layer) each node in Layer 2 is a non-adaptive node which means that its parameter values are fixed. The function of this node multiplies each incoming input signal as follows:

$$O_{2,i} = w_i = \mu_{A_i}(x) \cdot \mu_{B_i}(y); i = 1, 2$$

Each output node expresses the degree of activation of each fuzzy rule. The number of rules formed follows the number of nodes in this layer.

Layer 3 (normalization layer) each node in this layer is a non-adaptive node that expresses the normalized degree function which is the ratio of the output of the i -th node in the previous layer as follows:

$$O_{3,i} = w_i \frac{w_i}{w_1 + w_2}, \text{ with } i = 1, 2$$

If there are more than 2 rules, then the function can be expanded by dividing the total number w for all rules.

Layer 4 (defuzzification layer) each node in this layer is an adaptive node with the following²² node functions:

$$O_{4,1t} = w_{1t}^* Z_t^{(1)} = w_{1t}^* (\alpha_1 Z_{t-1} + \beta_1 Z_{t-2} + \gamma_1)$$

$$O_{4,2t} = w_{2t}^* Z_t^{(2)} = w_{2t}^* (\alpha_2 Z_{t-1} + \beta_2 Z_{t-2} + \gamma_2)$$

where, α_i , β_i and γ_i are the set of parameters of the node and are called consequent parameters.

Total output layer (Layer 5) is the last layer that functions to sum all inputs with the following node function:

$$O_{5t} = \hat{Z}_t = w_{1t}^* Z_t^{(1)} + w_{2t}^* Z_t^{(2)}$$

Input data processed into the ANFIS artificial neural network is the use of fertilizer with 4 treatments, fruit length, fruit thickness, fruit width and sachai inchi fruit weight. Processed as each network from each layer which is a fixed network that is in the layer which means the output value is generated from all incoming network inputs. Furthermore, each neuron is a fixed node which is the result of a calculation using the ratio value and predicate (w), from the i th rule to the sum of all predicates. Furthermore, each neuron is an adaptive node in the output layer, each neuron is a fixed node which is the result of the summation of all inputs. In this study as a result of predicting the weight of sachai inchi seeds.

RESULTS AND DISCUSSION

Neuro-fuzzy ANFIS analysis results: The results of ANFIS analysis, based on input data into the ANFIS program (Fig. 4a) in this study as an input variable consisting of data on the use of organic fertilizers (sachai inchi waste, chicken, goat and cow manure), fruit length, fruit thickness, fruit width and sachai inchi fruit thickness. This input data will be used as training

data to be able to obtain the output of the predicted weight of sachai inchi seeds. From the input training data, the Neuro-Fuzzy ANFIS system will automatically build a model in the program (Fig. 4b). This model is a display of the work scheme in ANFIS programming in determining the output.

The pattern in the data built by the ANFIS program will give rise to RMSE. The tolerance value of RMSE is 0-1, the value will appear from the best data pattern that will be used as a reference in the prediction process. Programming with the ANFIS method needs to go through the stages of clarifying the accuracy of the data as training data for prediction, namely train FIS and test FIS which aims as an initial detection of errors in the input data and visual detection of FIS graphs in the suitability of input data with prediction output. In train FIS (Fig. 5a) the maximum epoch of 120 obtained an error value of 0.033. This value indicates that the input data error is very low. This is in accordance with the opinion of Kusumadewi and Hartati³⁸, 2010 that the tolerance value in ANFIS is the error value ranging in rate 0-1. In the FIS test section of Fig. 5b, it can be seen that the training plot (blue) follows the pattern of the testing data (red). The accuracy of ANFIS program learning from input data to output data greatly affects the value for RMSE. By determining a more accurate learning rate, the epochs required are fewer, so that the convergence required is faster in determining the optimum weight so that the forecast results appear to have met the measurement standards of a prediction model.

Prediction of the weight of sachai inchi seeds is built with the ANFIS model with 4 input data as a member of function and 1 output shown in Fig. 6 with each input variable having a membership function consisting of data on the use of 4MF organic fertilizer (sachai inchi waste, chicken, goat and cow manure), 3MF fruit length (short, medium, long), 3MF fruit thickness (thin, medium, thick) and 3MF width (small, medium, wide). This membership function will build rules that become a reference in building prediction outputs.

Figure 7 shows the model that is built and becomes the output constraint, namely rules. From the combination of input data, 281 rules are obtained as a prediction builder for the output. In Fig. 7, it is shown that the prediction of the use of organic fertilizer will affect the weight of sachai inchi seeds, that with the variable values of length, thickness and width of the sachai inchi fruit are at the same graphic value but obtained from different organic fertilizer treatment results, it shows different seed weight results. In Fig. 7, with the treatment of organic fertilizer chicken manure, the resulting seed weight is 0.951 g. In Fig. 7b with the treatment of organic fertilizer goat manure, the resulting seed weight is 1.29 g. In Fig. 7c, with the treatment of organic fertilizer from sachai inchi

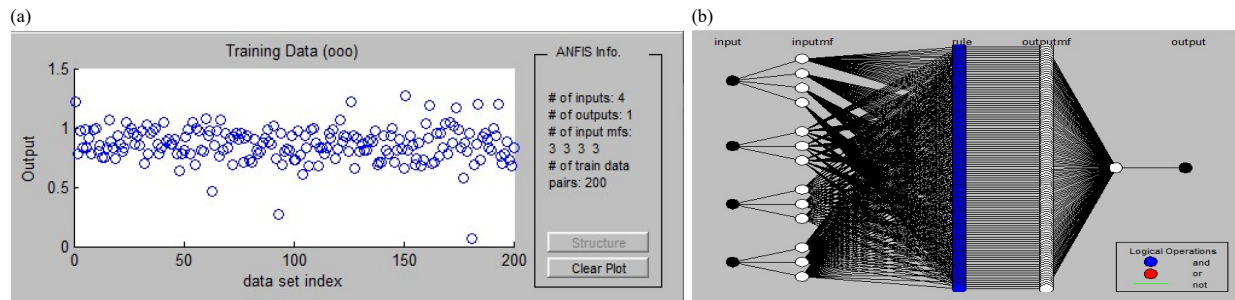


Fig.4(a-b): (a) Visualization of the distribution of input data to the ANFIS program and (b) ANFIS model architecture for predicting the weight of sacha inchi beans

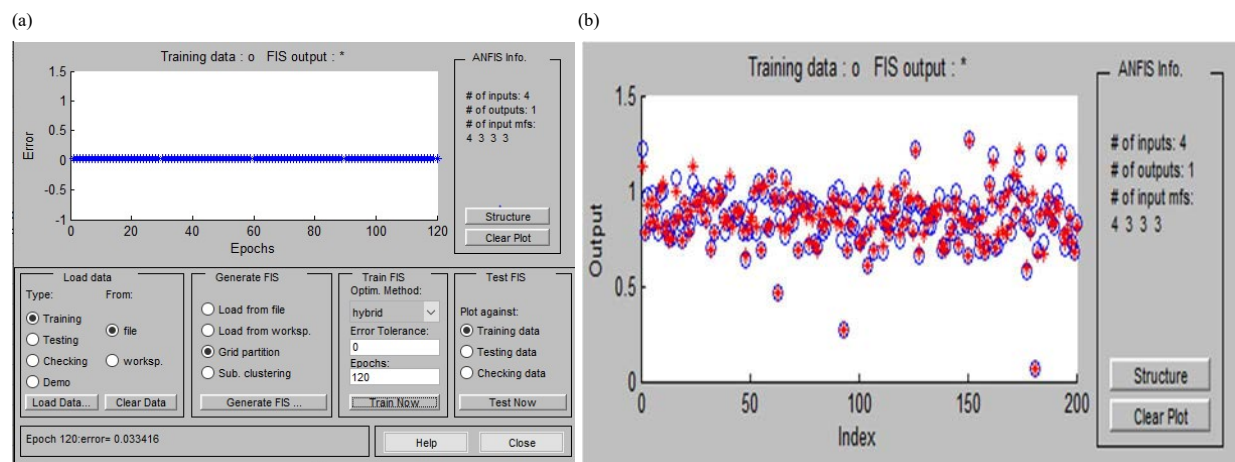


Fig.5(a-b): (a) Trend of errors of the trained fuzzy system and (b) Training data and FIS output with four inputs and one output
Training error and data: (a) Training error, (b) Plotting training (blue) and testing (red) data

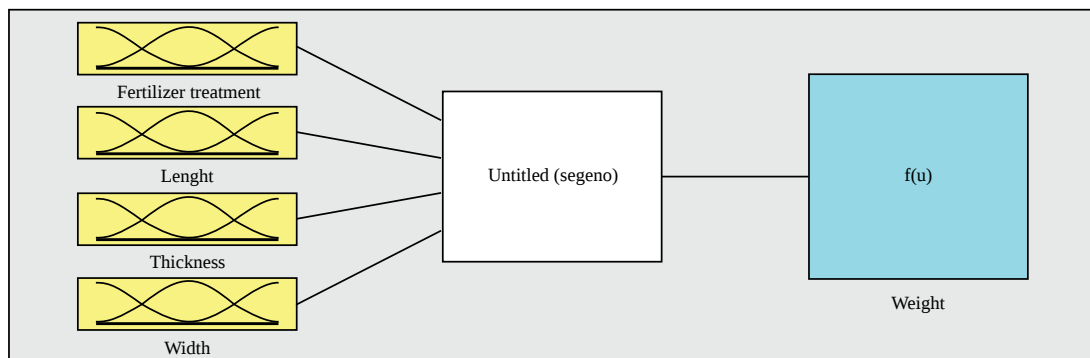


Fig. 6: Using the Sugeno-type FIS method in the proposed method

waste, the resulting seed weight is 1.59 g. In Fig. 7d, with the treatment of organic fertilizer from cow dung, the resulting seed weight is 1.36 g. The weight of the seeds greatly impacts the processing process because the fruit of this plant is taken for seeds to be processed. Seeds contain high oil content with unsaturated fatty acids¹¹. In addition, the seeds of this fruit can

be used as seed flour which is beneficial for health and food industry products³⁹. If the seed weight is optimized, it will also have an impact on increasing the quantity of seed coat which can be processed for cosmetic nutrition products, pharmaceuticals⁶ and its waste for liquid organic fertilizer processing.

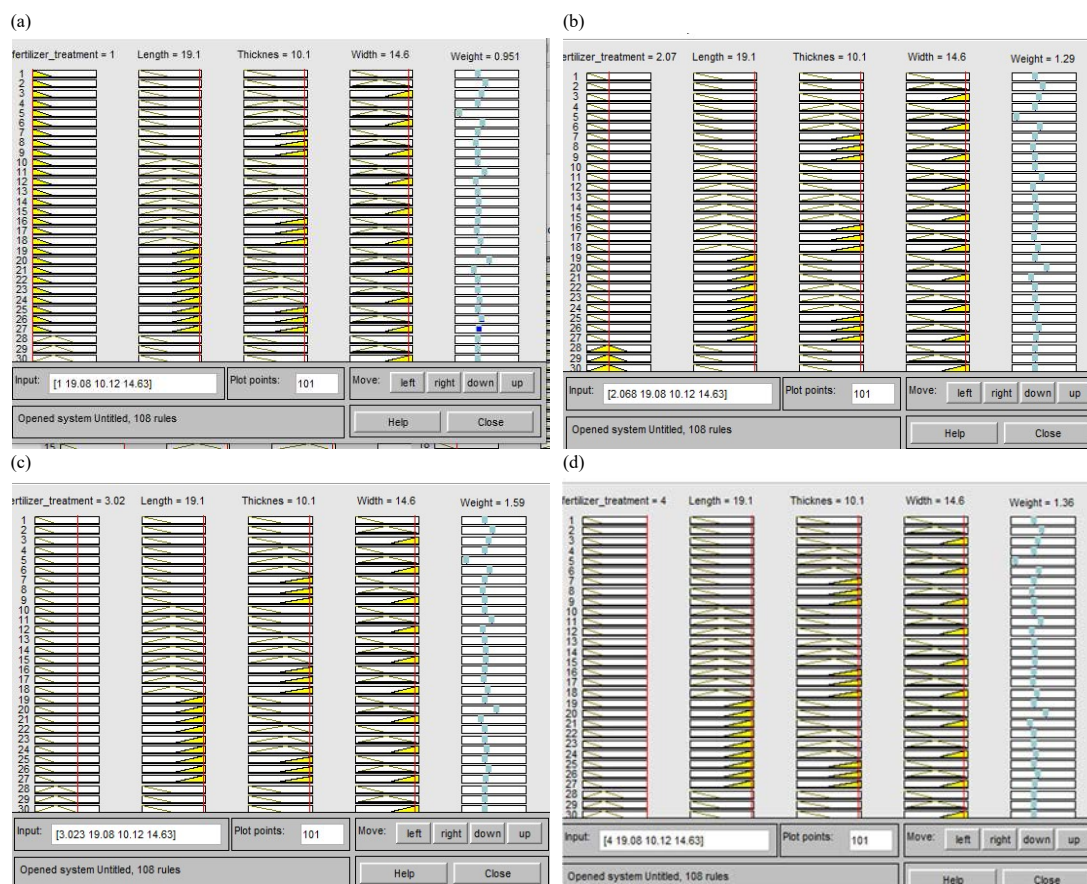


Fig. 7(a-d): Trained main ANFIS of indexes and output for predict weight of sachu inchi beans (MATLAB'S rule viewer); (a) MATLAB'S rule viewer fertilizer treatment with chicken manure, (b) MATLAB'S rule viewer fertilizer treatment with goat manure, (c) MATLAB'S rule viewer fertilizer treatment with sachu inchi waste and (d) MATLAB'S rule viewer fertilizer treatment with cow manure

Based on the prediction results built from the rules obtained from the ANFIS artificial neural network program, it can be concluded that the use of organic fertilizer certainly greatly affects the weight of the seeds in the sachu inchi plant. This will be a study material in the processing and sale of the results of this plant. This research produces predictions of the use of organic fertilizer from sachu inchi waste material is the right choice in maximizing the productivity of sachu inchi seed weight.

The seeds of the sachu inchi plant are not only useful for being used as raw materials for various human needs in the health, cosmetics, pharmaceutical and food industries, but sachu inchi seeds can be used as alternative raw materials for industrial applications¹¹ with various techniques in extracting sachu inchi seed oil such as through hydraulic cold pressed extraction (HCPE), which is an oil extraction technique from sachu inchi seeds while maintaining its nutritional integrity and efficiency³⁹.

Figure 8a-d shows the 3-dimensional graph generated from the rules formed by the ANFIS programming based on the training input data. The variations between different MF results are clearly visible from the 3D surface plots. The 3D image visualization of seed weight versus variable shows different minimal errors depending on the MF chosen. In Fig. 8a it can be seen that to obtain optimal weight results it is necessary to use fertilizer on a scale of 3 and the width of the sachu inchi seeds starting from 12 mm, which means that the use of organic fertilizer from sachu inchi waste will be able to produce better seed weight compared to the use of other fertilizers. It can also be seen in the 3D of Fig. 8b that the optimum weight value is obtained on a scale of 3 with the length of the sachu inchi seeds starting from 12 mm. Other variables also have a direct influence on the weight of sachu inchi seeds. As in Fig. 8c, the results of the 3D graph show a visualization of the results of the maximum sachu inchi seed weight obtained from the variables of seed thickness and

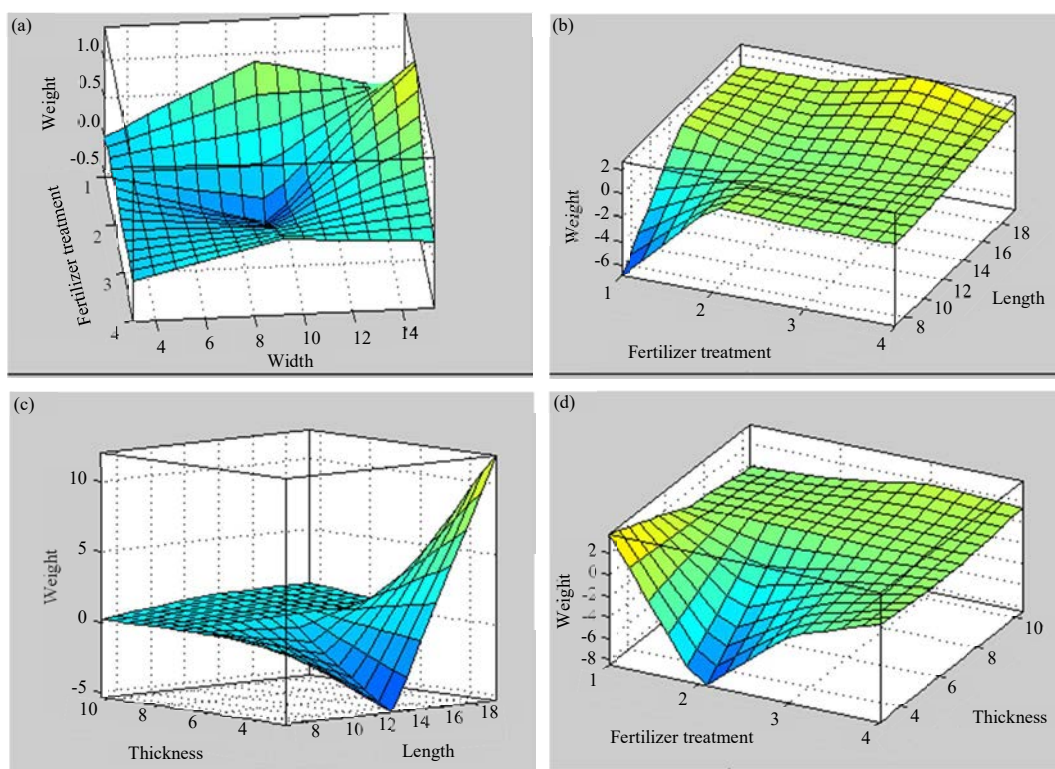


Fig. 8(a-d): Visualization of the 3D surface plots of the rule base system adapted for the data for different MF types; (a) Visualization of the influence of the variable fruit width and fertilizer treatment, (b) Visualization of the influence of the variable fruit length and fertilizer treatment, (c) Visualization of the influence of the variable fruit thickness and fruit length and (d) Visualization of the influence of the variable fruit thickness and fertilizer treatment

length of the sachu inchi seed. As in Fig. 8a-b, it can also be seen in the 3D visualization that the maximum weight is obtained on a scale of 3 with each specified seed thickness. Overall in the Fig. 8a-d shows the prediction visualization built by ANFIS. The use of organic fertilizer has an important role in determining weight, while other variables such as length, width and thickness of sachu inchi fruit have the same predictive direction, namely the higher the value of these variables, the more they will influence the weight of sachu inchi fruit seeds. The visualization shown is in accordance with the rules formed by the ANFIS artificial neural network, namely the optimal weight value obtained when using sachu inchi waste organic fertilizer.

The prediction accuracy based on the analysis of the ANFIS program was shown in Fig. 9. It can be seen that the results obtained from the training data are relatively in line with the data from direct observation. This shows that the output proposed by ANFIS can predict the weight of sachu inchi seeds and represent its statistical features with a very good accuracy of 99.7%. In the proposed model, the weight of sachu inchi seeds can be optimally managed by farmers

through the selection of appropriate fertilizer use with materials from sachu inchi plant waste. This will support production efficiency because fertilizer materials are already available from the waste and can also increase income due to the higher seed weight of this plant which has an impact on the processing of oil or sachu inchi derivative products with more optimal results. With accurate prediction results, it can be a recommendation for farmers in optimizing sachu inchi farming through proper fertilization activities and practically farmers can be more efficient and applicable for making liquid organic fertilizer from sachu inchi waste material.

This research can also be used as an appropriate recommendation for crop yields from fertilizer treatment of various organic materials even though in the Indonesian region it is not so widespread for farmers to plant this crop. The results of this study can be used as a basis for consideration in post-harvest activities, namely processing and sales of sachu inchi seeds which can be utilized for various needs. As a supporter of facilitating research activities, a system based on the Internet of things is carried out in the process of automatic fertilization.

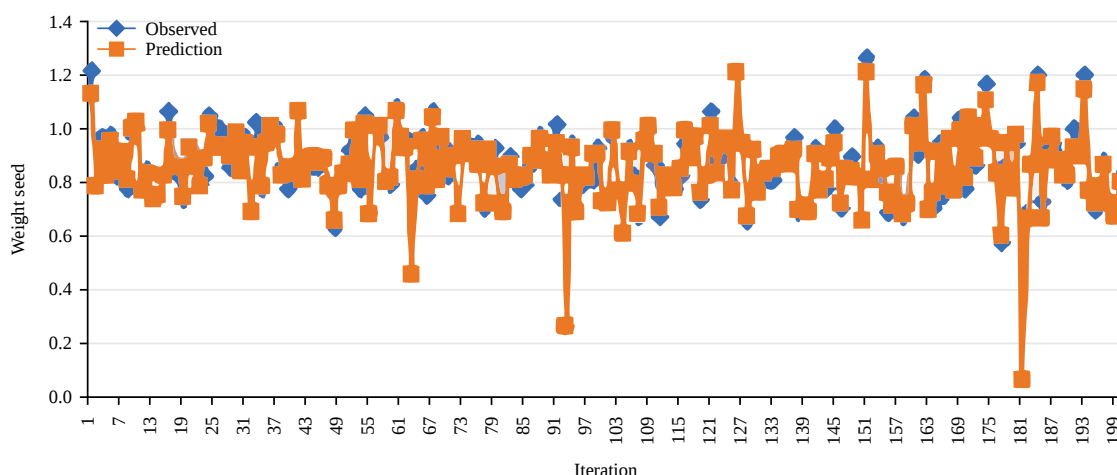


Fig. 9: Comparison of the proposed model between predicted weight of sachu inchi beans and the observed

CONCLUSION

The resulting analysis of 4 fertilizer treatments of chicken manure, goat, cow and sachu inchi waste materials on the effect of sachu inchi plant seed weight shows the results of 0.951, 1.29, 1.36 and 1.59 g. Fertilizer treatment of sachu inchi plant waste material that has an optimal impact on the weight of sachu inchi seeds and the output proposed by ANFIS in predicting the weight of sachu inchi seeds produces very good accuracy of 99.7%. The results of this study can be used as recommendations in the utilization of this plant waste in increasing productivity, especially the weight of sachu inchi seeds and can be used as additional business opportunities from the development of this plant. Utilization of sachu inchi plant waste is the latest application in liquid organic fertilizer and has only been applied only to sachu inchi plants, then it can be used as a research study for applications in other commodities.

SIGNIFICANCE STATEMENT

The sachu inchi seeds delivered are valuable as crude materials for corrective generation, the nourishment and wellbeing businesses. Seed weight has an effect on the sum of oil substance seen from morphology with variable width, length and thickness. On this premise, it is essential to think about the rummage around for ideal seed weight as a premise for handling and deals through distinctive fertilizer medications with computerized web of things frameworks. The point of the inquire about is to anticipate fertilizer treatment on ideal seed weight. The investigate comes about appear that fertilizer from seed shell crude materials from sachu inchi plants can create ideal seed weight with

anticipated comes about of around 99.7%. Inquire about contributes to the advancement of a circular economy by utilizing squander from sachu inchi plants and securing the environment as well as expanding generation taken a toll productivity in terms of fertilizer acquirement so that feasible generation of this plant can take put.

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