Modeling of Groundnut Shell Mercerization Process Using a Neuro-Fuzzy Technique

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ABSTRACT: *Natural fiber is growing relevant in composite processing due to its low cost, lightweight, and good mechanical properties; therefore, increased natural fiber composite development is desirable. This study predicted the mercerization effect on the moisture absorption properties of groundnut shell samples using neuro-fuzzy modeling. The groundnut shells were processed, dried, and treated with NaOH varying the time and concentration of the treatment. Sensitivity analysis using the Adaptive Neuro-Fuzzy İnference System (ANFIS) ANFIS's exhaustive search showed that treatment time and concentration impacted the moisture absorption rate of groundnut shells. Parametric analysis via ANFIS surface plot indicated that an increase in treatment time and concentration decreased the moisture absorption rate of the samples. The characterization results from SEM (Scanning Electron Micrograph) and FT-IR (Fourier Transform Infrared Spectroscopy) showed that the groundnut shells were suitably mercerized. ANFIS optimum result showed that the moisture absorption rate of 1.23% was obtained at a treatment time of 4 hours and a concentration of 4 mol; pi membership function (mf) had the best coefficient of determination* R^2 *(0.99364) and Mean Square Error (MSE, 0.011679) amongst other membership functions demonstrating a significant predictive behavior for the model. The observations from the study prove that the ANFIS technique is a practical approach for the prediction of the groundnut shell mercerization process.*

KEYWORDS: *ANFIS; time of treatment; concentration; mercerization; groundnut shell.*

INTRODUCTION

Groundnut shell, processed from groundnut seed, is considered a waste and remains underutilized in our environment. It can be referred to as a potential lignocellulosic waste or natural fibre applied as a reinforcing filler in polymer composite [1]. Fibres are load-carrying materials that provide strength and rigidity in composite reinforcement. The reinforcement enhanced the fiber-reinforced composites' mechanical properties and made them suitable for diverse applications. Natural fibres' motivation for composite reinforcements has recently increased due to their lightweight, non-toxic, low cost, and easy recyclability. However, the hydrophilic nature of fibres has been a significant impediment to their use as reinforcement during composite manufacturing [2].

Microcracking and degradation of the mechanical properties of the composites are caused by poor resistance to moisture absorption and lack of interfacial adhesion between the fibre [3-7]. Mercerization involves the

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alkaline treatment of fibres to eliminate lignin wax and promote interfacial adhesion between the fibre and the matrix during composite processing [8-11]. Several researchers have reported the efficiency of mercerization treatment; thus, *daSilva et al*. [12] studied the influence process on the surface of coconut fibre for composite reinforcement. ; Rajeshkumar[13] studied the moisture uptake and mechanical behaviour of sustainable fibre-reinforced epoxy composites. the influence of cotton fibre properties on the microstructural characteristics of mercerized fibres was studied by *Wang et al*. [14]. These findings demonstrated that the modification increased the mechanical behaviour of the fibre strength and stiffness, which will enhance its application in composite processing.

Various researchers have explored the application of Response Surface Methodology (RSM) in optimizing the mercerization process: *Ferror et al*. [15] successfully optimized cellulose mercerization for composite processing, *Hassan et al*. [16] optimized mercerized bamboo fibre-reinforced epoxy composites structure using a box-Behnken design, their observations revealed that RSM successfully optimized mercerization processes at a reduced time.

However, the relationship between input mercerization parameters (treatment time and concentration) and response (moisture absorption) is vague when assessed by the linear regression technique and RSM, owing to its inability to deal with complex variables, as reported earlier by researchers [17-20]. Furthermore, the challenges associated with linear regression techniques implementing experimental data is time-consuming making it cumbersome to obtain a large amount of experimental data; imprecision, uncertainty and increased error make it difficult to determine the optimal design of the process. Therefore, several studies have explored applying soft computation techniques such as ANN(Artificial neural network) and ANFIS to model intricate processes [21-23]. *Mashhadban et al*. [24] successfully modeled and predicted mechanical properties in fiber-reinforced self-compacting concrete using ANN with 183 variables, whereas reports from *Nwosu-Obieogu et al*. [25] on the mechanical properties of rice husk-reinforced low-density polyethylene composites consisted of 5 variables using the linear regression technique.

ANFIS combines ANN and fuzzy logic to predict the behavior of variables, capture the nonlinear structure of a process, improve error tolerance, and have rapid learning capacity [23,26]. ANFIS constructs a series of fuzzy if-then rules with appropriate membership functions to produce the stipulated input-output pairs. İt is employed in areas such as engineering and has applications in decision-making problems, planning and problem [22,26]. ANFIS seems to be an excellent model for mapping the interaction of process parameters in the mercerization process.

ANFIS has been used to forecast chemical processes by several researchers, such as biodiesel production from castor oil [27], oil extraction from almond seeds [28], *huracrepitan* and *luffa cylindrica* seed oil extraction prediction [23,29], prediction of heavy metal removal from textile effluent using *luffa cylindrica* [30] and antioxidant yield from *luffa* seed oil[31], fermentable sugar yield prediction from melon seed peel [32]; their report indicates that ANFIS predicts non-linear relationships effectively [33]. Predicting $C0_2$ solubility in potassium and sodium-based amino acid salt gas fraction in wastewater treatment and current density of coatings using neuro-fuzzy models, [34-36]. Nevertheless, the only reported literature on ANFIS modelling on the agro-waste modification for composite fabrication is on the successful modelling of moisture absorption characteristics of *ampelocissus cavicaulis* fibre reinforced epoxy composite by *Adeyi et al*. [37]; hence, this study model the groundnut shell mercerization process using the ANFIS technique.

EXPERIMENTAL SECTION

Materials and Equipment

Groundnut shell, NaOH, beakers, filter paper, distilled water, funnel, and oven (Binder Heating and Drying Oven, Tuttlingen, Germany).

Methodology

The groundnut shell was collected, rinsed with distilled water, sun-dried, ground, and sieved to a particle size of 2 mm; 40 g of the grounded groundnut shell sample was soaked in a produced 3%, 4%, and 5% NaOH solution for 3, 4, and 5 hours, respectively. The solution was then filtered, carefully rinsed with distilled water, and oven-dried for 2 hours at 110ºC.

Moisture Absorption Determination

Moisture absorption of the samples was determined by taking the weight of the samples after drying and allowing them to absorb moisture from the atmosphere for 24 hours; the moisture content was calculated at each interval using Eq. (1).

Table 1: Design of experiment

Factors	Units	Level		
		-1	0	1
Time of treatment	hour	3	4	5
concentration	%	3	4	5

$$\%\ moisture\ absorption = \frac{final\ weight - initial\ weight\ \ X\ \ 100}{initial\ weight} \quad (1)$$

Sample characterization

The functional groups present on the surface of the groundnut shell before and after mercerization were determined using the FT-IR spectroscope (PerkinElmer Spectrum one v3.02 Spectrometer, India); while the morphological structure of the groundnut shell before and after mercerization was determined using SEM (Model: (HITACHI S-5500, Japan)

Central composite design implementing response surface methodology in Design-Expert version 10 was used to study the combined effect of treatment time and concentration as the independent parameters and moisture absorption as the response, as shown in Table 1. In addition, the data generated from the experimental runs was populated and used for the ANFIS simulation.

ANFIS model development

A Multi-İnput Single-Output (MISO) fuzzy model based on 82 experimental datasets with 2 inputs and one output was developed for the groundnut shell mercerization process. Takagi-Sugeno fuzzy grid partitioning system was applied to model the non-linear variables. However, with the small number of the experimental dataset, the data is divided into two subsets; one for training and the other for testing with a ratio of 80 to 20. Two input variables (treatment time and concentration) and one output variable (moisture absorption) were used for the ANFIS modelling. This was performed using a fuzzy logic toolbox of MATLAB R2015b. 100 training epochs were selected to train the ANFIS model. normalization of the data was done using min-max scaling to improve ANFIS efficiency.

ANFIS architecture comprised five layers, as shown in Fig. 3. In Fig. 3, square nodes (adaptive nodes) show that the parameters are adjustable to be learned, while the circle nodes (fixed nodes) show selected parameters. A common rule set with two fuzzy if-then rules is as follows:

Rule 1: If x is A_1 and y is B_1, then $f_1 = p_1\ x + q_1\ x + r_1$ (2)

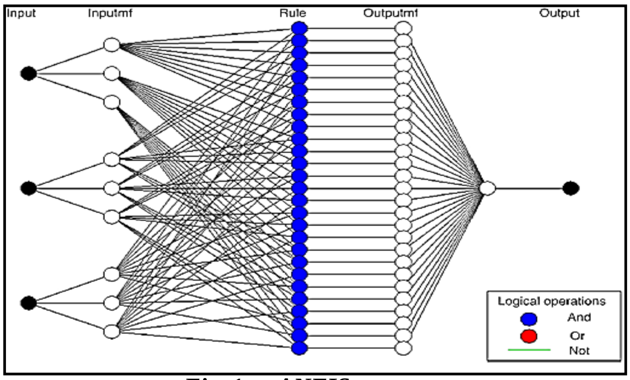

Fig. 1-a: ANFIS structure

Rule 2: If x is A_2 and y is B_2, then $f_2 = p_2\ x + q_2\ x + r_2$ (3)

Where A and B are linguistic terms that are user-defined and represent a range of values. The sequence and functions of the layers are as follows:

Layer 1: Square node equipped with node function

$$O_i^L = \mu_{Ai}(x) \quad (4)$$

Assuming x and y are the two typical input values fed at the two input nodes, transforming those values to the input membership functions. Where O_i^L is the membership function of A_i and x is the input parameter to the node. A_i is the linguistic label connected with the node function.

Layer 2: This node increases the homeward bound signal and releases the product out of the layer.

$$w_i = \mu_{Ai}(x) \times \mu_{Ai}(y). \qquad i = 1.2 \quad (5)$$

Layer 3: circle node. A node calculates the ratio of the i-th rule's firing strength to the sum of all rules' firing strengths:

$$w_i' = \frac{w_i}{w_1 + w_2}. \qquad i = 1.2 \quad (6)$$

Layer 4: Square node with node function:

$$O_i^4 = w_i' f_i = w_i'(p_i x + q_i y + r_i) \quad (7)$$

p, q, r – parameter set (consequent, linear parameters)

Layer 5: circle node. This node computes the overall output as the summation of all incoming signals.

$$O_i^5 = overalloutput = \sum_i w_i' f = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (8)$$

The model's architecture is given in Fig. 1, which comprises five layers: fuzzification, product, rule, defuzzification and output summation layers using the Takagi-Sugeno fuzzy system [32,33]. The development procedure is presented in Table 2. The model is trained until a satisfying small testing error is reached. Finally, the ANFIS design parameters are presented in Table 2.

Table 2: ANFIS design parameters

No. of inputs	No. of output	No. of hidden layers	No. of membership functions	No. of rules	Defuzzification method
2	2	10	7	9	Takagi-Sugeno

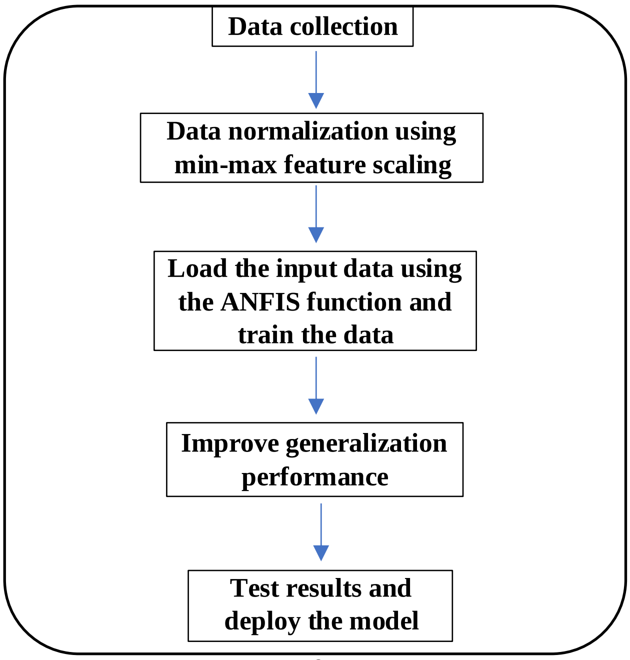

Fig 1-b: Procedures for developing ANFIS

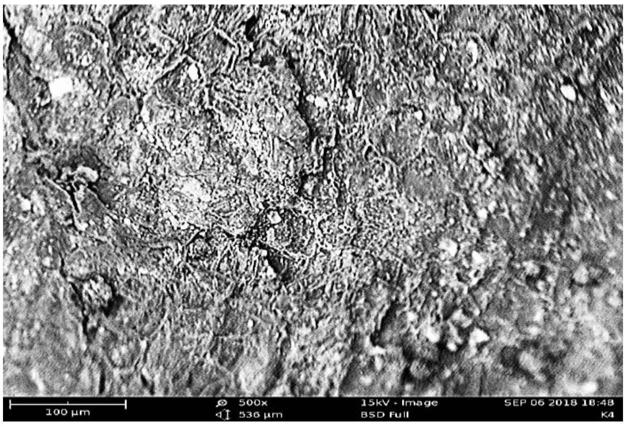

Fig. 2: SEM analysis of the untreated GS sample

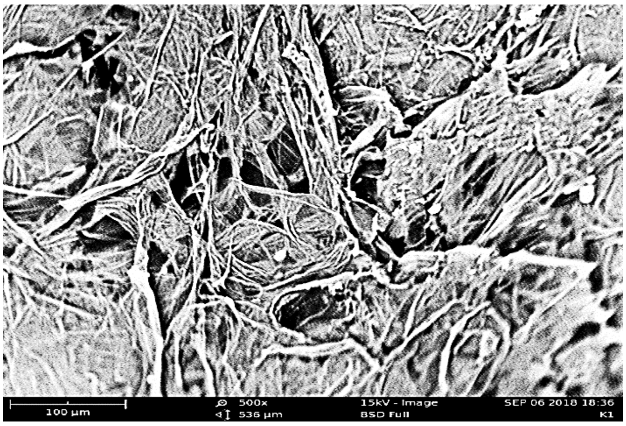

Fig. 3: SEM analysis of the treated GS sample

Performance evaluation of the developed models

Statistical parameters were applied to determine the performance of the proposed model for the prediction of the mercerization process. MSE and R^2 are shown in Equations (1, 2).

$$\text{MSE} = \frac{1}{P}\sum_{p=1}^{p}(d_p - O_p)^2 \qquad (1)$$

$$R^2 = 1 - \frac{\sum_{p=1}^{p}(d_p - O_p)^2}{\sum_{p=1}^{p}(O_p)^2} \qquad (2)$$

RESULTS AND DISCUSSION

According to the SEM analysis, the untreated groundnut shell sample in Fig. 2 has a smoother surface; this is because of the wax coating on the fibre surface, the mercerized groundnut shell fibre is shown in Fig 3, the concave and porous texture in the microfibril shape and the unequal distribution of microfibrils in cellulose was activated by mercerization treatment; which appeared on the treated groundnut shell sample, the surface area was increased, and the impurities (the lignin, hemicellulose); the entire fibres were converted into a swollen and straightened state, indicating that the assembly and orientation of microfibrils were utterly disrupted. The roughened surface of mercerized groundnut shell fibres directly resulted from the removed surface wax lay from the alkali treatment. This coincides with the findings of *Wang et al*. [14] on the microstructural properties of mercerized cotton fibre.

FT-IR spectra at 2851.4cm-1, 1595.3cm^{-1}, 1401.5 cm^{-1}, and 1017.6cm^{-1} in Fig. 4 indicate crystalline regions; peaks at 2922.2 cm^{-1} show aliphatic C-H stretch of the methyl and methylene, 3291.2 cm^{-1} showed absorption of –OH stretching area in untreated samples, suggesting that it absorbs moisture readily. Glycosidic group characterization was observed at the peak of 1099.6cm^{-1}. In Fig. 5, the band at 3306.cm^{-1} shows the presence of cellulose. The hydroxyl group vanished at the peak of 2918.5cm^{-1} due to the breakdown of lignin and hemicellulose bonds due to the treatment. Alkali-cellulose

Table 3: One-input variable ANFIS (exhaustive search) for groundnut shell mercerization process

No of Input	Input Variable	RMSE Training	RMSE Checking
1	Time of treatment	1.3102	1.4800
1	Treatment concentration	2.0263	2.3296
2	Time time/concentration	0.1194	0.1147

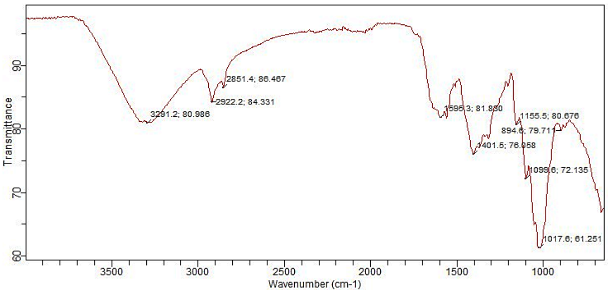

***Fig. 4**: FT-IR of the untreated GS sample*

synthesis is encouraged by stretching C=O and C=C groups at 678.4cm^{-1} and 1025.0 cm^{-1}. The increasing spectral intensity corresponds to the performed treatment, indicating greater exposure of the cellulose due to the removal of other constituents; the band at 678.4cm^{-1} is also attributed to angular deformation outside the plane of the C-O-H bond. As a result, its moisture intake was lowered [26]. These findings are in line with *Reichart et al*. [38] on the utilization of pineapple crown fibre and recycled polypropylene for the production of sustainable composites.

ANFIS Simulation results for groundnut shell mercerization process

In MATLAB, the (ANFIS) exhaustive search function employed Root Mean Square Error (RMSE) as a parameter to evaluate the sensitivity of the process parameter on mercerized groundnut shell fibre. The value of RMSE close to zero ascertains the degree of predictability and reliability of the model [33]. Tables 3 demonstrate the effect of one and combined input variables on the slightest training error. It indicates that time had the most significant impact as a single variable with RMSE (1.3102) on the groundnut shell fibre mercerization process. However, treatment time and concentration had the most effective combined effect on the mercerization process with an RMSE (0.1194). These results confirm that the process parameter significantly impacts groundnut shell fibre mercerization. This observation is similar and followed the claim of previous investigations from *Oke et al*. [22] on three leaved yam drying prediction and *Nwosu-Oobieogu et al*. [31] on ANFIS prediction of *luffa* seed oil antioxidant extraction where temperature (0.9077) and temperature/time (0.556) gave the least RMSE for polyphenol yield while time (2.29572) and time/solvent-seed ratio gave the least RMSE for terpineol yield.

Table 4: MSE of ANFIS model for groundnut shell mercerization process

Input membership function	MSE (constant)	R2
Gauss	0.056	0.99164
Gauss2	0.0292	0.99262
Gbell	0.0183	0.99105
Tri	0.069	0.99299
Trap	0.1265	0.99353
Pi	0.011679	0.99364
Dsig	0.13462	0.98699

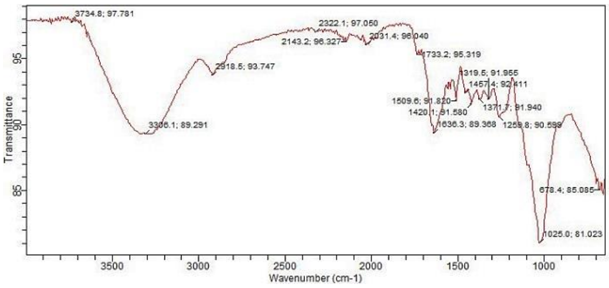

Fig. 5: FT-IR of the treated GS sample

The efficiency of ANFIS is represented in Table 4. The impacts of several input membership functions (mf) such as *gbell*, *gauss*, *gauss2*, *trap*, *pi*, and *dsig* on the groundnut shell mercerization process with a constant 1000 epoch number are summarized. R^2 (coefficient of determination) and MSE (mean square error) were used to assess the model's predictiveness. R^2 varies from 0.98699 to 0.99364, with MSE ranging from 0.011679 to 0.13462. The ranges of R^2 values are close to 1, and MSE values are close to zero. Although *pi* mf had the best R^2 (0.99364) and MSE (0.011679) for the process, other mfs such *tri* R^2 (0.99299), MSE (0.069), *dsig* R^2 (0.98699), MSE (0.13462), *trap* R^2 (0.99353), MSE (0.1265), *gbel* R^2 (0.99105), MSE (0.0183), *gauss* R^2 (0.99164), MSE (0.056), *gauss2* R^2 (0.99267), MSE (0.0292) suggested closeness to the experimental data as depicted by accurate prediction of the ANFIS model; this also indicates that ANFIS successfully predicted the groundnut shell mercerization process. This coincides with the reports of *Chong et al*. [39] where *psig*

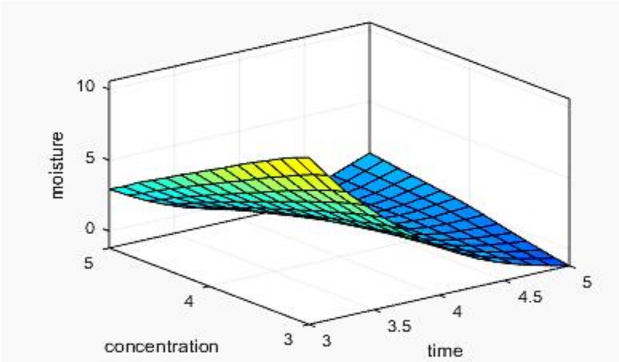

Fig. 6: ANFIS plot for the interaction effect of treatment time and concentration for the mercerization process.

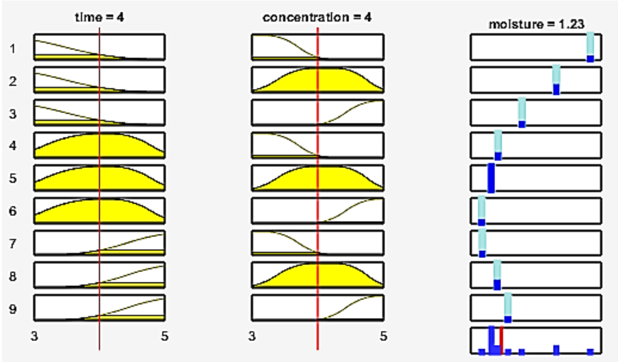

Fig 7: ANFIS rule viewer for groundnut shell mercerization process

mf gave the least MSE (0.00497) for dye concentration measurement and prediction using a plastic optical fiber sensor, *Hajj et al*.[40] obtained an R^2(0.9997) from the prediction of color strength of plasma-treated wool yarns dyed with a natural colorant using ANN and ANFIS; also the findings are consistent with the prior study by *Nwosu-Obieogu et al*. [29] on antioxidant yields from *luffa* oil, *Yue et al*.[25] in modeling biodiesel production from castor using ANFIS, *Roy et al*. [26] in the ANFIS prediction of the almond seed oil extraction process.

Fig. 6 demonstrates the interaction between the profess factors (treatment time and concentration) and response (moisture absorption). An increase in treatment time and concentration of the mercerization treatment led to a subsequent decrease in the moisture absorption rate of groundnut shells. Hence, this indicates that the groundnut shell was mercerized appropriately to enhance interfacial adhesion with the matrix during composite processing. The ANFIS surface plots agree with the findings of *Nwosu-Obieogu et al*. [29] on *luffa* seed oil extraction and *Adeyi et al*. [37] on the water absorption properties of *ampelocissus cavicaulis* fibre-reinforced epoxy composite using ANFIS.

The ANFIS-formulated rules are depicted in Fig. 7; The rules are essential in mapping input to output data. which is the fuzzy logic aspect of ANFIS [29]. The moment the ANFIS structure is created, these rules can be tuned to make a prediction even on points that were not experimentally examined but are within the experimental bound. 9 fuzzy rules were utilized to predict the moisture absorption rate of the groundnut shell. The predicted moisture absorption of 1.23 % was obtained at (a treatment time of 4 hours and a concentration of 4 mol) as shown in Fig 6. This validates the ANFIS model's accuracy in predicting groundnut shell mercerization. Furthermore, the findings are consistent with those of *Ojediran et al*. [26] on yam slices drying prediction and *Adeyi et al*. [37] on the water absorption properties of *ampelocissus cavicaulis* fibre reinforced epoxy composite using ANFIS.

CONCLUSIONS

- This study has successfully applied the ANFIS technique in predicting the groundnut shell mercerization process using statistical indicators (MSE, R^2).
- ANFIS model development was optimum when the trap membership function was utilized with R^2 and MSE. even though, the determination of the optimum size of the model and the permanence in local minima has been the significant disadvantage of ANFIS.
- The sensitivity and parametric analysis showed that the process factors (time of treatment and concentration) significantly affected the moisture absorption rate of the groundnut shell.
- The FT-IR confirmed the functional groups, while the SEM presented the surface morphology of the mercerized groundnut shell fibre.
- Hence the findings of this research are practically relevant in groundnut shell utilization as a reinforcement in composites and a fuzzy-based controller design involving mercerized groundnut shells.

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Nomenclature

mean square error	MSE
coefficient of determination	R^2
membership function	mf

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References

[1] Alaneme K.K., Bodunrin M.O., Awe A.A., Microstructure, Mechanical and Fracture Properties of Groundnut Shell Ash and Silicon Carbide Dispersion Strengthened Aluminium Matrix Composites, *Journal of King Saud University-Engineering Sciences*, **30(1):** 96-103 (2018).

[2] Nwosu-obieogu K., Ejim I.F., Adekunle K.F., Mechanical Properties of Rice Husk Reinforced Low-Density Polyethylene Composite, *International Journal of Research in Advanced Engineering and Technology*, **2(1):** 10-15 (2016).

[3] Obasi H.C., Nwanonenyi S.C., Chiemenem L., Nwosu-Obieogu K., Effects of Fibre Acetylation and Fibre Content on the Properties of Piassava Fibre Reinforced Polystyrene, *Futo. J. Ser.*, **4:** 475-491 (2018).

[4] Faria L.U.S., Pacheco B.J.S., Oliveira G.C., Silva J.L., Production of Cellulose Nanocrystals from Pineapple Crown Fibres through Alkaline Pretreatment and Acid Hydrolysis under Different Conditions, *Journal of Materials Research and Technology*, **9(6):** 12346-12353 (2020).

[5] Nwosu-Obieogu K., Aguele F.O., Chiemenam L.I., Akatobi K.N., Osoh K., Onyekwulu C.S., Creep and Stress Relaxation Behaviour of Rice Husk Reinforced Low-Density Polyethylene Composites, *European Journal of Sustainable Development Research*, **4(4):** em0144 (2020).

[6] Zhu L., Zhao H., Lan B., Hou L., Bi S., Xu Y., Lu Y., Bio-inspired Fabrication of Cu-Ni Coatings onto Mercerized Flax Fabric by Electroless Plating, *Fibres and Polymers*, **21(2):** 324-333 (2020).

[7] Camani P.H., Anholon B.F., Toder R.R., Rosa, D.S., Microwave-Assisted Pretreatment of Eucalyptus Waste to Obtain Cellulose Fibres, *Cellulose*, **27(7):** 3591-3609 (2020).

[8] Ayo M.D., Ekebafe L.O., Chukwu M.N., Madufor I.C., Effect of Carbonization Temperatures of the Filler Properties of Groundnut Shell Powder, *International Journal of Chemistry*, **21:** 55-58 (2011).

[9] Lazarenko G., Kasprzhitskii A., Yavna V., Mischinenko V., Kukharskii A., Kruglikov A., Yalovega G., Effect of Pre-Treatment of Flax Tows on Mechanical Properties and Microstructure of Natural Fibre Reinforced Geopolymer Composites, *Environmental Technology & Innovation*, **20:** 101105 (2020).

[10] Nomura S., Sato S.I., Erata T., DFT Approach to the Pathway of Conformational Changes of Cellulose C6-hydroxymethyl Group with Simple Cellotetraose Model İnvolving the Mechanism of Mercerization Process, *Chemical Physics Letters*, **742:** 137154 (2020).

[11] Kenechi N.O., Linus C., Kayode A., Utilization of Rice Husk as Reinforcement in Plastic Composites Fabrication-A Review, *American Journal of Materials Synthesis and Processing*, **1(3):** 32-36 (2016).

[12] da Silva Nicolau G., Weber R.P., Monteiro S.N., Loureiro G.A., Lavinsky A.A., da Fonseca L.V., Machado V.C., Influence of Mercerization Process on the Surface of Coconut Fiber for Composite Reinforcement, *Materials Science Forum*, **1012:** 37-42 (2020).

[13] Rajeshkumar G., An Experimental Study on the İnterdependence of Mercerization, Moisture Absorption and Mechanical Properties of Sustainable Phoenix sp. Fiber-reinforced Epoxy Composites, *Journal of Industrial Textiles*, **49(9):** 1233-1251 (2020).

[14] Wang H., Farooq A., Memon H., Influence of Cotton Fibre Properties on the Microstructural Characteristics of Mercerized Fibres by Regression Analysis, *Wood Fiber Sci*, **52(1):** 13-27 (2020).

[15] Ferro M., Mannu A., Panzeri W., Theeuwen C.H., Mele A., An İntegrated Approach to Optimizing Cellulose Mercerization, *Polymers*, **12(7):** 1559 (2020).

[16] Hassan M.Z., Roslan S.A., Sapuan S.M., Rasid Z.A., Mohd Nor A.F., Md Daud M.Y., Mohamed Yusoff M.Z., Mercerization Optimization of Bamboo (Bambusa Vulgaris) Fibre-Reinforced Epoxy Composite Structures using a Box–Behnken Design, *Polymers*, **12(6):** 1367 (2020).

[17] Nwosu-Obieogu K., Aguele F.O., Chiemenem L.I., Optimization on Rubber Seed Oil Epoxidation Process Parameters using Response Surface Methodology, *Iranian Journal of Chemistry and Chemical Engineering (IJCCE)*, **40(5):** 1575-1583 (2020).

[18] Nwosu-Obieogu K., Hamed J.O., Anike E.N., Aguele F.O., Ukandu O., Obasi H.C., Uduma C.K., Chiemenem L.I., Studies on the EPoxidation of Groundnut Seed Oil with Carboxylic Acid *FUTOJNLS*. **5:** 94-101 (2019).

[19] Kamar F.H., Nechifor A.C., Alwan G.M., Craciun M.E., Nechifor G., Comparative Removal of Lead, Copper and Cadmium İons from Wastewater in Single and Ternary Batch Biosorption Systems onto Dry Walnut Shells, *Rev. Chim. (Bucharest)*, **66(8):** 1083 (2015).

[20] Shakor Z.M., Mahdi H.H., Al-Sheikh F., Alwan G.M., Al-Jadir T., Ni, Cu, and Zn Metal İons Removal from Synthetic Wastewater Using a Watermelon Rind (Catullus Landaus), *Materials Today: Proceedings*, **42:** 2502-2509 (2021).

[21] Alwan G.M., Improving Operability of Lab-Scale Spouted Bed using Global Stochastic Optimization, *Journal of Engineering Research and Applications*, **5:** 136-146 (2015).

[22] Oke E.O., Nwosu-Obieogu K., Ude C.J., Experimental study and exergy efficiency prediction of three-leaved yam *(Dioscorea duodenum)* starch drying, *Int. J. Exergy*, **33(4):** 427-443 (2020).

[23] Nwosu-Obieogu K., Aguele F., Chiemenem L.I., Soft Computing Prediction of Oil Extraction from *Huracrepitan* Seeds, *Kem. Ind.*, **69(12):** 653-658 (2020).

[24] Mashhadban H., Kutanaei S.S., Sayarinejad M.A. Prediction and Modelling of Mechanical Properties in Fibre Reinforced Self-Compacting Concrete using Particle Swarm Optimization Algorithm and Artificial Neural Network, *Construction and Building Materials*, **119:** 277-287 (2016).

[25] Nwosu-Obieogu K., Ejim I.F., Adekunle K.F., Mechanical Properties of Rice Husk Reinforced Low-Density Polyethylene Composite, *International Journal of Research in Advanced Engineering and Technology*, **2(1):** 10-15 (2016).

[26] Ojediran O.J., Okonkwo C.E., Adeyi A.J., Adeyi O., Olaniran F.O., George N.E., Olayanju A.T., Drying Characteristics of Yam Slices (Dioscorea Rotundata) in a Convective Hot Air Dryer: Application of ANFIS in the Prediction of Drying Kinetics, *Heliyon*, **6:** e03555 (2020).

[27] Yue X., Chen Y., Chang G., Accurate Modelling of Biodiesel Production from Castor Oil using ANFIS, *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, **1:** 1-7 (2018).

[28] Roy K., Mukherjee A., Jana K.D., Prediction of Maximum Oil Yield from Almond Seed in the Chemical İndustry: A Novel Type-2 Fuzzy Logic Approach, *South African Journal of Chemical Engineering*, **29:** 1-9 (2019).

[29] Nwosu-Obieogu K., Dzarma G.W., Ugwuodo B.B., Chiemenem L.I., Akatobi K.N., *luffa* Seed Oil Extraction: Response Surface and Neuro-Fuzzy Modelling Performance Evaluation and Optimization, *Process İntegration and Optimization for Sustainability*, **1:** 1-14 (2021).

[30] Nwosu-Obieogu K., Dzarma G.W., Ehimogue P., Ugwuodo C.B., Chiemenem L.I., Textile wastewater heavy metal removal using *luffa cylindrica* activated carbon: an ANN and ANFIS predictive model evaluation, *Applied Water Science*, **12(3):** 1-11 (2022).

[31] Nwosu-Obieogu K., Dzarma G., Chiemenem L., ANFIS Prediction of Antioxidants Yield for *Luffa* Oil, *Acta Technica Corviniensis-Bulletin of Engineering*, **14(4):** 65-68 (2021).

[32] Nwosu-Obieogu K., Dzarma G.W., Ugwuodo C.W., Chiemenem L.I., Environmental Sustenance *via* Melon Seed Peel Conversion to Fermentable Sugars using Soft Computing Models, *Cleaner Engineering and Technology*, **7:** 100452 (2022).

[33] Nwosu-Obieogu K., Muofunnaya U., Rubber Seed Oil Epoxidation; Experimental Study and Soft Computational Prediction, *Annals of the faculty of Engineering Hunedoara-International Journal of Engineering*, **4:** 65-70 (2021).

[34] Yin G., Alazzawi F.J.I., Bokov D., Marhoon H.A., El-Shafay A.S., Rahman M.L., Nguyen H.C., Multiple Machine Learning Models for Prediction of CO_2 Solubility in Potassium and Sodium based Amino Acid Salt Solutions, *Arabian Journal of Chemistry*, **15(3):** 103608 (2022).

[35] Xu P., Alqsair U.F., El-Shafey A.S., Prediction of Gas Fraction in Wastewater Treatment with ANFIS Method for Different Height of Single Sparger Location, *Environmental Technology & Innovation*, **26:** 102350 (2022).

[36] Alhumade H., Rezk H., An Accurate Model of the Corrosion Current Density of Coatings Using an Adaptive Network-based Fuzzy İnference System, *Metals*, **12(3):** 392 (2022).

[37] Adeyi A.J., Adeyi O., Ogunsola A.D., Fajobi M.O., Ajayi O.K., Oyelami S., Otolorin J.A., Moisture Absorption Characteristics and Adaptive Neuro Fuzzy Modelling of *Ampelocissus Cavicaulis* Fiber Reinforced Epoxy Composite, *LAUTECH Journal of Engineering and Technology*, **14(2):** 89-97 (2020).

[38] Reichart A.A., DaSa R.M., DaSilva H.E.G., Beatrice G.A.C., Fajardo A.R., de Oliveira D.A., Utilization of Pineapple Crown Fibre Recycled Polypropylene for Production of Sustainable Composite, *Journal of Renewable Materials*, **8(10):** 1327-1341 (2020).

[39] Chong S.S., Aziz A.A., Harun S.W., Arof H., Shamshirband S., Application of Multiple Linear Regression, Central Composite Design, and ANFIS Models in Dye Concentration Measurement and Prediction using Plastic Optical Fibre Sensor, *Measurement*, **74:** 78-86 (2015).

[40] Haji A., Payvandy P., Application of ANN and ANFIS in the Prediction of Colour Strength of Plasma-Treated Wool Yarns Dyed with a Natural Colourant, *Pigment & Resin Technology*, **49(3):** 171-180 (2020).