Performance evaluation of ANFIS, ANN and RSM in biodiesel synthesis from Karanja oil with Domestic Microwave set up

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Abstract

The investigated considering time (4–8 min), methanol/oil mole ratio (30–50%), volume (100–300 mL) and catalyst concentration (1–2 wt%) using Box Behnken design. Statistical performance gauge showed ANFIS (Root mean square error (RMSE) = 1.086, coefficient of determination(R^2) = 0.94 and mean square error (MSE) = 1.179) and ANN (R^2 = 0.866, RMSE = 1.55, MSE = 2.42) models narrate process with excellent precision differentiate to RSM (R^2 = 0.85, RMSE = 1.67, MSE = 2.789). modified Domestic Microwave used for experimentation, which is functioning at 2450 MHz, topmost power output of 700W attached with DC motor having 100 rpm for stirring action. The optimized parameters of reaction are catalyst (1.5 %), Methanol/oil ratio (35 %), time (5 minutes), and volume (150 ml). Highest yield of 87.34% is extracted with above optimum condition.

Keywords: microwave, karanja oil, ANFIS, ANN, Box–Behnken design.

1. Introduction

In past studies, clean and frothy oil has been chosen by researchers' research in respect of biodiesel development, as oils have shortest process time and not require pre-treatment before transesterification base [1]. However, inedible oils from rubber, castor, tobacco, jatropha and more have been obtained for biodiesel generation worldwide. Biodiesel is a favourable alternate for petroleum-extracted diesel due to similarities between the physicochemical characteristics of diesel and biodiesel [2]. Karanja oil, inedible oil grown in huge quantities on Indian regions, is promising raw material for biodiesel generation [3]. Microwave is an energy combination of a magnetic field along with electric field, which is form of electromagnetic waves having wavelengths of 1 mm - 1 m (300 MHz - 300 GHz frequency) [4]. Process is depends on heating liquid by microwave energy and not affect molecular structure due to microwave energy is less than ionization energies of compounds or van der Waals intermolecular interactions. Consequently, effect of microwaves in extraction and chemical processes is alone responsible for transformation of electromagnetic energy into heat [5]. Several investigators [6, 7, 8] have reported studies related to use of microwave irradiation with related to transesterification technique [6,7,8]. RSM is multifaceted tool utilize for experimental design, optimization and modelling. It is distinctive in that it provides statistical indicators on individual model terms and interaction [9]. Production of biodiesel from various oils using RSM [10, 11]. However, it is not as efficient as ANFIS and ANN techniques in terms of evalution capacity [12, 13]. ANN is learning tool that mimics neurological ability of human brain. It is shown to be an excellent tool in simulation and modeling of non-linear and highly multiplex problem due to its capability to use algorithms and create relationship between output and input [14]. Neural Network is one of known types of evolutionary computational technique in recent period. Artificial neural networks have demonstrated the capability to solve complex problems of identification and control of non-linear systems and are described as mathematical models for approximation of non-linear functions, data classification, non-parametric regression and clustering, or as behavioural simulations based on accumulation of model biological neurons. Numerous ANN topologies had created to optimize biodiesel production, along with to improve physicochemical properties, engine emission and performance properties of biodiesel [15, 16, 17]. ANFIS is bled of neural networks and fuzzy systems. It incorporates with concepts of both in single capsule, giving its ability to catch synergistic advantages of both tools [18]. Therefore, to help establish importance of choosing optimization and modeling techniques for process improvement and for further determine performance of modeling tools, specifically in transesterification process.

The present work concentrate on modeling of transesterification process for transformation of karanja oil to biodiesel through application of ANFIS, RSM and ANN tools. The effectiveness of techniques was statistically determined using coefficient of determination (R^2), adjusted R^2, MSE, and RMSE. Influence of the volume, catalyst loading, methanol to oil ratio and reaction time their synergies on biodiesel yield is calculated by DoE.

2. Materials and method

Karanja oil (KO) is purchased through Vijaya Agro Industries. Chemicals such as NaOH, methanol and H_2SO_4 are purchased by the nearby market. Tables-1 show four varriables values for microwave heated trans esterification. An LG intellowave domestic microwave utilize for testing carried out at 2450 MHz at highest power of 700W is modified. Trans esterification of oils consists of reducing viscosity of biodiesel extracted from the KO. Influence of microwave energy on both thermal and non-thermal chemical or biochemical reactions. The quantum of microwave energy is written by equation, W = hν. Within microwave and hyper-frequency frequency domain (300MHz-300GHz), the energies are 1.24 $\times 10^{-6}$ -1.24 $\times 10^{-3}$ eV, respectively. These energies are lesser than the ionization energies of covalent bond energies (5 eV), biological compounds (13.6 eV), hydrogen bonds (2 eV), van der Waals intermolecular interactions (less than 2 eV) and lower than associated energy with Brownian motion at 37 ° C (2.7×10^{-3} eV) [19,20].

Table-1 Parameters used in experiment.

Factor	Maximum value	Minimum value
Time (minute)	8	4
Catalyst (wt. %)	2	1
Methanol/ oil (%)	50	30
Volume (ml)	300	100

Biodiesel extraction

Starting phase is pre-treatment, methanol and H_2SO_4 used to reduce FFA below 2%. Process is carried out by oil of100 ml. reaction mixture is heated for fixed stirring (100 rpm), time (5 minutes), methanol (20% w / w) and H_2SO_4 (5% w / w). In processing further, mixture was differentiated and FFA content is calculated. The oil that has lesser than 1% FFA is processed for further process. Microwave supported transesterification of Karanja oil is processed with a different quantity as per experiment design of time (minutes), volume (ml), catalyst (% w / w) and methanol (% w / w). Microwaves contain non-ionizing electromagnetic waves having wavelength between 1 mm to 1 m, depends on frequency value (0.3 to 300 GHz) [21]. Methanol structure is polar molecule having large dielectric constant that is favours for microwave heated. During last step samples are cooled and obtained separately in funnel. Biodiesel separated on upper surface because of its lesser density compared to glycerol phase. Mechanism reaction is shown by equation-1. Biodiesel yield can be estimated by equation -2.

$$\text{Triglycerides} + 3\ \text{MeOH} \xrightarrow{\text{NaoH}} \text{Glycerol} + 3\ \text{Methyl ester} \quad (1)$$

$$\text{Yield} = \frac{Weight\ of\ methyl\ ester\ produced}{Weight\ of\ Oil\ used} \times 100 \quad (2)$$

RSM Model developed

3-level-3 factor Box Behnken design (BBD) of RSM is implemented in modeling of Karanja biodiesel and 29 experimental conditions were generated. Table-2 depicts output of extract level of generated design. Independent parameters ponder for modeling include catalyst loading, methanol/oil ratio, quantity of oil and reaction time. Design expert is utilized for experimental data and graphical demonstration. Equation used for regression is written as (Eq. (3)) linear & quadratic coefficients are I and j. C_i is regression coefficient, C_0 is constant. X_i and X_j are independent non-coded parameters, C_{ij} is regression coefficient of product, C_{ii} is regression coefficient of product term ith predictor variable, e is represented uncertainty of Y. K is quantity of factors.

$$yield(Y) = C_0 + \sum_{i=1}^{k} C_i X_i + \sum_{i=1}^{K} C_{ii} X_i^2 + \sum_{i,i>j}^{k} \sum_{i=1}^{k} C_{ij} X_i X_j + e \quad (3)$$

Table-2 ANFIS,ANN and RSM results

S.no.	X-Time (minute)	Y-Catalyst (wt.%)	Z-Methanol/ Oil (%)	V-Volume (ml)	Biodiesel yield(Y) (Experimental)	Biodiesel yield (ANFIS)	Biodiesel yield (ANN)	Biodiesel yield (RSM)
1	6	1.5	40	200	90.76	89.25	88.11	89.25
2	6	2	40	100	86.54	86.54	86.58	86.59

3	6	1.5	50	300	79.73	79.73	79.74	79.25
4	6	1.5	50	100	82.73	82.73	82.73	83.56
5	6	2	50	200	86.49	86.49	86.49	87.08
6	6	1	50	200	75.46	75.46	75.46	79.14
7	4	1.5	30	200	85.86	85.86	85.81	87.80
8	8	1.5	30	200	79.64	79.64	79.64	81.10
9	6	2	40	300	78.38	78.38	78.39	79.35
10	8	1.5	40	100	85.73	85.73	85.76	85.63
11	6	1	30	200	84.79	84.79	84.78	85.76
12	6	1.5	40	200	84.13	89.25	88.11	89.25
13	8	1.5	50	200	87.24	87.24	87.24	84.69
14	6	1.5	40	200	89.78	89.25	88.11	89.25
15	6	1.5	30	100	89.17	89.17	89.18	88.71
16	6	1.5	30	300	78.68	78.68	78.67	76.90
17	4	1.5	50	200	83.47	83.47	83.47	81.41
18	6	1	40	300	76.46	76.46	76.50	75.81
19	6	1.5	40	200	91.13	89.25	88.11	89.25
20	6	1	40	100	86.28	86.28	82.96	84.70
21	4	1.5	40	300	77.63	77.63	79.88	79.28
22	4	2	40	200	86.34	86.34	83.69	85.68
23	8	1.5	40	300	75.46	75.46	75.70	75.75
24	6	2	30	200	85.38	85.38	87.49	83.26
25	8	2	40	200	82.37	82.37	82.38	83.55
26	6	1.5	40	200	90.46	89.25	88.11	89.25

27	8	1	40	200	81.53	81.53	81.54	81.25
28	4	1.5	40	100	84.26	84.26	87.71	85.52
29	4	1	40	200	84.67	84.67	84.60	82.54

Development of the ANFIS model

The ANFIS technique is adequately trained utilize an experimental data. After evaluating output of hybrid algorithm, it is run to train set data. Figure 2 explains fuzzy inference systems generated to predict yield of transesterification reaction, along with its fuzzy inputs, that is, catalyst (% by weight), volume (ml) methanol / oil ratio (%) and reaction time (minute). A fuzzy system has 3 Gaussian membership functions (mf) for every input, and 81 rules can fairly represent performance of process. Table-2 display the parameter uses for model formation between 4 input parameters and output of responses, using household microwaves. The estimated and experimental yields are represented by run numbers in Figure 3, which demonstrates the precision of model.

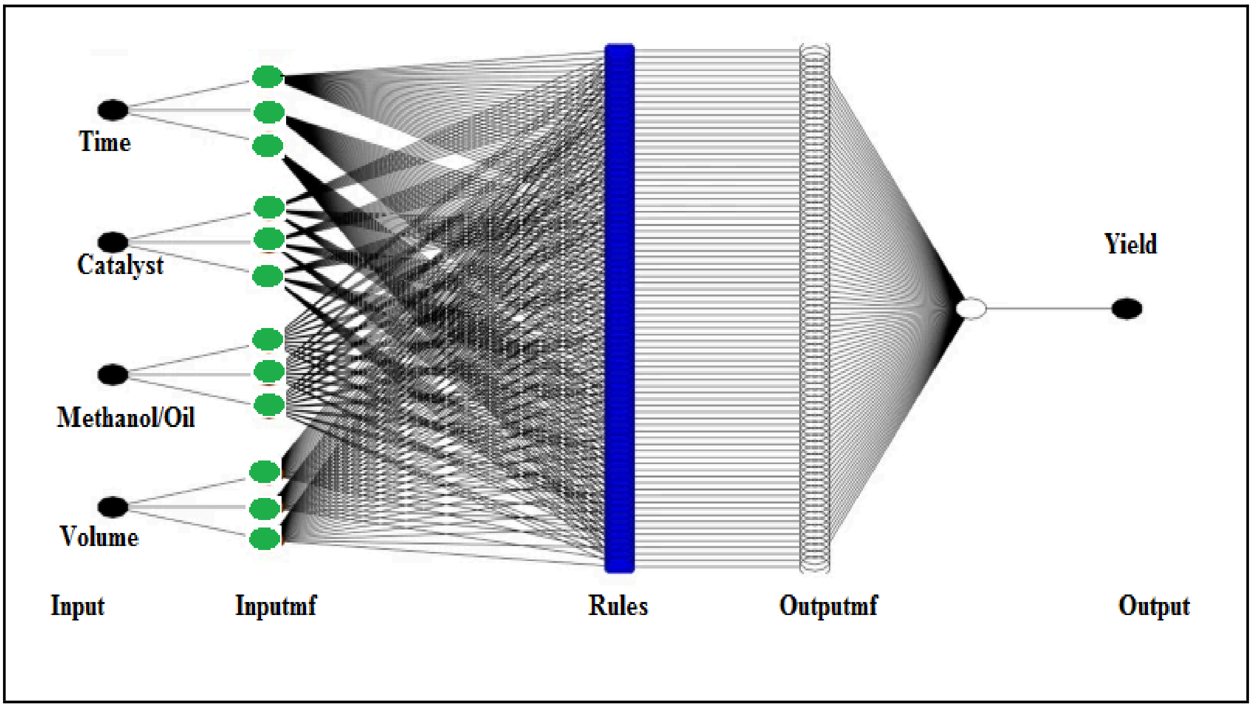

Figure-2 ANFIS structure

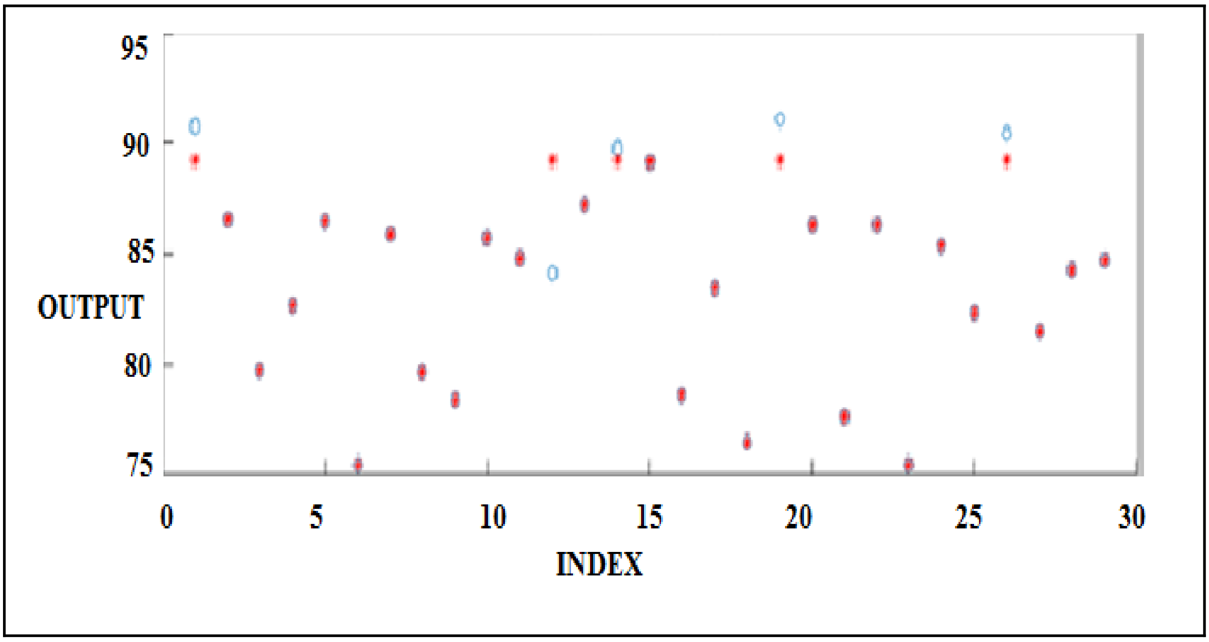

Figure-3 Training data (O) versus FIS output

Development of the ANN model

Tables-2 Depict output for formulation of model between biodiesel yields and input parameters, using a NaOH catalyst with a domestic microwave. The trans esterification process for transformation of esterified karanja oil into biodiesel is modeled by ANN. A back-propagation and multilayer perceptron (MLP) neural network is selected with algorithm Levenberg-Marquardt (LM). This is executed with MATLAB toolbox neural network. For this, 2 to 20 hidden neurons are investigated to build network architecture. Then each of these hidden neurons is trained numerous times and additionally apprised to generate smallest MSE-based output error and highest value of R. final topology chosen for performance estimation is 4-6-1 (figure 4). Figure 5 describes the regression reading for training, validation, testing, and overall. The optimum number of neurons is carefully found out by trial and error. Figure 6 depicts validation performance extracted from curve from different epoch. As depicted Best validation performance is 5.7996 at epoch 10.

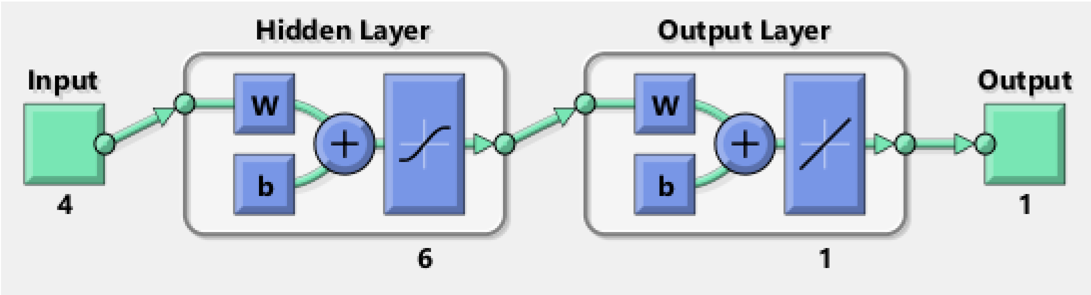

Figure-4 Topology of ANN

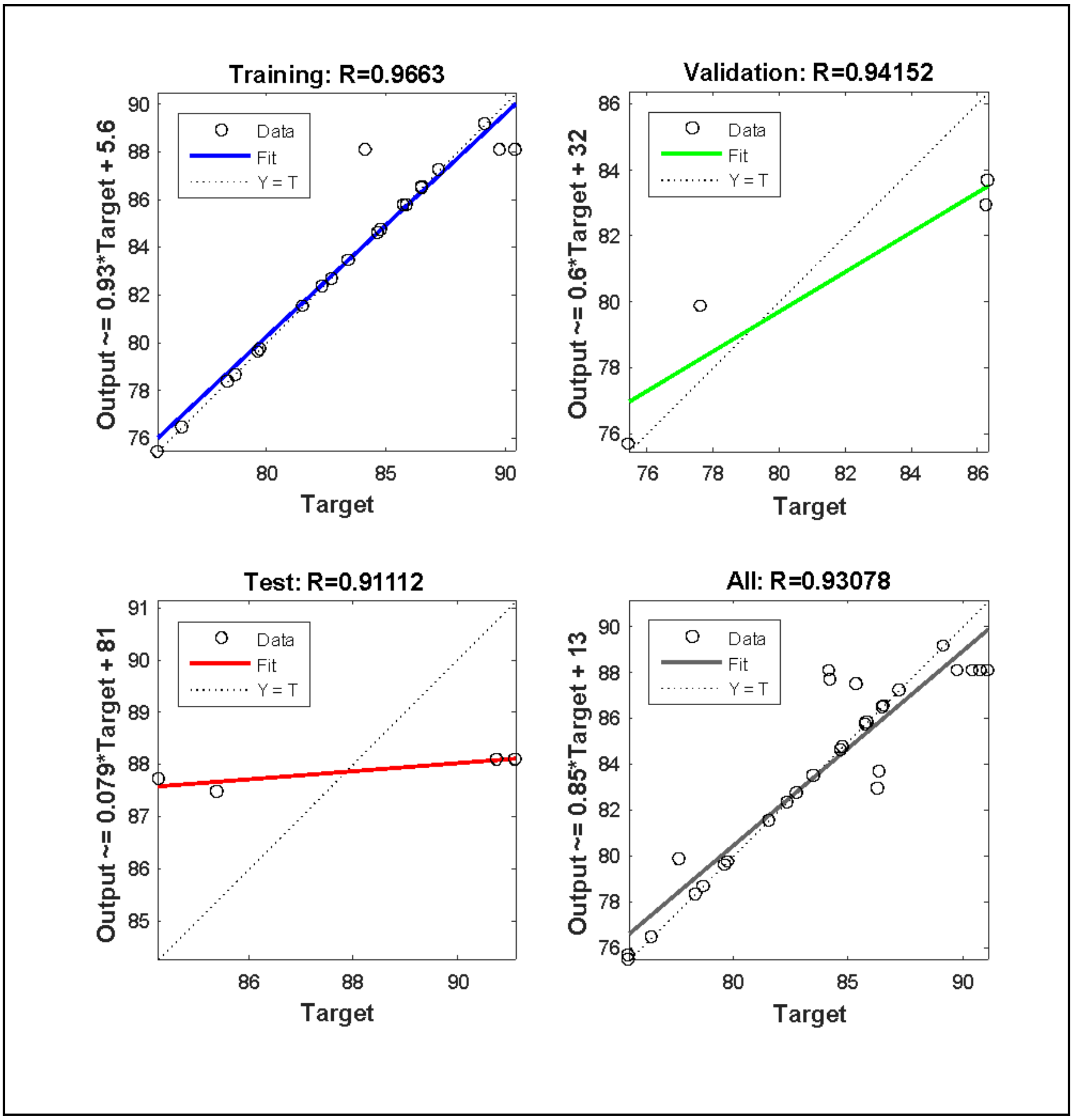

Figure-5 Regression plot for training, validation, test and overall

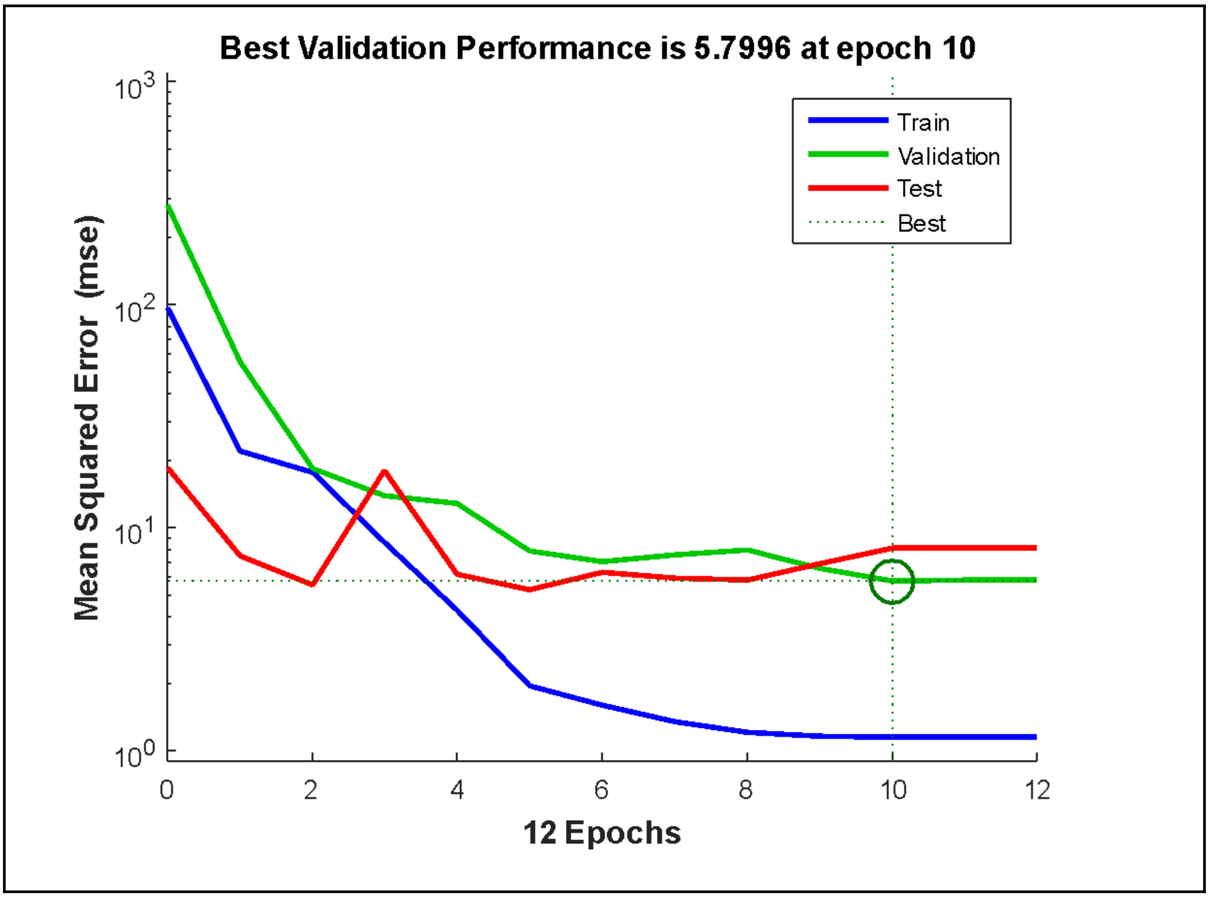

Figure-6 Iterations Plot

3. Results and discussion

Interactive effect of parameters using RSM model

Regression equations (4) for prediction of dependent variable of Karanja biodiesel are written:

Yield=+57.759+17.045×(Y)+4.88×(X)+0.003×(Z)+0.086×(V)0.207×(Y*X)+0.522×(Y*Z)+0.008×(Y*V)+0.124×(X*Z)-0.004×(X*V)+0.001×(Z*V)-11.87×(Y^2)-0.757×(X^2)-0.024×(Z^2)-0.000×(V^2) (4)

ANOVA results of the experiments given in the Table-3. Just 0.01% possibility remains if noise has grater F value. If prb > F less than 0.05000 described that generated model is significant.

Table-3 ANOVA Results

S.N	Values	Parameters
1	significant	Model
2	not significant	Lack of fit
3	0.8499	R^2
4	0.6999	Adjusted R^2

Surface plot described relation between inputs and their combined outcome on KO biodiesel. Model contain 4 parameters, each having 2 specific parameters, whereas other 2 parameters are put fixed in zero in coding as depicts in figures-7 -12. From plots, conclusion drawn yield is depends on input variables. Reaction time is important variable for production of KO biodiesel, which is related with speedup of transesterification. To evaluate their response on biodiesel extraction, reaction times (4 to 8 minutes) are explored and outcomes are displayed in Figure 7, 10, 11. From the response, it is found that biodiesel production increases rapidly in initial phase, but ends up with minimal rate of production. Current process can be described that, in the early stages, microwave heating support thermal collection of reaction mixture that directed to positive production of biodiesel. After that, noticed sudden decrease in production of fuel. Biodiesel production also influenced by catalyst concentration percentage. This alters effect that catalyst has on trans esterification and is checked by altering catalyst concentration (1 to 2.0 W / W). By results (Figure 7, 8, 9) it can be seen that increase in percentage of catalyst speedup production rate. This can be credited to fact that higher percentage of catalyst causes a formation of strong nucleophiles via deportation of alcohol, thus increasing generation of biodiesel. The results distinctly depict importance of catalyst concentration. Concentrations having high value of NaOH catalyst leads to saponification and in emulsification. Methanol: oil ratio is an important parameter in biodiesel extraction from Karanja oil. So that, alternate proportions of methanol to oil (30, 40 and 50% w / w) are used and final results can be drawn in Figures 8, 10, 12. These results depicts same trend as a time factor. Biodiesel production initially increased and thereafter decreased trend. Yield percentage early stage increases in Z (Methanol / oil) and X (Time) and after achieving highest point, it decreases, although there is no sudden change. The volume shows an important role, the sample value from 100 to 200 ml depicts good % age of yield, though 300 ml sample depict decrease of yield percentage. Study described that catalyst concentration and sample volume is main factor affecting microwave heating process.

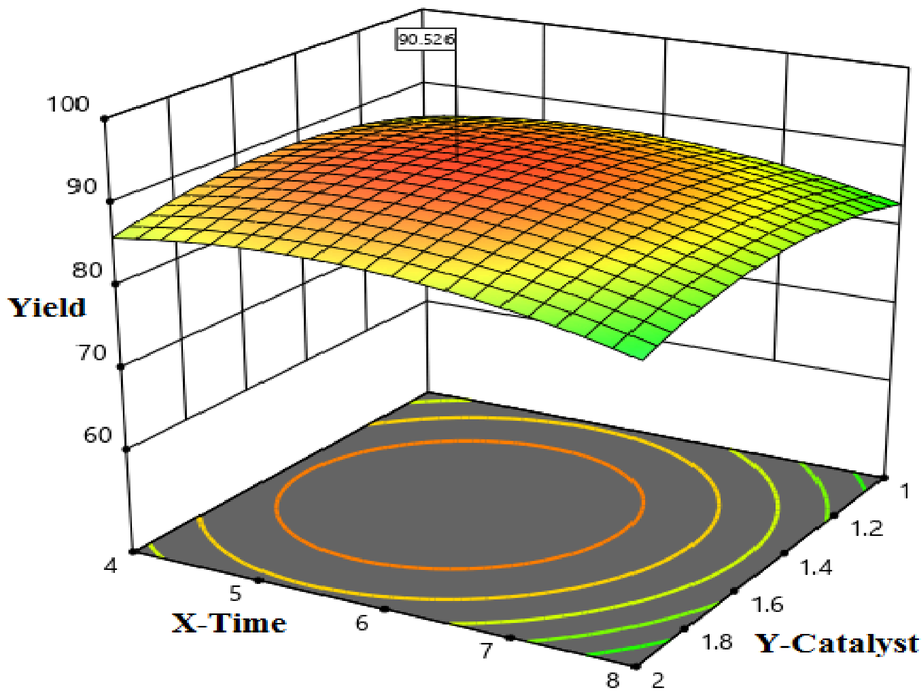

Figure-7 Surface plot between Time V/S Catalyst

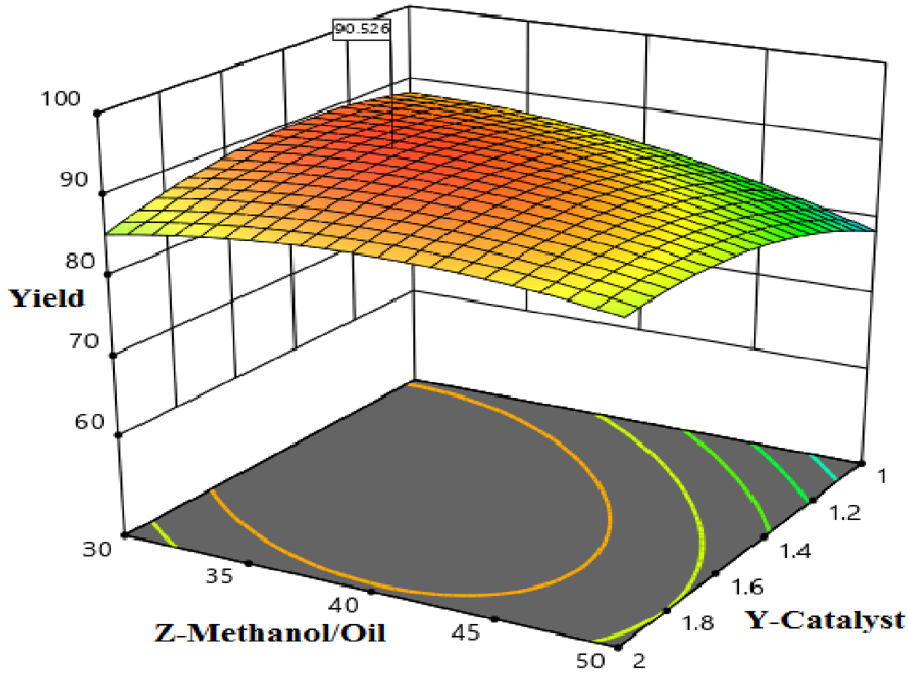

Figure-8 Surface plot Methanol/Oil V/S Catalyst

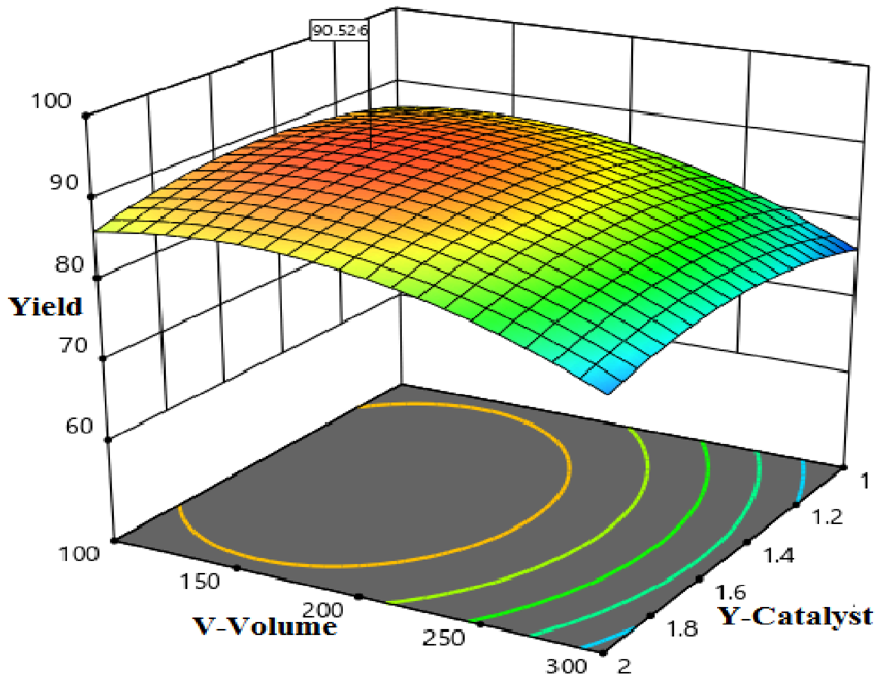

Figure-9 Surface plot Volume V/S Catalyst

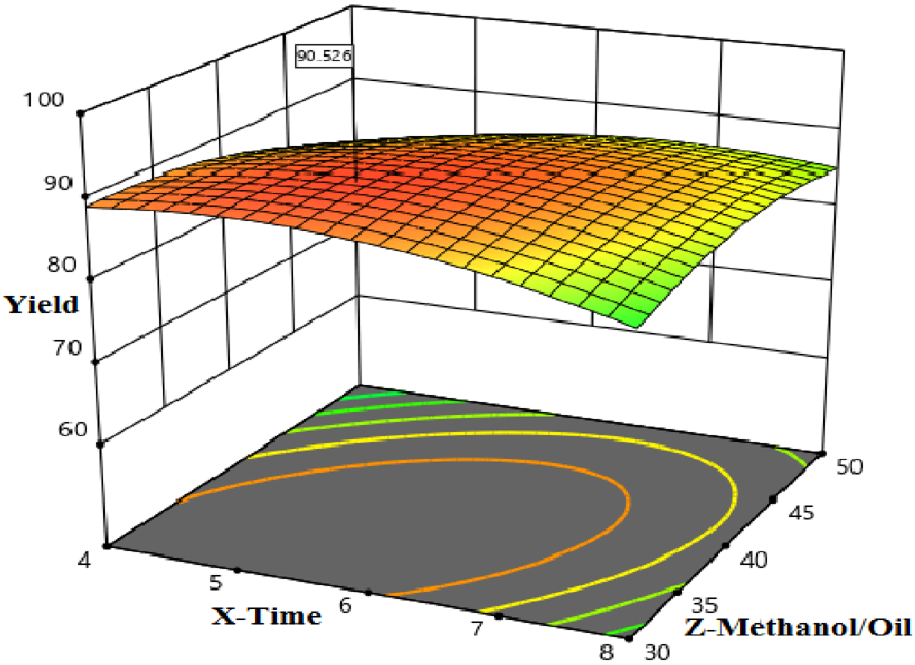

Figure-10 Surface plot Time V/S Methanol/Oil

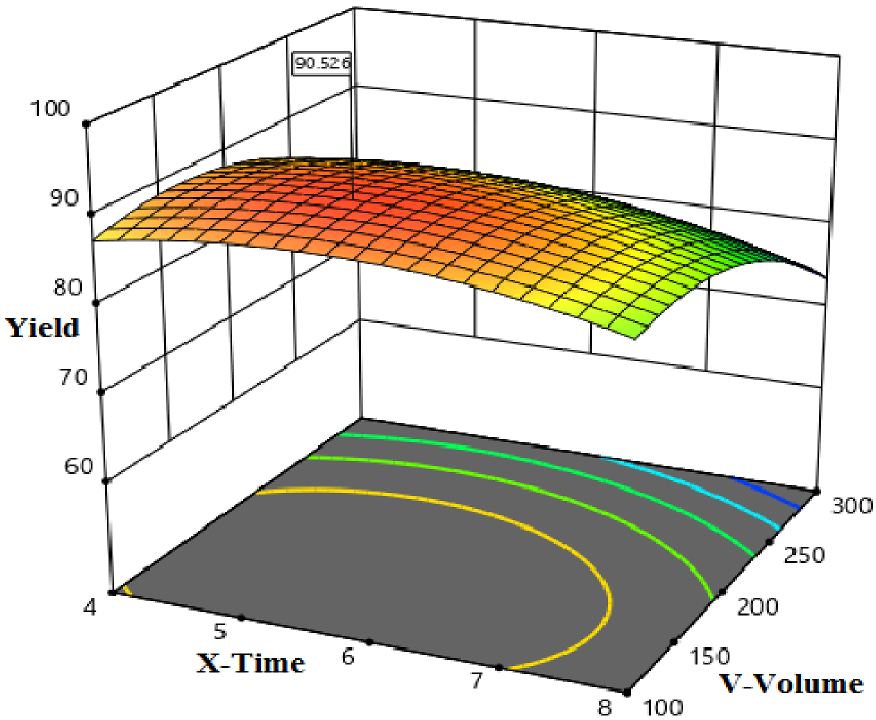

Figure-11 Surface plot Time V/S Volume

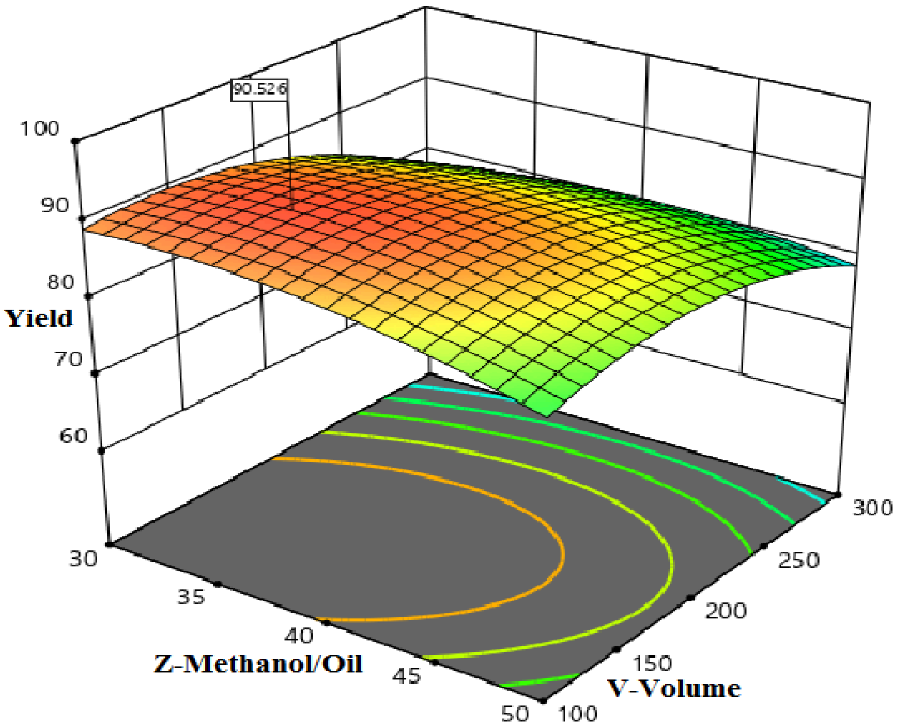

Figure-12 Surface plot Methanol/Oil V/S Volume

Optimization and Properties of Biodiesel

Optimum parameters value is written in Tables 4 for of yield. Error in experimental and estimated is 3.52 %, which is best. Characteristics are concluded according to standards (Table 5). Properties of biodiesel (cloud point, kinematic viscosity, pour point, density, fire point flash point and FFA) are estimated according to ISI448, ASTM D6751, ASTM-D5555-95 and ASTM D2500 standard test methods.

Table-4 Optimization of parameters

Parameters	**Experimental value**	**Theoretical value**
Time (minute)	5	5.490
Methanol/oil (%)	35	35.432
Catalyst (%)	1.5	1.501
Volume (ml)	150	150.151
Yield (%)	87.34	90.53
Error	3.52	

Table-5. Properties of Oil & biodiesel.

Properties	**Karanja biodiesel**	**Karanja Oil**
Density (kg/m^3)	884	987
FFA (%)	< 1%	23
Kinematic viscosity (mm^2/s)	4.8	42
Flash point(^0C)	143	239
Fire point (^0C)	222	254
Cloud point (^0C)	-3	7
Pour Point(^0C)	-8	5

Performance of predictive capacity of models

Effectiveness of ANFIS, BBD and ANN models developed to estimate yield of pre-treated karanja oil is estimated using R^2, adjusted R^2, RMSE, MSE and SSE. Results evaluated are shown in Table 6. Regression graphs of theoretical and experimental are shown in Figure-13. This corroborates large values of R^2 observed for 3 models. All three models have high R^2 values are nearby unitary, indicating a good fit of models [22]. Based on results of statistical indices, ANFIS is best followed by ANN and finally RSM model. Experimental as well as predicted values of 3 models are plotted with run numbers (Figure-14). It is easily concluded that RSM model is less precise. ANFIS seems highly precise than ANN in comparison of predictability. Current work has shown that both ANN and ANFIS are superior than RSM in terms of performance of predictions. ANFIS is better than ANN.

Table-6 Comparison between ANFIS, ANN and RSM

S.NO.	Technique	R^2	ADJ-R^2	SSE	RMSE	MSE
1	ANFIS	0.94	0.9408	31.84	1.086	1.179
2	ANN	0.8663	0.8614	65.35	1.556	2.421
3	RSM	0.85	0.6999	75.41	1.671	2.789

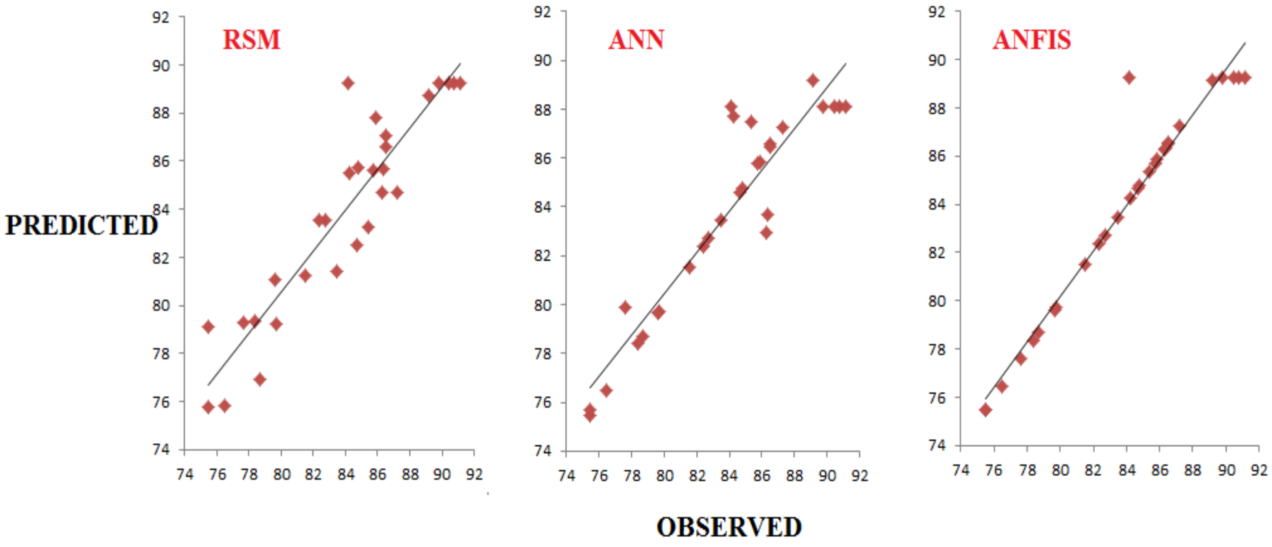

Figure- 13 Regression plot of Predicted and Experimental output

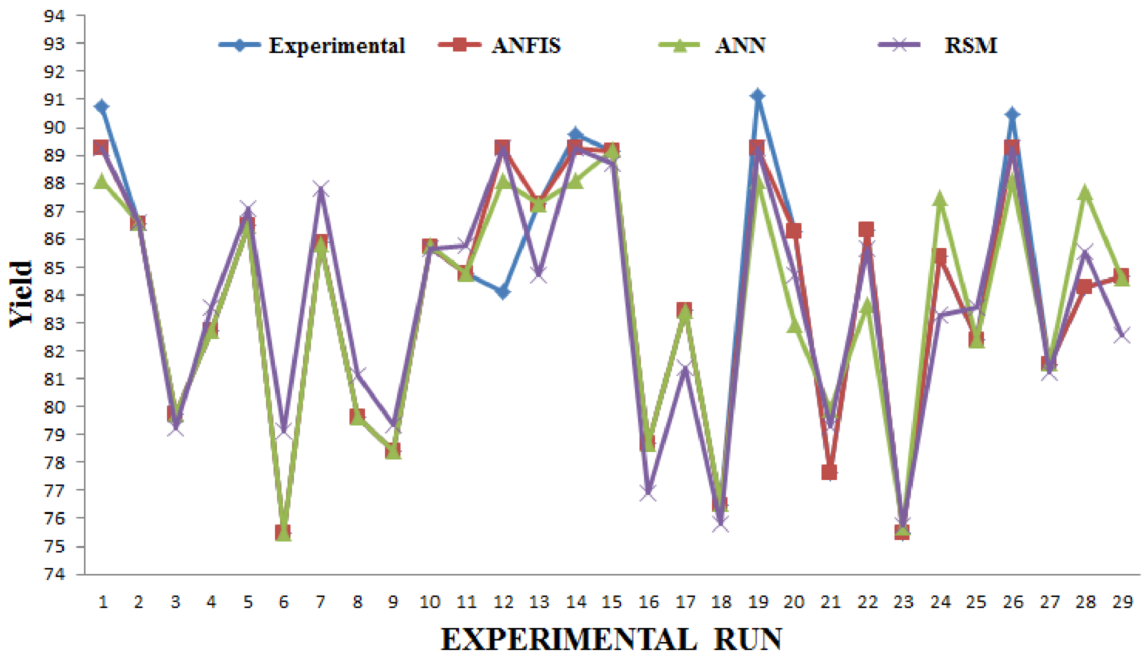

Figure- 14 Experimental and Predicted value

4. Conclusions

In current work, importance of choosing optimization and modeling techniques in transformation of karanja oil to biodiesel with microwave-assisted transesterification process. Based on statistical point estimated, performance of created models in the form of precision and accuracy is in this sequence: ANFIS, ANN and RSM. Statistical indicators implemented to evaluate performance of created models showed RSM the model (R^2 = 0.85, ADJ-R^2 = 0.699, RMSE = 1.671, SSE = 75.41 and MSE = 2.789) is least effective in the form of precision and accuracy of extracted biodiesel. ANFIS model (R^2 = 0.94, ADJ-R^2 = 0.9408, RMSE = 1.086, SSE = 31.84 and MSE = 1.197) is higher ranking to ANN model (R^2 = 0.86, ADJ-R^2 = 0.86144, RMSE = 1.556, SSE = 65.35 and MSE = 2,421). optimization results showed that good combination of process input variables is estimated: catalyst NaOH 1.5 (w / w)%, Methanol / oil ratio 35 (w / w)%, volume 150ml and time of 5 minutes at 100 rpm and 700 W . Its properties are close to standards.

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