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Use of ANN and General Factorial Method to Predict Performance of Maize Dehusker cum Sheller based on Seed Quality Parameters

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SUMMARY

India is the third largest producer of maize, where the majority of land holdings are of small (1-2 ha) and medium (2-4 ha) size. Dehusking and shelling are two major operations carried out after harvesting of maize. Farmers need a dehusker cum sheller with medium capacity that suits their requirement for successful adoption in maize growing regions of India. In the present study, the electric motor (2.23 kW) operated Maize Dehusker cum Sheller (MDS) performance was assessed for different combinations of operational parameters,*viz.* cylinder peripheral speed (PS) (6.2, 6.6, 7.1 & 7.6 m/s), concave clearance (CC) (20, 25, 30 & 35 mm) and feed rate (FR) (400, 600 & 800 kg/h) and evaluation carried against response variables,*viz.,* Dehusking efficiency (DE), %; Shelling efficiency (Sh.E), %; Broken grain losses (BG), %; seed coat damage (SCD), %; and germination percentage (GE), %. The optimization of operational parameters of the machine was done using a numerical optimization technique and performance was evaluated based on response variables using quadratic and artificial neural network (ANN) models. The performance of these models was evaluated based on their R^2, SSE, and RMSE. The optimum operating conditions for MDS with a desirability value of 0.85 are 6.77 m/s of PS, 27.08 mm of CC and 630.46 kg/h of FR. The response variables obtained from these optimum operating parameters were 96.57%, 99.53%, 0.751%, 99.306% and 1.792% for DE, Sh.E, BG, GE, and SCD, respectively. The ANN is a good tool to express the relationship between operating parameters and response variables as compared to the quadratic model.

Keywords: Maize, Seed quality, ANN model, Quadratic model, Optimization.

1. INTRODUCTION

In developing countries like India, the agricultural productions system is the main source of livelihood for one-third of the population. The farmers' dependency on food and fodder supplementing with main crops of cultivation rather than selling commercial crop produce for capital generation (Chaudhary *et al.,*2012; Chilur *et al.,* 2014b). As per the study of Directorate of Maize Research, livestock production is contributing 7% to National GDP and a source of employment and livelihood for 70% of the population in rural areas. In addition, climate change presents a major risk to long-term food security as it may decline wheat and maize yield by 5 to 10 % by 2050 (Anonymous, 2016). In the world, India ranks third in maize production (24.17 mt) and fifth in the area (9.06 m-ha) during 2013-14. In India, maize is grown in all the seasons (Anonymous, 2013), where Karnataka is the second largest maize producing (4.1 mt) state contributing to 17% of total country's production after Andhra Pradesh (Anonymous, 2016b).

Traditionally, dehusking and shelling of maize is carried out manually that involves a lot of drudgery (Mudgal *et al.,* 1998, Singh, 2010, Kumar, 2011, Anonymous, 2012). The output of manual separation is reported to be 30 kg/h with shelling efficiency 80-100%, grain damage 0-8.3% (Mudgal *et al.* 1998, Anonymous. 2005).The capacity of manually operated shellers (27-150 kg/h) is suitable for marginal farmers (Chilur *et al.,* 2014a), where as engine operated (1000-1800 kg/h) and tractor operated (>2000 kg/h) maize shellers are suitable for large farmers. There are no machines to fulfil the requirement of small and medium farmers with a capacity of 200-1000 kg/h.

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Since, 80.3% of farmers in the country comes under small and medium group cultivating 36% of the area (Kumar, 2011). The MDS (Maize dehusker cum sheller) was developed with a capacity of 400-600 kg/h by considering the machine performance and seed quality aspects.

Though many researchers have evaluated different machine performance aspects (dehusking efficiency (DE), shelling efficiency (Sh.E), losses (blower, sieve, total), brokens), till now, no research has been carried out on seed quality parameters,*viz.*, seed-coat damage (SCD) and germination percentage (GE) (Sachin, 2008; Tastra, 2009; Tiwari *et al.*, 2010; Chilur *et al.,* 2014c; Vyavahare and Kallurkar, 2015). Therefore, the performance of the developed MDS was optimized including seed quality parameters using artificial neural network (ANN).

ANNs are a general class of non-linear models (Morse *et al.,* 2011; Sharma & Sawhney, 2015; Sharma *et al.*, 2014a). These are heuristic models, recognized as good tools for dynamic modelling and it is a useful tool for nonparametric regression. ANN model does not require knowledge, assumptions, predefined mathematical relationship, explicit expressions, and inputs-outputs relationships about the nature of undergoing phenomenological mechanisms (Aghbashlo *et al.,* 2015). When the relation between explanatory and response variables is complicated, in that case ANN is a good tool to develop amodel (Omid *et al.,* 2009; Sharma *et al.*, 2013, 2014b). The aim of the present research is optimization of operational parameters and development of the ANN model; and to compare the same with a quadratic model for also developed in the study, for best prediction of response variables.

2. MATERIALS AND METHODS

2.1 Study of machine and seed parameters

The engineering properties (*viz.,* physical, aero-dynamical and frictional) of most commonly growing maize varieties (*viz.,*Mahyco (Hero 550), Hema hybrid variety, Ganga Kaveri (GK-3090) and CP818) were used as suggested by Chilur and Sushilendra (2016) and considered in design of MDS (Mohsenin 1970, Jayan and Kumar 2004, El-Fawal *et al.,*2009, Coskun *et al.*, 2006). The developed MDS was investigated under live conditions in the laboratory and was furthermore, evaluated on-farm with CP 818 maize variety in CAE, Raichur (16.205057° N, 77.329972° E), and Agricultural Research Station, Siraguppa (15.630577° N, 76.916559° E), respectively. The working principle of machine and procedure followed for performance evaluation were discussed elsewhere (Chilur *et al.,* 2014c; Chilur and Sushilendra, 2017).

Performance evaluation of developed MDS was carried in accordance with procedure and guidelines prescribed by the Indian standard test codes IS: 7051-1973 and IS: 6284-1985 for maize and cereals, respectively. The machine operating parameters and response variables used in this study are shown in

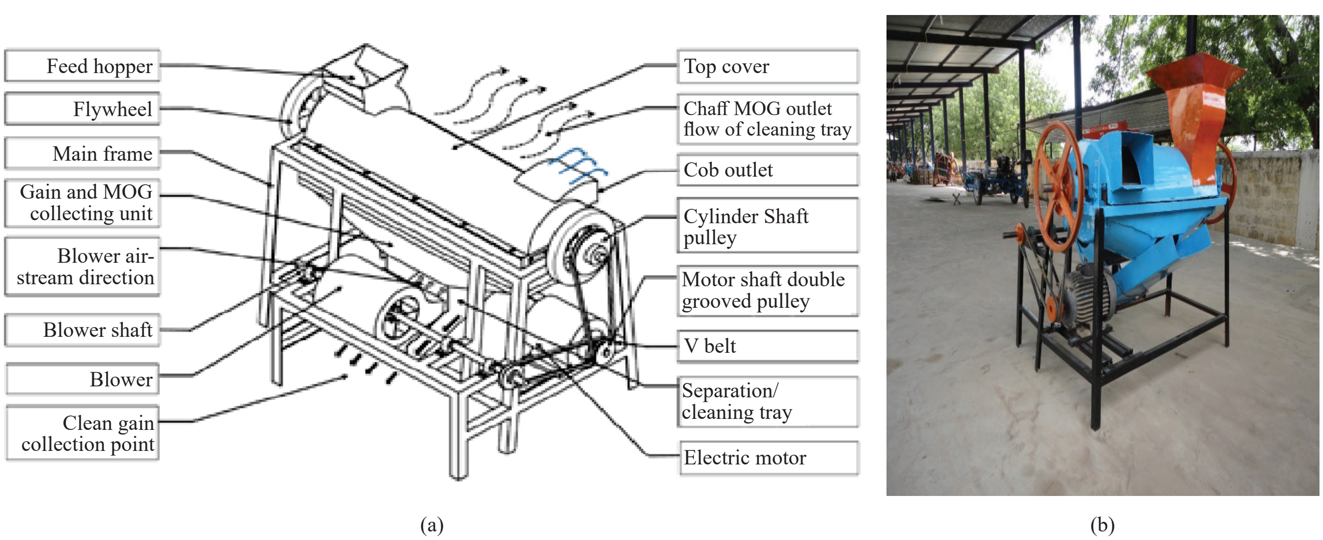


Fig. 1. The line diagram and pictorial view of developed maize dehusker cum sheller (MDS)

Table 1. The operational and response parameters used in the study

Independent/Operational parameters				Response variables of seed-quality
	Levels	Description	Value	
Cylinder peripheral speed (PS), m/s	4	S_1	6.2	1. Dehusking efficiency (DE), % 2. Shelling efficiency (Sh.E), % 3. Broken grain losses (BG), % 4. Germination percentage (GE), % 5. Seed-coat damage (SCD), %
		S_2	6.6	
		S_3	7.1	
		S_4	7.6	
Concave clearance (CC), mm	4	C_1	20	
		C_2	25	
		C_3	30	
		C_4	35	
Feed rate (FR), kg/h	3	F_1	400	
		F_2	600	
		F_3	800	

Table 2. Different equations of dependent parameters used for performance study

Dependent variable	Equation	Terms	Reference
1. Dehusking efficiency (DE), %	$DE = \left[1 - \frac{G}{H}\right] \times 100$	G=Number of un-dehusked cobs in test run of 25 kg H= Total number of cobs in test run of 25 kg	Tiwari *et al.* 2010;
2. Shelling efficiency (Sh.E), %	$Sh.E = (100 - T_u)$ $T_u = \frac{D}{A} \times 100$ $A = B + C + D$	T_u= Unthreshed grain, % D= Quantity of unthreshed grain obtained from all outlets per unit time A= Total grain input per unit time B= Quantity of clean grain from all outlets per unit time C= Quantity of broken grain from all outlets per unit time	Desta and Mishra 1990; IS: 7051-1973; Behera*et al.* (1990); Muhammad (2009)
3. Broken grain losses (BG), %	$BG = \frac{C}{A} \times 100$	A= Total grain input per unit time C= Quantity of broken grain from all outlets per unit time	Tastra, 2009
4. Seed-coat damage (SCD), %	$SD = \frac{L}{K} \times 100$	L= Number of black coloured seeds in test	Copeland and McDonald, 2010
5. Germination percentage (GE), %	$GE = \frac{J}{K} \times 100$	J= Number of grains were germinated at the end of II count K= Total number of seeds used in the test	Bansal and Kumar, 2009

Table 1. The different equations used to calculate the response variables are illustrated in Table 2.

2.2 Data analysis and optimization

Statistical data analysis was done by the asymmetric factorial experiment laid in Completely Randomized Design (CRD) with 3 replications for each combination of PS, CC, and FR factors. The operating parameters of MDS were optimized by numerical optimization technique using Design Expert® Version 7.0.0 (developed by Stat-Ease, Inc., 2021 East Hennepin Ave., Suite 480, Manneapolis-55413) package. Which was based on desirability value constructed on response variables. Myers and Montgomery, 2002 described that the desirability is unitless numerical measure (Varies 0 to 1) of identifying the best combination for peak optimal performance of responses (Dependent variable) from factors (Independent variable). The set of constraints,*viz.,* maximization (for DE, Sh.E, and GE), minimization (for BG, and SCD) and in-the-range (for PS, CC, and FR) were applied to variables to find desirability value. Similarly, an equal level of importance (“+++”) was chosen for all dependents. The optimized operational parameters combination were chosen against the highest value of desirability obtained against a particular treatment combination (Montgomery, 2001). The 3D surface was obtained and inferences were drawn against optimized operating conditions individually for all the response variables studied.

2.3 Modelling

2.3.1 Non-linear regression (Quadratic function) modelling

The general factorial method was used to determine the optimum operating parameters for the performance evaluation of MDS. The operating parameters selected for the study were listed in Table 1. Regression analysis was carried out three times (triplicate), to estimate the variability of measurements. The relationship between the operating parameters and the response variables was calculated by using the following second-order polynomial equation (quadratic function) (Eq.1)

$$Y = \beta_0 + \sum_{i=0}^{k} \beta_i X_i + \sum_{i=0}^{k} \beta_{ii} X_i{}^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} X_i X_j \quad (1)$$

Where, Y = predicted response; β_0 = constant; β_i = linear coefficient; β_j = squared coefficient; β_{ij} = cross product coefficient and k = number of factors.

2.3.2 Configuration of ANN

A feed forward back propagation neural network with topology comprising two layers was empirically found to be optimum in this study for the prediction of performance characteristics of maize dehusker cum sheller. The number of neurons in the input layer is equal to the number of independent variables, i.e., PS, CC and FR; the number of output neurons is equal to the number of dependent variables, i.e., DE, Sh.E, BG, SCD and GE. There is no hard and fast rule for determining the required number of hidden neurons in a hidden layer (Huang and Mujumdar, 1993). The number of neurons in the hidden layer was selected based on the trail and error method by varying from 2 to 100 and the optimum number of neurons were finalized based on the statistical parameters (coefficient of determination (R^2), root mean square error (RMSE), and error sum of squares (SSE). The structure of a multilayer feed forward back propagation artificial neural network (FFANN) used in the present study is shown in Fig. 2.

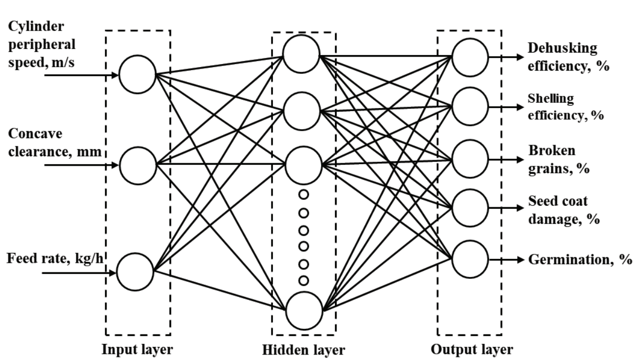


Fig. 2. The structure of a multilayer feed forward artificial neural network used.

Normalization of data

In the process of network learning, it is necessary to preprocess the sample data to make training easy and to reflect better correlations among them (Peng *et al.,* 2007). The whole input data are scaled within the range of 0 to 1. The normalization is required in order to obtain good results as well as to fasten up significantly the learning (Sola and Sevilla, 1997). The normalization of data is carried out using the minimum-maximum technique (Eq.2).

Normalized input data

$$N_I = \frac{N_i - N_{imin}}{N_{imax} - N_{imin}} \quad (2)$$

Where,

N_{imin} = the minimum input data

N_{imax} = the maximum input data

Ni = the values before normalization

N_I = the values after normalization

Network learning

A total of 144 experiments were conducted with three replications as given in Table 1 and the experimental data were used for training and testing the selected network. The training was done with 70% of the experimental data and the remaining 30% of the data were used for testing the performance of the network, similarly k-fold cross validation method was also employed with three folds. JMP Pro10 Software was used for training the neural network and testing its performance. The activation function for the hidden layer and output layer of the network were taken as a hyperbolic function [tanh=$(e^{2x}$-1)/$(e^{2x}$+1)] and linear function, respectively. The training algorithm used for updating the weights of the input layer to the hidden layer and hidden layer to output layer connections was the quasi-Newton method, BFGS (Broyden–Fletcher–Goldfarb–Shanno) algorithm. As the BFGS iterations proceed, the value of the likelihood function of the model on the validation data is monitored. When the cross-validation likelihood is no longer improving, the BFGS algorithm will terminate. This is commonly referred to as the early stopping rule. The network learning was carried out with a learning rate of 0.2 and the number of tours equal to 100 (both the values were determined empirically). The iteration with best validation statistics is chosen as the final model. The statistical parameters obtained from validation data was used to evaluate the performance of the model. The R^2, RMSE (Eq.3), and SSE (Eq.4) were used to evaluate the performance of the model. The penalty squared method ($\Sigma\beta^2{}_i$) was used to extenuate the over fitting of the model

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} \tag{3}$$

Where y_i is the observed value for the i^{th} observation and $\bar{y}_i$ is the predicted value.

$$\text{SSE} = \sum_{i=1}^{n}(y_i - \bar{y})^2 \tag{4}$$

y_i is the value of the i^{th} observation and $\bar{y}$ is the mean of all the observations

3. RESULTS AND DISCUSSIONS

3.1 Optimization of operational parameters of MDS

The desirability curve among operating parameters at optimum FR (630.46 kg/h) is shown in Fig 3. The maximum desirability value obtained was 0.85 at 6.77 m/s of PS, 27.10 mm of CC and 630.46 kg/h of FR, it is shown (Flag location) in Fig. 3a.

3.2 Quadratic model

The estimated coefficients (β), standard error (SE) and level of significance obtained after fitting experimental data with the quadratic function of different response variables are listed in Table 3. From Table 3, it is clear that some of the operating parameters are significant and some are non-significant. In case of DE, all the operating parameters are significant except for the square of feed rate (FR^2). The interaction effect of FR with CC and PS (FR-CC and FR-PS) are non-significant in Sh.E. In case of BG, all the operating parameters are significant except the interaction effect of PS with CC and FR (PS-CC and PS-FR) and the square of FR (FR^2). In the case of SCD and GE except for the interaction effect of FR with CC and PS (FR-CC and FR-PS) and the square of FR (FR^2) were non-significant. The quadratic model for GE by combining coefficients in Table 3 is in the following form (Eq.5).

$$GE = 99.073 - 1.423S + 0.622C + 0.289F + 0.177SC + 0.047SF + 0.098CF - 0.999S^2 - 0.303C^2 - 0.073F^2 \tag{5}$$

The response variables obtained at optimum operating parameters were 96.57%, 99.53%, 0.751%, 99.306% and 1.792% for DE, Sh.E, BG, GE and SCD, respectively.

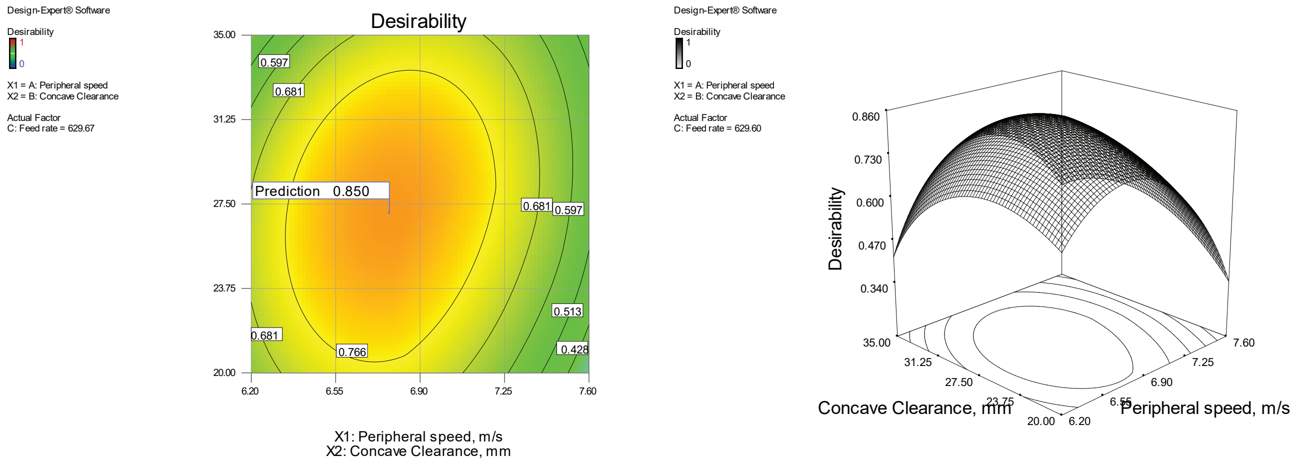
3.3 Performance measures

3.31 Dehusking efficiency (DE)

The effect of PS, CC, FR and their interaction on DE is shown in Fig. 5. The DE decreased with increase in CC for all PS at constant FR because of increase in CC makes less dense cobs inside leads to less abrasion and further cob moves towards the outlet in a shorter time it leads to decrease in dehusking action, it is shown in Fig. 5a. Similar findings have been reported by Singh (2010). The effect of feed rate on DE w.r.t. CC and PS is shown in Fig. 5b. The DE increased up to a certain level of FR at constant CC and PS and decreased thereafter. The DE increased with an increase in peripheral speed up to 7 m/s at constant FR and CC thereafter there is no effect has been observed with an increase in PS, it is shown in Fig. 5c. The interaction effect of PS and FR is highly significant (0.0008) followed by PS and CC (0.0076) and CC and FR (0.0193) (Table 3).

3.3.2 Shelling efficiency (Sh.E)

The effect of different operating parameters and their interaction on Sh.E of MDS is shown in Fig.6. The Sh.E increased with increasing CC from 20 mm to 25 mm and thereafter it reduces with increasing CC at a given PS and FR of 630.46 kg/h (Fig.6a). The Sh.E increases up to a certain level with an increase in FR and thereafter it starts declining at constant CC and PS of 6.77 m/s (Fig.6b). This trend is due to less energy spent per cob in terms of less number of impacts were taken place on cobs for the same length of the cylinder and due to cushioning effect at higher FR caused to decrease the Sh.E. The similar results were reported by Vas and Harrison (1969) and Singh (2010). The increase in PS leads to increase in Sh.E up to 7m/s at any FR and constant CC (27.08 mm) due to the increased detachment with higher impacts and friction created between the cylinder and concave, it is shown in Fig.6c. The further increase in PS leads to decrease in Sh.E due to less retention time of cobs in concave and it might have an increasing conveyance of plant mass by angled (45°) lugs arrangement (Chilur and Sushilendra, 2017). The interaction effect of PS and CC is significant (0.0002) and has a negative impact on Sh.E, while the remaining interactions (PS-FR and CC-FR) are non-significant (Table 3).



(a) (b)

Fig. 3. Desirability contours (a) and 3D surface (b) based on different seed quality parameters against concave clearance and cylinder peripheral speed for developed MDS at the centre value of feed rate, *i.e.,* 630.46 kg/h

Table 3. The estimated coefficient (β), standard error (SE) and their significance of individual and interaction effect (p-value) on different response variables were fitted with aquadratic function

Factor	DE, %		Sh.E, %		BG, %		GE, %		SCD, %	
	β (SE)	p	β (SE)	p	β (SE)	p	β (SE)	p	β (SE)	p
Int.	97.262(0.294)	< 0.0001	99.932(0.182)	< 0.0001	0.838(0.038)	< 0.0001	99.073(0.121)	< 0.0001	2.049(0.123)	< 0.0001
PS	3.547(0.156)	< 0.0001	1.638(0.097)	< 0.0001	0.501(0.02)	< 0.0001	-1.423(0.064)	< 0.0001	1.565(0.066)	< 0.0001
CC	-3.688(0.158)	< 0.0001	-1.53(0.098)	< 0.0001	-0.318(0.021)	< 0.0001	0.622(0.065)	< 0.0001	-0.621(0.066)	< 0.0001
FR	-1.138(0.144)	< 0.0001	-0.394(0.089)	< 0.0001	-0.161(0.019)	< 0.0001	0.289(0.059)	< 0.0001	-0.292(0.061)	< 0.0001
PS-CC	0.567(0.209)	0.0076	-0.503(0.13)	0.0002	0.009(0.027)	0.7522	0.177(0.086)	0.0411	-0.178(0.088)	0.0445
PS-FR	0.653(0.191)	0.0008	0.228(0.119)	0.0558	-0.021(0.025)	0.4090	0.047(0.079)	0.5576	-0.045(0.08)	0.5798
CC-FR	-0.456(0.193)	0.0193	-0.218(0.12)	0.0702	0.068(0.025)	0.0072	0.098(0.079)	0.2195	-0.099(0.081)	0.2222
PS^2	-1.904(0.27)	< 0.0001	-2.638(0.167)	< 0.0001	0.327(0.035)	< 0.0001	-0.999(0.111)	< 0.0001	1.071(0.113)	< 0.0001
CC^2	-1.794(0.264)	< 0.0001	-1.444(0.164)	< 0.0001	0.235(0.034)	< 0.0001	-0.303(0.109)	0.0060	0.299(0.111)	0.0077
FR^2	-0.114(0.249)	0.6488	-0.983(0.154)	< 0.0001	0.031(0.032)	0.3322	-0.073(0.102)	0.4780	0.075(0.105)	0.4727

3.3.3 Broken grain losses (BG)

The BG majorly depends on the operational parameters. The effect of operational parameters CC, PS, FR and their interaction on BG is shown in Fig.7. The BG decreased with increasing CC for all PS and constant FR of 630.46 kg/h (Fig.7a), since the impact by cylinder lugs on less number of grains in each revolution of the cylinder may be attributed as the reason for decreased BG (Akubuo, 2002). Similarly, the increase in FR leads to decrease in a decrease in BG for all CC and constant PS of 6.77 m/s (Fig.7b). The BG increases with increase in PS for all FR and constant CC of 27.08 mm (Fig.7c). The interaction effect of PS with CC and FR are found to be non-significant, but the interaction effect of CC and FR was significant (0.0072) on BG (Table 3).

3.3.4 Germination percentage (GE)

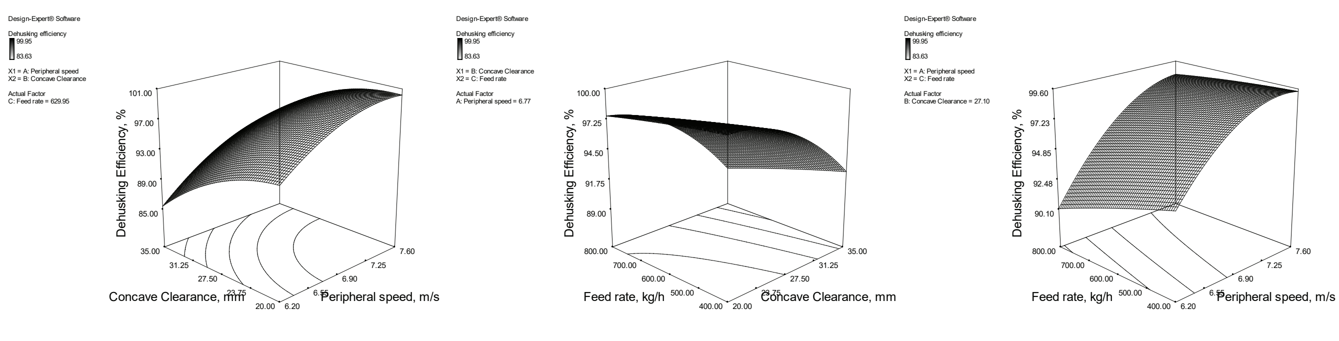
The maize has higher GE as compared to other cereals (Anon. 2016a), the minimum GE obtained in the present study was 94% and maximum up to 99%. The grain GE majorly depends upon the operating levels of MDS, so it is necessary to study the effect of operating parameters and their interaction effect on GE. The effect of operational parameters (CC, PS, and FR) and their interaction on GE is shown in Fig. 8. The GE increased with increasing CC for all PS and constant FR (630.46 kg/h), it is shown in Fig.8a. Similarly, FR also has a positive effect for all CC and constant PS of 6.77 m/s (Fig. 8b), but PS has a negative effect on GE for all FR and constant CC (27.08 mm) (Fig. 8c). The result shows that the percentage of non-germinated seeds was higher as compared to the BG, which means some of the unbroken seeds also not get germinated may be due to mechanical damage of embryo, seed-coat, etc. to obtain the greater GE of the MDS, it is recommended that the PS should be low, high, CC and optimum FR. The interaction effect of FR with CC and PS was non-significant and the interaction effect of PS with CC was significant (0.0411) (Table 3).

3.3.5 Seed-coat damage percentage (SCD)

The germination of the seed depends upon the SCD also, so it is necessary to know the effect of operational parameters on SCD. The effect of operational parameters and their interaction on SCD is shown in Fig.9. From this, it is clear that SCD decreases with increase in CC for all PS and constant FR 630.46 kg/h (Fig.9a). Similarly, an increase in FR also has positive effect on SCD for all CC and constant PS (6.77 m/s) (Fig.9b). But the increase in PS has a negative impact on SCD for all FR and constant CC of 27.08 mm (Fig.9c).The interaction effect of FR with CC and PS was non-significant, while the interaction effect of PS and CC are found to be significant (Table 3). The maximum SCD (5.90%) was observed at higher PS and lower CC and FR, while the minimum SCD (1%) was observed at lower PS and higher FR and CC. The mechanical damage of maize was observed in the range of 6.38 to 16% by Chowdhury and Buchele (1976) and Singh *et al.* (2011) for conventional combines whereas, in this study it was less (1 to 6%) due to lower operating speed compare to combine threshing drum speed (>20 m/s) and angled lugs threshing drum design. The lesser damage in developed MDS may be due to the use of chamfered lugs on the cylinder and the helical arrangement which not sustenance to augment of SCD. From the reviewed data of Handbook, the PS was recommended as 9 m/s for dehusking and shelling of maize cobs (Anon., 2004). Since the present problem to produce maize grains for seeding purpose, the lower speed, *i.e.,* below 7.1 m/s was found in agreement with concern to seed-quality aspects.

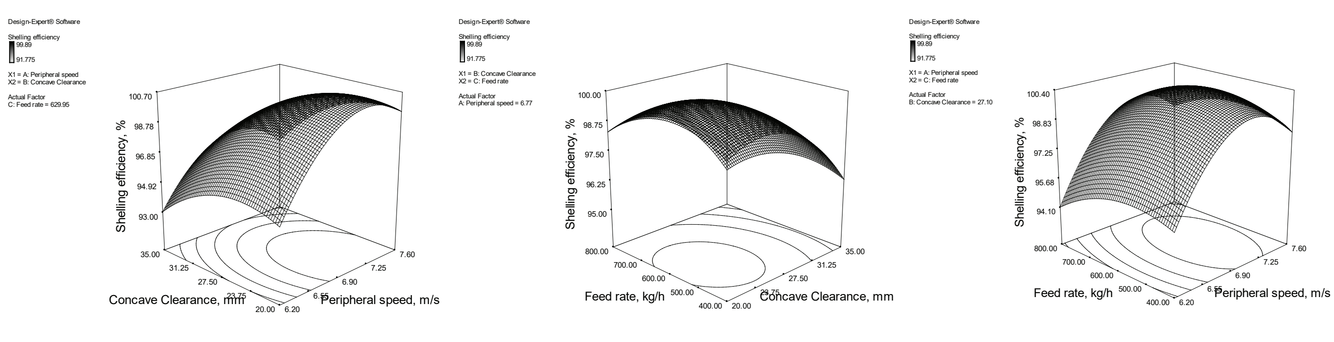
3.4 ANN modelling

ANN model for different machine performance parameters was developed using 70% of data and the developed model was validated using 30% of data. The performance of the model was tested at a different number of hidden neurons (2-100) and the optimum number of neurons for all the response variables was



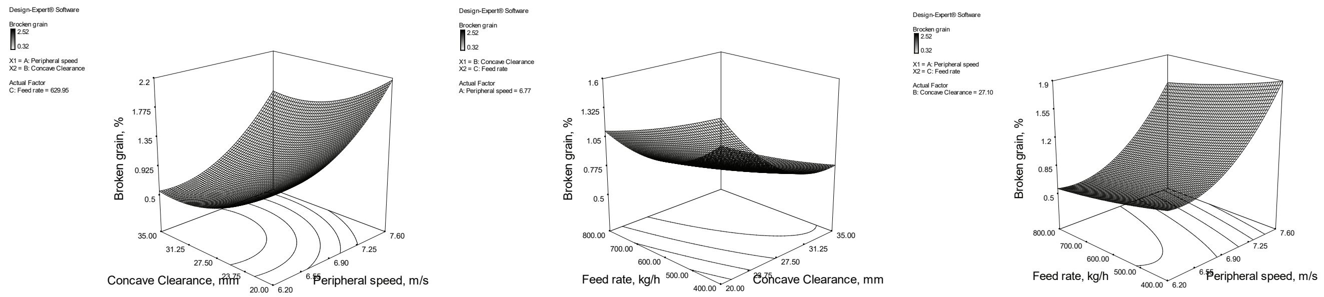
(a) At feed rate of 630.46 kg/h (b) At cylinder peripheral speed of 6.77 m/s (c) At concave clearance of 27.10 mm

Fig. 5. The effect of PS, CC and FR factors on DE at optimized FR (a) at optimized PS (b) and at optimized CC (c)



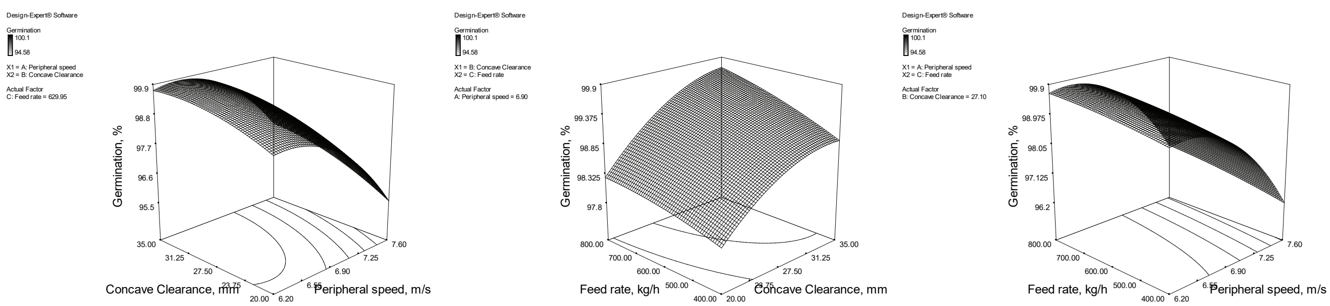
(a) At feed rate of 630.46 kg/h (b) At cylinder peripheral speed of 6.77 m/s (c) At concave clearance of 27.10 mm

Fig. 6. The effect of PS, CC and FR factors on Sh.E at optimized FR (a) at optimized PS (b) and at optimized CC (c)



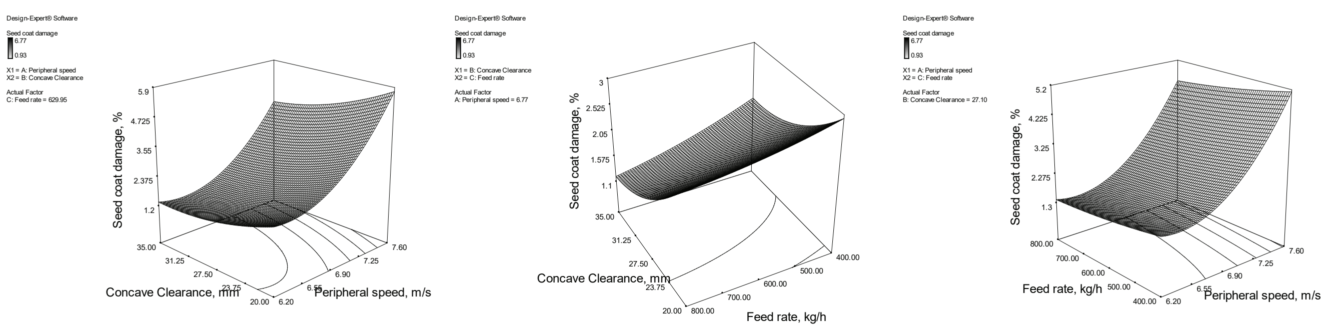
(a) At feed rate of 630.46 kg/h (b) At cylinder peripheral speed of 6.77 m/s (c) At concave clearance of 27.10 mm

Fig. 7. The effect of PS, CC and FR factors on BG at optimized FR (a) at optimized PS (b) and at optimized CC (c)



(a) At feed rate of 630.46 kg/h (b) At cylinder peripheral speed of 6.77 m/s (c) At concave clearance of 27.10 mm

Fig. 8. The effect of PS, CC and FR factors on GE at optimized FR (a) at optimized PS (b) and at optimized CC (c)



(a) At feed rate of 630.46 kg/h (b) At cylinder peripheral speed of 6.77 m/s (c) At concave clearance of 27.10 mm

Fig. 9. The effect of PS, CC and FR factors on SCD at optimized FR (a) at optimized PS (b) and at optimized CC (c)

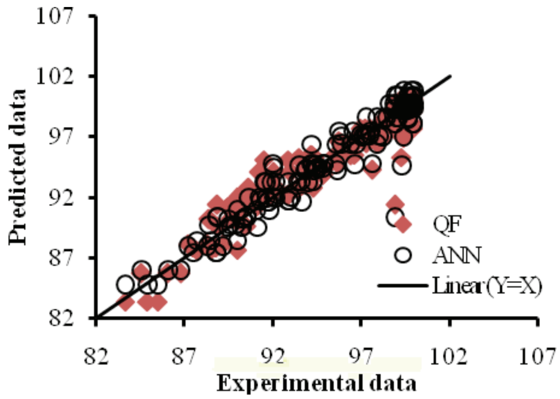
optimised based on the minimum error and maximum R^2 value. The statistical results for different response variables at a different number of hidden neurons for hold back and k-fold cross validation methods were listed in the Appendix. The optimum number of neurons for DE, Sh.E, BG, SCD, and GE in hold back and k-fold validation methods are tabulated in Table 4. The optimum number of neurons in both the validation methods were too high. More than 94% accuracy of the model is obtaining within the 10 neurons but to increase the accuracy by 2% it is necessary to select the optimum number of neurons which may lead to over fitting and increase in complexity of the model. Therefore, it is recommended to select the number of hidden neurons as low as possible. The k-fold cross validation method is advisable for a small data set and hold back method is suitable for a large data set.

3.5 Comparison of quadratic and ANN modelling

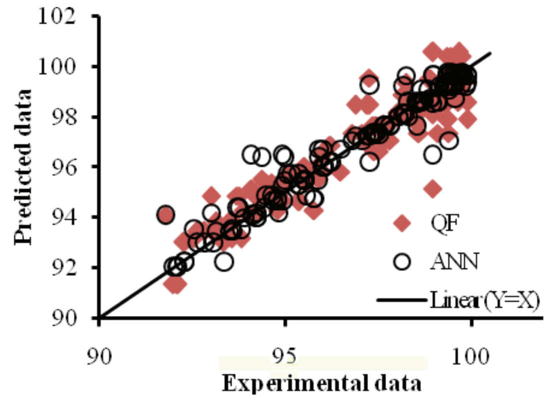
The comparison between QF and ANN modelling was done using statistical parameters,*viz.*, RMSE, SSE, and R^2. The statistical parameters obtained from QF

Table 4. Statistical results obtained from fitting experimental data with quadratic and ANN model

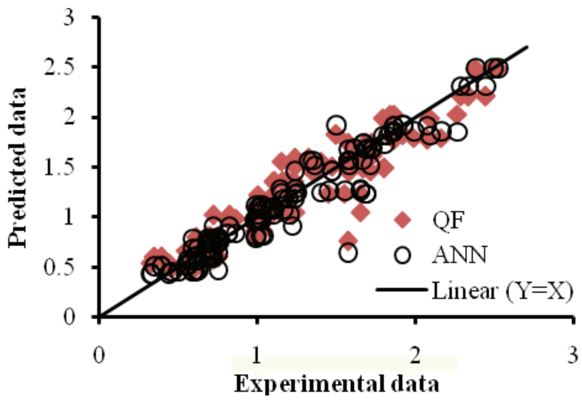
Response variables	Quadratic function			ANN-Model (Holdback)				ANN-Model (k-Fold)			
	R^2	RMSE	SSE	Optimum neurons	R^2	RMSE	SSE	Optimum neurons	R^2	RMSE	SSE
DE	0.9036	5.0824	2479.75	88	0.95	1.002	44.17	65	0.984	0.586	17.857
Sh.E	0.8742	2.7102	705.14	71	0.967	0.519	11.845	83	0.961	0.476	10.863
BG	0.8933	0.6124	36	60	0.963	0.128	0.720	46	0.987	0.063	0.188
SCD	0.8563	1.6969	276.45	12	0.959	0.341	5.119	82	0.968	0.265	3.378
GE	0.8421	1.5726	237.43	26	0.957	0.333	4.875	82	0.963	0.265	3.381



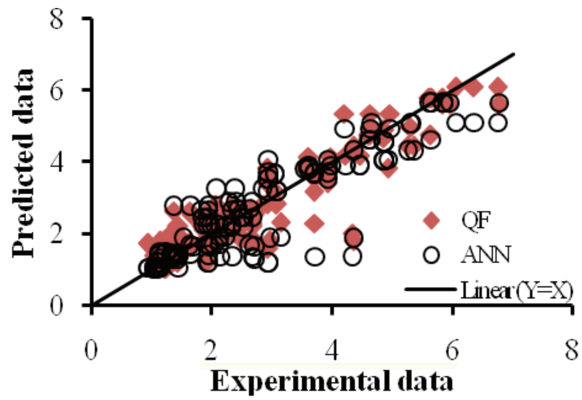
(a) Dehusking efficiency



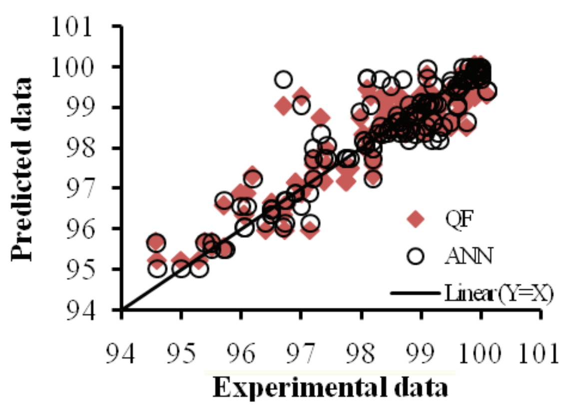
(b) Shelling efficiency



(c) Broken grain losses



(d) Seed-coat damage



(e) Germination percentage

Fig. 4. Comparison between actual and predicted values obtained from ANN and quadratic models for the (a) DE, (b) Sh.E, (c) BG, (d) SCDand (e) GE

and ANN modelling of different response variables (at an optimum number of hidden neurons) have been listed in Table 4. From this table, it is clear that the ANN model explained a good relationship between operational parameters and response variables. The plot of predicted data obtained from QF and ANN against experimental data for all response variables is shown in Fig 4. The QF model shows greater deviation than the ANN model. The ANN model shows a greater generalization capacity than the QF model. The higher predictive accuracy of the ANN model was due to the universal ability to approximate the non-linearity of the system, whereas the QF is restricted to a second-order polynomial (Youssefi *et al.*, 2009). Another advantage with ANN over the QF is the ability to calculate multi-responses in a single process. To obtain a multi-response optimization, the QF model must be run several times (equal to the number of the parameters to be predicted) (Youssefi *et al.,* 2009).

4. CONCLUSIONS

In this study, the optimization of operational parameters and performance evaluation of maize dehusker cum sheller (MDS) based on seed quality parameters using quadratic and ANN model was conducted. The optimum operating parameters obtained from numerical optimization technique for peripheral speed (PS), concave clearance (CC), and feed rate (FR) were 6.77 m/s, 27.08 mm, and 630.46 kg/h, respectively. The response variables obtained at optimum operating parameters were 96.57%, 99.53%, 0.751%, 99.306% and 1.792% for dehusking efficiency (DE), shelling efficiency (Sh.E), broken grain losses (BG), germination percentage (GE) and seed coat damage (SCD), respectively. The R^2 value of the developed quadratic model for all the response variables (DE, SE, BG, GE, and SCD) varies between 0.8421-0.9036, the RMSE values varies between 0.6124-5.0824 and SSE values varies from 36-2479.75. More than 94% accuracy of the ANN model was achieved within the 10 neurons. The R^2, RMSE and SSE values of the developed ANN models for all the response variables were >0.9, <1.5 and <90, respectively even at below 10 number of hidden neurons. The maximum R^2 and minimum error (SSE and RMSE) were observed in case of ANN model over the quadratic model. Hence, the ANN models described the best relationship between operating parameters and response variables. Therefore, ANN is a good tool to assess the performance parameters of MDS.

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APPENDIX

Table: Statistical results obtained from ANN modelling for different response variables at a different number of hidden neurons for hold back cross validation method

No. of neurons	Shelling efficiency, %			Dehusking efficiency, %			Germination percentage, %			Seed coat damage, %			Broken grain losses, %		
	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE
2	0.802	1.445	91.891	0.942	1.105	53.729	0.926	0.441	8.558	0.933	0.442	8.593	0.929	0.177	1.379
3	0.848	1.275	71.472	0.946	1.088	52.045	0.917	0.470	9.736	0.929	0.468	9.645	0.929	0.167	1.220
4	0.853	1.252	68.985	0.939	1.150	58.146	0.932	0.429	8.101	0.941	0.433	8.239	0.922	0.194	1.660
5	0.869	1.210	64.464	0.937	1.164	59.639	0.939	0.412	7.462	0.947	0.427	8.036	0.928	0.195	1.679
6	0.853	1.205	63.905	0.944	1.161	59.280	0.945	0.411	7.445	0.948	0.429	8.084	0.912	0.208	1.895
7	0.889	1.087	52.006	0.936	1.196	62.982	0.946	0.380	6.363	0.955	0.378	6.274	0.935	0.174	1.333
8	0.867	1.098	53.064	0.944	1.073	50.694	0.943	0.382	6.435	0.956	0.372	6.088	0.929	0.195	1.671
9	0.925	0.908	36.292	0.936	1.172	60.473	0.928	0.421	7.799	0.937	0.426	7.992	0.927	0.207	1.881
10	0.881	1.146	57.755	0.941	1.126	55.781	0.948	0.374	6.142	0.944	0.410	7.405	0.920	0.205	1.845
11	0.921	0.975	41.816	0.947	1.084	51.688	0.953	0.362	5.776	0.958	0.366	5.882	0.914	0.196	1.683
12	0.891	0.998	43.844	0.944	1.143	57.528	0.954	0.334	4.915	**0.959**	**0.341**	**5.119**	0.879	0.260	2.964
13	0.914	1.017	45.467	0.947	1.084	51.736	0.948	0.365	5.861	0.959	0.357	5.594	0.917	0.194	1.651
14	0.864	1.120	55.178	0.947	1.122	55.347	0.949	0.354	5.520	0.957	0.360	5.706	0.941	0.175	1.352
15	0.874	1.092	52.425	0.945	1.143	57.527	0.948	0.367	5.917	0.943	0.400	7.054	0.936	0.181	1.445
16	0.893	1.043	47.881	0.949	1.128	56.005	0.941	0.391	6.741	0.942	0.416	7.611	0.930	0.187	1.541
17	0.907	1.041	47.664	0.938	1.200	63.372	0.959	0.343	5.187	0.949	0.385	6.522	0.904	0.201	1.780
18	0.903	0.985	42.731	0.950	1.050	48.500	0.917	0.463	9.450	0.954	0.403	7.161	0.935	0.210	1.937
19	0.904	0.987	42.868	0.939	1.183	61.620	0.947	0.383	6.438	0.932	0.456	9.151	0.906	0.217	2.069
20	0.900	1.033	46.914	0.922	1.280	72.128	0.960	0.349	5.352	0.966	0.348	5.315	0.934	0.180	1.433
21	0.917	0.837	30.795	0.940	1.105	53.679	0.942	0.382	6.424	0.939	0.411	7.418	0.902	0.229	2.313
22	0.952	0.690	20.929	0.951	1.071	50.471	0.917	0.474	9.877	0.936	0.428	8.067	0.940	0.158	1.100
23	0.927	0.752	24.867	0.952	1.056	49.028	0.934	0.418	7.706	0.951	0.391	6.711	0.941	0.200	1.756
24	0.942	0.713	22.367	0.921	1.317	76.329	0.912	0.463	9.427	0.938	0.409	7.354	0.938	0.178	1.388
25	0.944	0.751	24.794	0.914	1.348	79.948	0.892	0.513	11.573	0.943	0.426	7.990	0.930	0.178	1.399
26	0.929	0.752	24.851	0.929	1.302	74.586	**0.957**	**0.333**	**4.875**	0.921	0.456	9.148	0.923	0.187	1.540
27	0.911	0.866	33.015	0.914	1.337	78.611	0.947	0.379	6.319	0.956	0.361	5.739	0.900	0.213	1.991
28	0.947	0.692	21.054	0.914	1.338	78.787	0.920	0.487	10.440	0.916	0.547	13.163	0.955	0.154	1.040
29	0.904	0.837	30.814	0.928	1.315	76.063	0.940	0.390	6.688	0.923	0.438	8.429	0.937	0.175	1.349
30	0.938	0.754	25.010	0.936	1.202	63.559	0.927	0.450	8.918	0.957	0.385	6.535	0.917	0.203	1.813
31	0.938	0.729	23.414	0.902	1.401	86.372	0.890	0.682	20.472	0.920	0.651	18.643	0.952	0.144	0.917
32	0.960	0.663	19.322	0.936	1.181	61.357	0.882	0.758	25.283	0.906	0.667	19.585	0.954	0.152	1.023
33	0.929	0.765	25.751	0.947	1.124	55.595	0.882	0.688	20.813	0.880	0.745	24.453	0.955	0.137	0.823
34	0.938	0.695	21.241	0.938	1.156	58.846	0.906	0.627	17.279	0.904	0.651	18.645	0.949	0.141	0.876
35	0.943	0.732	23.570	0.947	1.094	52.686	0.910	0.626	17.241	0.908	0.668	19.614	0.940	0.146	0.934
36	0.948	0.680	20.328	0.929	1.251	68.839	0.866	0.803	28.375	0.915	0.638	17.914	0.963	0.131	0.751
37	0.950	0.657	18.984	0.915	1.324	77.093	0.906	0.625	17.163	0.938	0.594	15.503	0.931	0.173	1.323
38	0.948	0.716	22.572	0.928	1.274	71.396	0.886	0.697	21.403	0.914	0.660	19.172	0.953	0.152	1.017
39	0.944	0.752	24.878	0.934	1.232	66.795	0.896	0.687	20.743	0.895	0.734	23.730	0.945	0.153	1.035
40	0.960	0.670	19.737	0.911	1.325	77.242	0.890	0.746	24.499	0.918	0.631	17.510	0.952	0.149	0.980
41	0.899	1.034	47.012	0.903	1.809	144.022	0.922	0.600	15.827	0.936	0.605	16.089	0.925	0.173	1.324
42	0.904	0.964	40.860	0.870	2.101	194.311	0.900	0.682	20.450	0.910	0.696	21.286	0.930	0.170	1.276
43	0.844	1.233	66.931	0.892	2.022	179.902	0.909	0.678	20.247	0.919	0.657	19.019	0.934	0.172	1.295

44	0.860	1.134	56.549	0.925	1.849	150.454	0.912	0.590	15.297	0.928	0.614	16.597	0.923	0.175	1.344
45	0.736	1.858	151.975	0.919	1.691	125.852	0.898	0.655	18.882	0.916	0.705	21.839	0.940	0.168	1.242
46	0.888	1.149	58.066	0.906	1.915	161.289	0.925	0.577	14.648	0.920	0.635	17.717	0.942	0.157	1.081
47	0.891	1.060	49.468	0.911	1.821	145.953	0.909	0.635	17.758	0.930	0.623	17.099	0.943	0.162	1.155
48	0.922	0.862	32.693	0.928	1.754	135.419	0.904	0.691	20.991	0.898	0.801	28.262	0.946	0.153	1.025
49	0.913	1.046	48.156	0.921	1.688	125.322	0.920	0.657	18.985	0.916	0.672	19.853	0.946	0.170	1.266
50	0.830	1.320	76.634	0.887	2.021	179.642	0.914	0.621	16.974	0.921	0.621	16.958	0.937	0.168	1.243
51	0.843	1.194	62.687	0.907	1.692	126.026	0.894	0.683	20.510	0.910	0.687	20.784	0.943	0.165	1.199
52	0.858	1.076	50.940	0.898	2.006	177.099	0.895	0.758	25.295	0.925	0.660	19.190	0.942	0.158	1.099
53	0.914	0.967	41.186	0.907	1.919	162.105	0.906	0.655	18.850	0.937	0.588	15.229	0.939	0.175	1.347
54	0.930	0.909	36.345	0.839	2.266	225.860	0.922	0.618	16.779	0.921	0.659	19.116	0.932	0.164	1.177
55	0.866	1.290	73.257	0.928	1.744	133.781	0.901	0.647	18.415	0.930	0.603	16.002	0.928	0.178	1.389
56	0.912	0.928	37.875	0.921	1.649	119.675	0.902	0.675	20.077	0.947	0.552	13.402	0.930	0.165	1.195
57	0.875	1.105	53.734	0.901	1.885	156.298	0.886	0.721	22.892	0.898	0.736	23.855	0.948	0.166	1.216
58	0.901	0.959	40.490	0.906	1.760	136.359	0.913	0.677	20.172	0.917	0.633	17.627	0.949	0.160	1.130
59	0.889	1.090	52.285	0.921	1.757	135.829	0.898	0.699	21.480	0.892	0.725	23.100	0.942	0.150	0.987
60	0.894	1.083	51.569	0.883	1.986	173.541	0.902	0.684	20.608	0.915	0.644	18.260	**0.963**	**0.128**	**0.720**
61	0.935	0.776	26.518	0.902	1.614	114.618	0.782	0.643	18.219	0.848	0.607	16.217	0.880	0.196	1.683
62	0.940	0.775	26.461	0.920	1.349	80.076	0.812	0.625	17.185	0.808	0.662	19.259	0.902	0.167	1.224
63	0.951	0.719	22.765	0.926	1.307	75.107	0.781	0.725	23.097	0.865	0.582	14.901	0.906	0.168	1.242
64	0.949	0.694	21.163	0.910	1.372	82.850	0.847	0.550	13.321	0.824	0.609	16.314	0.865	0.200	1.759
65	0.939	0.744	24.360	0.923	1.319	76.594	0.749	0.718	22.708	0.815	0.661	19.236	0.916	0.155	1.064
66	0.940	0.774	26.383	0.919	1.396	85.701	0.776	0.623	17.104	0.776	0.654	18.841	0.915	0.171	1.286
67	0.915	0.879	33.981	0.924	1.353	80.514	0.782	0.621	16.953	0.852	0.631	17.524	0.879	0.185	1.513
68	0.947	0.712	22.299	0.921	1.357	81.027	0.809	0.645	18.287	0.831	0.609	16.302	0.871	0.212	1.977
69	0.940	0.753	24.948	0.916	1.400	86.192	0.855	0.522	11.995	0.855	0.585	15.063	0.869	0.191	1.604
70	0.946	0.714	22.452	0.895	1.537	104.011	0.806	0.623	17.082	0.800	0.655	18.901	0.872	0.204	1.827
71	**0.967**	**0.519**	**11.845**	0.900	1.510	100.318	0.838	0.587	15.152	0.827	0.641	18.064	0.911	0.172	1.297
72	0.963	0.645	18.328	0.912	1.359	81.271	0.818	0.658	19.068	0.831	0.676	20.114	0.887	0.182	1.456
73	0.966	0.581	14.830	0.917	1.440	91.295	0.812	0.661	19.219	0.815	0.611	16.401	0.900	0.170	1.274
74	0.952	0.618	16.786	0.920	1.364	81.844	0.817	0.640	18.044	0.826	0.649	18.548	0.871	0.199	1.741
75	0.965	0.477	9.993	0.882	1.700	127.138	0.809	0.630	17.489	0.821	0.614	16.612	0.877	0.183	1.477
76	0.942	0.749	24.667	0.910	1.418	88.464	0.797	0.614	16.596	0.813	0.672	19.899	0.902	0.166	1.218
77	0.948	0.703	21.731	0.928	1.309	75.411	0.811	0.593	15.493	0.833	0.581	14.862	0.924	0.149	0.973
78	0.940	0.766	25.811	0.925	1.284	72.502	0.835	0.574	14.498	0.860	0.609	16.339	0.875	0.202	1.804
79	0.949	0.718	22.682	0.920	1.344	79.453	0.786	0.611	16.401	0.870	0.573	14.453	0.910	0.164	1.190
80	0.954	0.673	19.913	0.891	1.529	102.921	0.819	0.652	18.688	0.832	0.669	19.698	0.872	0.184	1.483
81	0.940	0.756	25.155	0.937	1.090	52.275	0.794	0.658	19.073	0.859	0.547	13.143	0.917	0.163	1.165
82	0.943	0.662	19.282	0.946	1.050	48.492	0.782	0.607	16.205	0.806	0.647	18.395	0.906	0.170	1.275
83	0.945	0.739	24.000	0.920	1.312	75.716	0.828	0.605	16.098	0.825	0.594	15.543	0.934	0.143	0.900
84	0.938	0.845	31.423	0.940	1.062	49.630	0.856	0.570	14.315	0.854	0.562	13.902	0.899	0.174	1.332
85	0.936	0.750	24.723	0.905	1.395	85.673	0.846	0.593	15.452	0.843	0.634	17.712	0.867	0.190	1.587
86	0.955	0.627	17.322	0.904	1.363	81.780	0.841	0.567	14.128	0.842	0.589	15.280	0.877	0.192	1.619
87	0.892	0.873	33.543	0.942	1.030	46.658	0.810	0.627	17.322	0.866	0.603	16.012	0.892	0.184	1.497
88	0.955	0.678	20.209	**0.950**	**1.002**	**44.170**	0.836	0.660	19.170	0.810	0.683	20.537	0.895	0.180	1.425
89	0.953	0.662	19.285	0.910	1.275	71.516	0.764	0.608	16.261	0.813	0.643	18.193	0.908	0.164	1.183
90	0.951	0.678	20.212	0.927	1.230	66.557	0.845	0.568	14.211	0.846	0.568	14.219	0.819	0.212	1.974

91	0.955	0.658	19.038	0.926	1.264	70.325	0.821	0.640	18.007	0.750	0.779	26.678	0.915	0.181	1.443
92	0.958	0.604	16.072	0.898	1.362	81.573	0.786	0.667	19.603	0.817	0.663	19.354	0.916	0.183	1.468
93	0.960	0.656	18.913	0.936	1.201	63.463	0.807	0.646	18.347	0.826	0.665	19.456	0.914	0.172	1.308
94	0.956	0.603	16.008	0.935	1.161	59.274	0.731	0.739	24.025	0.754	0.783	27.005	0.937	0.170	1.269
95	0.941	0.712	22.287	0.936	1.125	55.720	0.749	0.682	20.483	0.834	0.630	17.479	0.909	0.191	1.613
96	0.956	0.667	19.563	0.945	1.070	50.375	0.807	0.659	19.082	0.803	0.708	22.080	0.887	0.189	1.568
97	0.955	0.675	20.077	0.927	1.205	63.906	0.788	0.671	19.807	0.812	0.695	21.282	0.933	0.175	1.354
98	0.954	0.693	21.118	0.935	1.207	64.094	0.787	0.633	17.629	0.780	0.739	24.005	0.908	0.191	1.609
99	0.957	0.614	16.602	0.930	1.117	54.943	0.811	0.602	15.939	0.797	0.699	21.516	0.902	0.180	1.420
100	0.957	0.652	18.723	0.930	1.154	58.575	0.826	0.639	17.977	0.821	0.700	21.542	0.900	0.181	1.442
Note: Bold text represents an optimum number of neurons for respective response variables															

Table: Statistical results obtained from ANN modelling for different response variables at a different number of hidden neurons for k-fold cross validation method

No. of neurons	Shelling efficiency, %			Dehusking efficiency, %			Germination percentage, %			Seed coat damage, %			Broken grain losses, %		
	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE
2	0.763	1.180	66.802	0.917	1.270	77.474	0.716	0.752	27.152	0.751	0.746	26.748	0.740	0.283	3.837
3	0.828	0.946	42.995	0.876	1.415	96.043	0.832	0.583	16.329	0.838	0.619	18.379	0.871	0.186	1.653
4	0.882	0.785	29.569	0.887	1.353	87.810	0.832	0.582	16.261	0.838	0.618	18.333	0.867	0.188	1.702
5	0.927	0.653	20.455	0.955	0.934	41.877	0.787	0.652	20.409	0.810	0.653	20.445	0.877	0.195	1.820
6	0.936	0.611	17.947	0.965	0.821	32.370	0.786	0.653	20.443	0.808	0.656	20.685	0.875	0.196	1.836
7	0.931	0.638	19.558	0.967	0.805	31.099	0.784	0.656	20.643	0.805	0.660	20.936	0.869	0.201	1.938
8	0.934	0.624	18.697	0.965	0.829	33.004	0.827	0.587	16.559	0.845	0.589	16.629	0.894	0.180	1.563
9	0.941	0.589	16.630	0.963	0.851	34.755	0.857	0.533	13.649	0.874	0.531	13.559	0.932	0.144	0.996
10	0.933	0.629	19.019	0.966	0.814	31.814	0.890	0.468	10.500	0.902	0.469	10.566	0.903	0.173	1.431
11	0.930	0.683	22.389	0.956	0.976	45.726	0.910	0.421	8.507	0.923	0.417	8.357	0.948	0.114	0.622
12	0.928	0.693	23.023	0.949	1.051	52.998	0.928	0.375	6.747	0.938	0.373	6.683	0.904	0.155	1.154
13	0.940	0.635	19.328	0.944	1.092	57.246	0.925	0.384	7.070	0.934	0.385	7.108	0.934	0.128	0.786
14	0.926	0.703	23.696	0.955	0.982	46.320	0.933	0.363	6.331	0.941	0.366	6.442	0.959	0.101	0.488
15	0.920	0.733	25.782	0.954	0.994	47.379	0.944	0.333	5.308	0.952	0.328	5.168	0.969	0.089	0.378
16	0.925	0.706	23.920	0.955	0.979	45.998	0.938	0.350	5.886	0.945	0.352	5.940	0.960	0.100	0.484
17	0.939	0.526	13.286	0.855	1.574	118.846	0.850	0.445	9.491	0.853	0.471	10.649	0.884	0.165	1.307
18.	0.942	0.621	18.531	0.959	0.940	42.384	0.941	0.341	5.585	0.948	0.342	5.603	0.951	0.110	0.586
19.	0.924	0.637	19.447	0.907	1.281	78.786	0.846	0.566	15.373	0.864	0.569	15.565	0.937	0.135	0.874
20	0.942	0.622	18.577	0.957	0.959	44.117	0.917	0.403	7.783	0.926	0.409	8.048	0.952	0.109	0.571
21	0.934	0.664	21.191	0.961	0.912	39.960	0.943	0.333	5.328	0.949	0.338	5.481	0.957	0.104	0.514
22	0.943	0.618	18.334	0.959	0.942	42.582	0.929	0.373	6.681	0.939	0.372	6.634	0.959	0.101	0.486
23	0.942	0.624	18.712	0.954	0.992	47.248	0.927	0.378	6.862	0.935	0.383	7.040	0.955	0.106	0.541
24	0.947	0.596	17.039	0.955	0.986	46.679	0.934	0.359	6.177	0.942	0.362	6.277	0.964	0.095	0.434
25	0.932	0.555	14.760	0.875	1.464	102.935	0.843	0.455	9.953	0.853	0.472	10.676	0.896	0.156	1.172
26	0.941	0.628	18.919	0.954	0.994	47.450	0.939	0.347	5.770	0.947	0.347	5.783	0.962	0.098	0.460
27	0.922	0.644	19.931	0.913	1.237	73.412	0.809	0.630	19.047	0.832	0.633	19.249	0.922	0.150	1.081
28	0.941	0.626	18.838	0.957	0.956	43.904	0.945	0.329	5.209	0.951	0.332	5.295	0.960	0.100	0.479
29	0.929	0.615	18.156	0.914	1.231	72.737	0.826	0.601	17.340	0.850	0.599	17.223	0.919	0.153	1.130
30	0.925	0.709	24.150	0.956	0.971	45.211	0.936	0.354	6.011	0.944	0.355	6.052	0.966	0.092	0.403
31	0.939	0.636	19.427	0.959	0.936	42.037	0.932	0.365	6.381	0.940	0.368	6.486	0.962	0.097	0.450
32	0.953	0.559	14.993	0.961	0.919	40.533	0.940	0.344	5.696	0.948	0.343	5.660	0.964	0.095	0.434

33	0.935	0.661	20.960	0.959	0.937	42.121	0.938	0.348	5.813	0.946	0.349	5.846	0.951	0.110	0.583
34	0.941	0.629	19.006	0.961	0.920	40.589	0.950	0.314	4.747	0.956	0.317	4.821	0.962	0.097	0.453
35	0.948	0.589	16.632	0.952	1.019	49.880	0.961	0.277	3.691	0.965	0.280	3.754	0.963	0.096	0.443
36	0.935	0.588	16.608	0.840	1.681	135.605	0.823	0.607	17.658	0.845	0.609	17.827	0.915	0.157	1.183
37	0.952	0.566	15.366	0.961	0.914	40.130	0.952	0.308	4.558	0.957	0.312	4.661	0.975	0.079	0.300
38	0.949	0.583	16.320	0.956	0.969	45.030	0.955	0.297	4.247	0.961	0.296	4.202	0.975	0.079	0.299
39	0.933	0.553	14.672	0.900	1.308	82.164	0.875	0.405	7.885	0.883	0.421	8.498	0.912	0.144	1.000
40	0.958	0.532	13.592	0.962	0.903	39.100	0.959	0.283	3.838	0.965	0.283	3.851	0.973	0.083	0.328
41	0.958	0.470	10.623	0.978	0.644	19.938	0.946	0.324	5.043	0.952	0.327	5.118	0.964	0.105	0.525
42	0.959	0.462	10.261	0.978	0.642	19.804	0.940	0.344	5.664	0.946	0.348	5.797	0.971	0.093	0.416
43	0.947	0.618	18.318	0.981	0.651	20.329	0.928	0.392	7.371	0.937	0.393	7.416	0.984	0.069	0.230
44	0.912	0.610	17.866	0.687	2.161	224.065	0.819	0.570	15.571	0.825	0.597	17.130	0.736	0.253	3.065
45	0.914	0.603	17.455	0.578	2.510	302.323	0.733	0.692	22.974	0.740	0.728	25.430	0.776	0.233	2.601
46	0.947	0.617	18.279	0.983	0.622	18.572	0.932	0.380	6.918	0.941	0.380	6.918	0.987	0.063	0.188
47	0.955	0.488	11.438	0.964	0.831	33.139	0.925	0.383	7.028	0.937	0.375	6.764	0.974	0.088	0.371
48	0.933	0.592	16.845	0.965	0.813	31.749	0.929	0.373	6.680	0.933	0.386	7.153	0.974	0.089	0.380
49	0.950	0.514	12.658	0.964	0.832	33.208	0.931	0.366	6.437	0.944	0.356	6.069	0.976	0.086	0.355
50	0.953	0.495	11.766	0.966	0.800	30.734	0.933	0.362	6.289	0.946	0.348	5.813	0.971	0.094	0.426
51	0.946	0.531	13.551	0.960	0.872	36.538	0.929	0.373	6.666	0.938	0.373	6.664	0.973	0.090	0.386
52	0.953	0.499	11.937	0.964	0.822	32.467	0.942	0.335	5.396	0.948	0.341	5.598	0.975	0.087	0.362
53	0.944	0.635	19.378	0.969	0.845	34.276	0.921	0.409	8.018	0.932	0.407	7.944	0.985	0.066	0.209
54	0.955	0.487	11.369	0.969	0.765	28.127	0.940	0.342	5.600	0.942	0.360	6.235	0.974	0.089	0.376
55	0.936	0.521	13.041	0.801	1.725	142.874	0.808	0.587	16.553	0.807	0.627	18.869	0.812	0.213	2.185
56	0.948	0.522	13.059	0.967	0.788	29.835	0.929	0.373	6.663	0.938	0.374	6.697	0.975	0.087	0.361
57	0.918	0.658	20.774	0.958	0.891	38.089	0.919	0.397	7.568	0.925	0.409	8.035	0.966	0.102	0.500
58	0.910	0.615	18.181	0.751	1.927	178.323	0.818	0.571	15.637	0.817	0.610	17.889	0.772	0.235	2.650
59	0.952	0.504	12.188	0.963	0.836	33.534	0.936	0.353	5.982	0.944	0.354	6.006	0.975	0.086	0.359
60	0.896	0.663	21.093	0.723	2.033	198.387	0.796	0.606	17.603	0.817	0.611	17.890	0.755	0.244	2.848
61	0.924	0.654	20.534	0.983	0.612	17.960	0.919	0.384	7.086	0.925	0.397	7.574	0.973	0.085	0.344
62	0.952	0.474	10.789	0.940	0.908	39.543	0.894	0.400	7.695	0.910	0.398	7.614	0.949	0.105	0.531
63	0.960	0.436	9.108	0.949	0.837	33.621	0.912	0.366	6.434	0.927	0.358	6.162	0.967	0.085	0.345
64	0.892	0.778	29.088	0.961	0.911	39.846	0.895	0.437	9.152	0.898	0.463	10.288	0.962	0.101	0.487
65	0.925	0.651	20.427	0.984	0.586	17.857	0.919	0.384	7.089	0.932	0.377	6.716	0.971	0.088	0.343
66	0.959	0.436	9.195	0.941	0.892	39.109	0.899	0.396	7.372	0.914	0.464	7.305	0.966	0.350	0.391
67	0.957	0.449	9.667	0.945	0.872	36.459	0.904	0.382	7.019	0.919	0.379	6.887	0.966	0.086	0.353
68	0.917	0.683	22.396	0.980	0.658	20.784	0.918	0.387	7.171	0.916	0.420	8.485	0.972	0.087	0.361
69	0.919	0.676	21.930	0.978	0.693	23.025	0.923	0.374	6.730	0.932	0.379	6.899	0.972	0.086	0.355
70	0.950	0.486	11.340	0.938	0.920	40.657	0.904	0.382	7.003	0.908	0.402	7.767	0.956	0.098	0.457
71	0.893	0.781	29.310	0.942	1.085	56.494	0.917	0.399	7.638	0.941	0.357	6.109	0.971	0.086	0.354
72	0.924	0.661	20.984	0.958	0.927	41.281	0.961	0.273	3.570	0.961	0.291	4.071	0.977	0.076	0.276
73	0.919	0.681	22.229	0.956	0.945	42.846	0.956	0.289	4.003	0.964	0.278	3.709	0.978	0.074	0.264
74	0.919	0.683	22.383	0.956	0.945	42.856	0.960	0.276	3.656	0.964	0.279	3.737	0.979	0.074	0.260
75	0.952	0.522	13.095	0.960	0.901	38.931	0.959	0.278	3.717	0.963	0.283	3.831	0.977	0.076	0.275
76	0.901	0.755	27.345	0.942	1.085	56.504	0.934	0.356	6.097	0.937	0.370	6.587	0.976	0.079	0.297
77	0.900	0.757	27.493	0.941	1.100	58.065	0.910	0.416	8.294	0.927	0.397	7.582	0.975	0.079	0.300
78	0.937	0.600	17.286	0.953	0.978	45.898	0.957	0.286	3.926	0.960	0.293	4.116	0.978	0.074	0.262
79	0.897	0.769	28.420	0.949	1.021	50.067	0.919	0.393	7.408	0.936	0.373	6.688	0.973	0.082	0.323

80	0.907	0.729	25.501	0.948	1.030	50.959	0.930	0.366	6.430	0.924	0.407	7.963	0.977	0.076	0.276
81	0.952	0.524	13.164	0.962	0.883	37.414	0.961	0.273	3.580	0.967	0.267	3.424	0.979	0.073	0.259
82	0.942	0.579	16.077	0.958	0.930	41.497	0.963	0.265	3.381	0.968	0.265	3.378	0.978	0.074	0.261
83	0.961	0.476	10.863	0.961	0.855	35.120	0.963	0.290	4.044	0.967	0.293	4.112	0.962	0.107	0.545
84	0.927	0.648	20.125	0.958	0.927	41.220	0.960	0.275	3.632	0.965	0.275	3.627	0.978	0.075	0.269
85	0.951	0.535	13.723	0.956	0.907	39.506	0.945	0.352	5.936	0.956	0.337	5.437	0.957	0.114	0.621
86	0.906	0.733	25.811	0.948	1.034	51.352	0.919	0.394	7.453	0.933	0.380	6.940	0.967	0.091	0.398
87	0.898	0.766	28.198	0.947	1.044	52.288	0.948	0.317	4.811	0.954	0.317	4.813	0.973	0.083	0.330
88	0.934	0.613	18.037	0.959	0.911	39.826	0.962	0.269	3.465	0.967	0.267	3.418	0.979	0.073	0.257
89	0.917	0.690	22.850	0.946	1.047	52.619	0.925	0.380	6.915	0.935	0.376	6.799	0.973	0.083	0.332
90	0.931	0.627	18.893	0.957	0.932	41.711	0.961	0.273	3.583	0.965	0.276	3.645	0.978	0.075	0.269
91	0.847	0.900	38.840	0.939	1.122	60.394	0.863	0.557	14.911	0.880	0.559	15.006	0.953	0.126	0.763
92	0.961	0.476	10.871	0.923	1.119	60.053	0.889	0.454	9.911	0.899	0.463	10.279	0.922	0.139	0.933
93	0.959	0.485	11.288	0.922	1.126	60.876	0.877	0.478	10.964	0.887	0.489	11.491	0.924	0.138	0.908
94	0.961	0.473	10.756	0.923	1.122	60.458	0.885	0.462	10.256	0.888	0.487	11.399	0.925	0.136	0.892
95	0.960	0.480	11.046	0.928	1.086	56.622	0.887	0.459	10.101	0.896	0.470	10.609	0.925	0.136	0.893
96	0.960	0.478	10.963	0.922	1.126	60.815	0.891	0.452	9.790	0.896	0.470	10.622	0.925	0.137	0.897
97	0.960	0.480	11.039	0.921	1.131	61.444	0.871	0.490	11.502	0.873	0.519	12.945	0.924	0.137	0.903
98	0.960	0.479	11.028	0.918	1.159	64.519	0.877	0.479	10.995	0.877	0.511	12.550	0.924	0.137	0.902
99	0.959	0.485	11.273	0.924	1.110	59.149	0.888	0.457	10.012	0.896	0.471	10.633	0.925	0.137	0.895
100	0.960	0.479	10.992	0.926	1.096	57.677	0.889	0.454	9.911	0.892	0.478	10.987	0.926	0.136	0.885