



MULTI- OBJECTIVE OPTIMIZATION OF SHELLING PROCESS OF AN ENGINE - OPERATED MELON (*CITRULLUS LAENATUS KUNTZE*) SHELLER

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ABSTRACT

The quest to develop an optimally operating mechanical device to shell melon seed (*citrullus laenatus kuntze*) has been a desirable objective over the past three decades. A melon sheller was constructed and optimized. The machine shelling performance analysis were based on shelling capacity, shelling efficiency, cleaning efficiency, seed loss, and damaged kernel. MATLAB 7.0, R2010a software was implemented using genetic algorithm technique for the optimization of the independent parameters and dependent response variables. A layout of the experiment was three speeds (S_1, S_2, S_3), three feeding rate (P_1, P_2, P_3) and three moisture contents (M_1, M_2, M_3) which were arranged in a randomized complete design ($3 \times 3 \times 3$) in 3 replications. Melon (egusi) seed of Bara variety was used as test crop. Results showed that the machine shelling capacity and shelling efficiency increased with increase in the shelling drum speed, while the shelling capacity ranged between 20.07 and 44.90 kg/hr and the shelling efficiency ranged between 59.21 to 97.59 %. The optimum inputs were: moisture content (19.9 %), speed (1248 rpm), feed rate (42 kg/hr) at 4 passes and best performance parameters were: shelling efficiency (98.38 %), cleaning efficiency (48.79%), seed loss (8.74 %) and damaged kernel (10.44 %). The means of three replication of performance parameters were used in analysis. The shelling efficiency, cleaning efficiency, seed loss and damaged kernel were: 96.14, 49.15 %, 9.72 % and 10.52 % respectively, which is very close to the values (98.38 %, 48.79 %, 8.74 % and 10.44 %, respectively) obtained from the optimization process.

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1.0 Introduction

There is awareness of the need for food security and the renewed and growing concern by the Federal Government of Nigeria to increase agricultural productivity with the objectives of increasing indigenous crop and development of agricultural machinery that could impact positively on the productivity and the living standard of the citizens. This is achievable through sustainable and adaptive research and development in the areas of crop production, processing and storage. However, agricultural machine prototypes produced in private sector in Nigeria are done without much reference to science and fundamental principle of machine design (Ukatu, 2006). Melon (egusi) seeds (*citrullus laenatus kuntze*) are increasingly used for their oil in the cosmetic and pharmaceutical industry (Aregbe, 2008). The many uses of melon (egusi) cannot be achieved without post-harvest operations such as gathering of the harvested fruits, softening of the fruit, extraction of seeds, washing, drying and shelling. Among these operations shelling is the most difficult and time consuming (Isiaka et al., 2006). Over years, little research has been done in the area of melon (egusi) seed processing machine. Odigboh (1979) reported that, there has been no interest in the industrialization of oil extraction from (egusi) melon largely due to the difficulty involved in shelling the seeds. He employed arrangement of radial vane impeller, impeller with vane positioned at varying angles to the radius having four vanes each. He used different vane configuration on the spinning disc at radial position and at both 45 ° and 90 ° to the radii of the spinning disc concentric circle. The study revealed that impeller with vane positioned at 45° to the

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radius gave the best combination of higher shelling and low percentage of damage to the shelled seed. In addition, his work found that 8.64 – 17.05% of wetted seeds were broken while 14.24 - 24.93% of seeds that was not wetted were broken. This showed that reduction in the damage of the seed was achieved by increasing the moisture content of the melon seeds. However, the size of the sheller makes it cumbersome for household application. The shelling process is particularly tedious and time consuming (Anonymous, 2001). (Skwarcz, 2006) reported that the condition of optimization is needed to be fulfilled in order to make a machine operate at its optimum capacity with minimum input and enhanced operation efficiency. This is to find parameter values (shelling capacity, shelling efficiency, cleaning efficiency, seed loss, and damaged kernel) that match predictions with reality by choosing the right set of parameters that improve the performance of the sheller. The interest in application of modern optimization technique is considerable, primarily as a result of development of modern computers and software (Enaburkhan, 1994). Oluwabukola et al., (2021) carried out numerical optimization for investigating the effects of the speed of shelling, melon seed moisture content and number of beaters of a developed mechanized centrifugal melon shelling and cleaning machine. They reported optimum values of speed of 2200rpm, moisture content of 12% (w.b) and 19 beaters for shelling efficiency of 88.80%. Aturu et al., ((2021) studied the effects of parameters of a centrifugal melon shelling and cleaning machine. Optimum values of speed of 1842rpm, moisture content of 11.6% (w.b), and 15 beaters for cleaning efficiency of 90.2% were obtained. Optimization of the shelling parameters of melon seed for power operated machine was to define seed kinematics in the shelling process as a requisite tool for design procedure of shelling unit. The objectives of this study were to: (1) construct a melon sheller, and evaluate its performance and (2) optimize the shelling process of the melon sheller on the basis of machine shelling performance indices (shelling capacity, shelling efficiency, cleaning efficiency, seed loss, and damaged kernel).

2. Materials and methods

2.1 Materials

Melon (*Citrullus laenatus* kuntze) seed of Bara variety was used as test crop. It has large brown seeds with thick black edges especially thickened toward the apex, about 16 x 9.5 mm and common in northern and western part of the Nigeria. Some of the instruments used include; vernier caliper (least count 0.01 mm), overhead projector model Quantum 2521, stop watch, digital weighing scale model No: OPH-T3001, 0.01 g sensitivity, drying oven model DHG XMDT-8222. Others are: photo type microprocessor digital tachometer model DT-2234A+ and anemometers, compression testing machine type 'W' Monsanto serial No. 9875 and seed hardness tester model GWJ-I, all in the material processing laboratories of Agricultural and Mechanical Engineering Departments, Ahmadu Bello University, Zaria, Nigeria and Agricultural Engineering Department, Bayero University, Kano, Nigeria. Design considerations for optimum performance and easy maintenance of the melon shelling machine include: the type of material used for each component, simplicity of design to meet the required standard and specifications, materials of adequate strength were used to ensure their durability and reliability, and cost of the materials used. In addition, local and available materials construction method for reliability and durability, and mobility of the machine were considered.

2.2 Methods

2.2.1 Moisture content

The moisture content of the test crop (melon seed) was determined by oven drying method according to ASAE (1984) Standard. A 15 g weight of sample seeds at three replications was oven dried using Harris England oven of model DHG XMTD-8222. The initial moisture content of seed was determined using the oven dry method at $103 \pm 2^\circ\text{C}$ until a constant weight was reached (Kashaninejad et al., 2005). The moisture content was calculated on dry basis as shown in Equation 1:

$$\text{Moisture content, } MC_{DB} = \frac{M_w - M_d}{M_d} \times 100 \quad (1)$$

where, MC_{DB} is the moisture content in dry basis (%) of the material, M_w is the initial weight of the material (g), and M_d is the weight of the material after drying (g).

2.2.2 Compressive strength

The force exerted on a seed for it to rupture was determined by using a Honesfield tensiometric material testing machine. The machine was used to obtain the values of compressive force from which the compressive stress and Young modulus were determined. The machine has a graduated scale of five Newton (5 N) intervals and a maximum range of 300 N. The seed was loaded between two spherical seated nose points by chunk attachment pins. This caused the operating screw to move to the left and transmit pressure to the seed. The other end of the seated nose was connected through compression head and a spring beam. The deflection of this spring beam was transmitted to a mercury piston which displaces mercury into a uniform bore glass tube that magnified the beam deflection to provide easily readable scale of load. It should be noted that the compressive force applied on the mercury reservoir causes a thread of mercury to rise along the scales.

2.2.3 Require energy to shear the seed

The determination of both the melon seed dimensions and the coefficient of friction of the materials surfaces used for shelling drum and concave surface enabled the calculation of an adequate pressure sufficient to supply the require energy to shear the seed, using Guzel et al., (2005) relationship as:

$$P_F = Mg / A_m \times 100 \quad (2)$$

where: P_F = pressure applied (N/m^2), M = mass of the moving surface, g = specific force and A_m is the surface area.

2.2.4 Tensions in both the transmission belt and pulley: They were calculated as:

$$T = Fr \quad (3)$$

where: T is the torque (Nm), F is the total tension exerted on belt and pulley, r radius of pulley (m)

$$P_T = 2\pi NT/60 \quad (4)$$

where: P_T is power in the transmission unit; (kW) and N is revolution of the shelling drum., and T is the torque, ($N.m$).

2.3 Machine components

2.3.1 The hopper

The machine hopper was developed from geometric shape of trapezoidal and anthropometric consideration so as to give desirable fitting and also to enhance easy flow of the melon seed base on the determination of the angle of the repose on the mild steel. The determination of the hopper's volume is achieved using the following relationship:

$$W = 1/3(YZ^2H - yz^2h) \quad (5)$$

where: W = Volume of hopper (mm^3), YZ = the upper width of the hopper(mm), H = total height of the hopper(mm), Yz = base width of the hopper(mm), and h = hopper base height of the hopper(mm).

2. 3.2 Shelling drum

The diameter (D) of the shelling drum is given as:

$$D = v/\pi N \quad (6)$$

where: v is the peripheral speed of cylinder (m/min), and N is the number of drum revolution in a minute (rpm).

2.3.3 Belt drives

The required pulley sizes (diameters) for both the shelling and separation units were determined from the following relationship:

$$N_1 D_1 = N_2 D_2 \quad (7)$$

where: N_1 = speed of the driven pulley (rpm), N_2 = speed of the driving pulley (rpm), D_1 = diameter of driven pulley (cm), and D_2 = diameter of driving pulley (cm),

2.3.4 Belt length

The effective belts length for both units was selected using (Bainier et al., 1995) relationship as:

$$L_b = \pi / 2 (D_2 + D_1) + 2C + \frac{(D_2 - D_1)^2}{4C} \quad (8)$$

where: L_b = belt length (cm), C = center distance between the driving and driving pulleys, D_1

2.3.5 Belt tension

It was calculated as (Hannan and Stephen, 1984):

$$m_t = (T_1 - T_2)R \quad (9)$$

where, m_t = Torsional moment (Nm), R = radius of the shaft pulley, T_1 and T_2 = force on the tight and slack side of the belt, respectively (N).

2.3.6 Contact angle of the belt

The angle of contact (θ) of the belt was determined using equation (Hall et al., 1982):

$$\theta = 180 - (D_2 - D_1/C \times 60) \quad (10)$$

where, θ is the angle of contact.

2.3.7 Shaft design: Mild steel of code (c1040) with strength properties as stated by ASME (1948); Yield strength (yield stress) of 568.7 MN/m² and Ultimate strength (tensile stress) of 668.8 MN/m² was used. Shaft diameter (d) was determined using the relationship given by Hall et al. (1982) as:

$$d^3 = 16 / \pi SS \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (11)$$

where: d = shaft diameter (m), SS = allowable shear stress of a steel shaft, K_b and K_t = combined shock and fatigue factor applied to bending and torsional moment, respectively. M_b and M_t = bending and torsional moment on shaft, respectively. The minimum safe diameter for the shelling drum is 16 mm. Hence, we choose 20 mm as the shaft diameter for the shelling unit.

2.4. Operation of melon sheller

In the machine chamber, the kernel of a seed is removed from the seed cotyledons. The melon seed is kept between the shelling drum and the concave and subjected to rubbing and stripping action which is caused by impact generated on the materials from both the vanes of the shelling drum and vanes of the concave surface. The actions of attrition, shearing, rubbing and bending, strip off the outer cotyledons of the melon seeds. The actions create a material flow through high velocity of the mass of shelled seed, unshelled seed and chaff to a blower where shelled seeds are separated from chaff. The clean seed fall into the collecting tray and the chaff is blown away. The isometric view, and orthographic projection are shown in Figures 1, and 2, respectively.

2.4.1 Shelling capacity

The machine shelling capacity was calculated as (FAO, 1994):

$$C = q_s / t \quad (12)$$

where: C = shelling capacity, (kg/h), q_s = weight of shelled seed, (kg), t = shelling time, (hours)

2.4.2 Shelling efficiency

The machine shelling efficiency was calculated as (FAO, 1994):

$$S_E = 100 - (USB / TWS \times 100) \quad (13)$$

where: S_E = shelling efficiency, %, USB = weight of unshelled seed, kg, TWS = total weight of seed, kg

2.4.3 Cleaning efficiency: The machine shelling efficiency was calculated as (FAO, 1994):

$$C_E = B/D \times 100 \quad (14)$$

where: C_E = cleaning efficiency, %, B = weight of whole clean seed at outlet, kg and

D = weight of whole material collected at outlet, kg

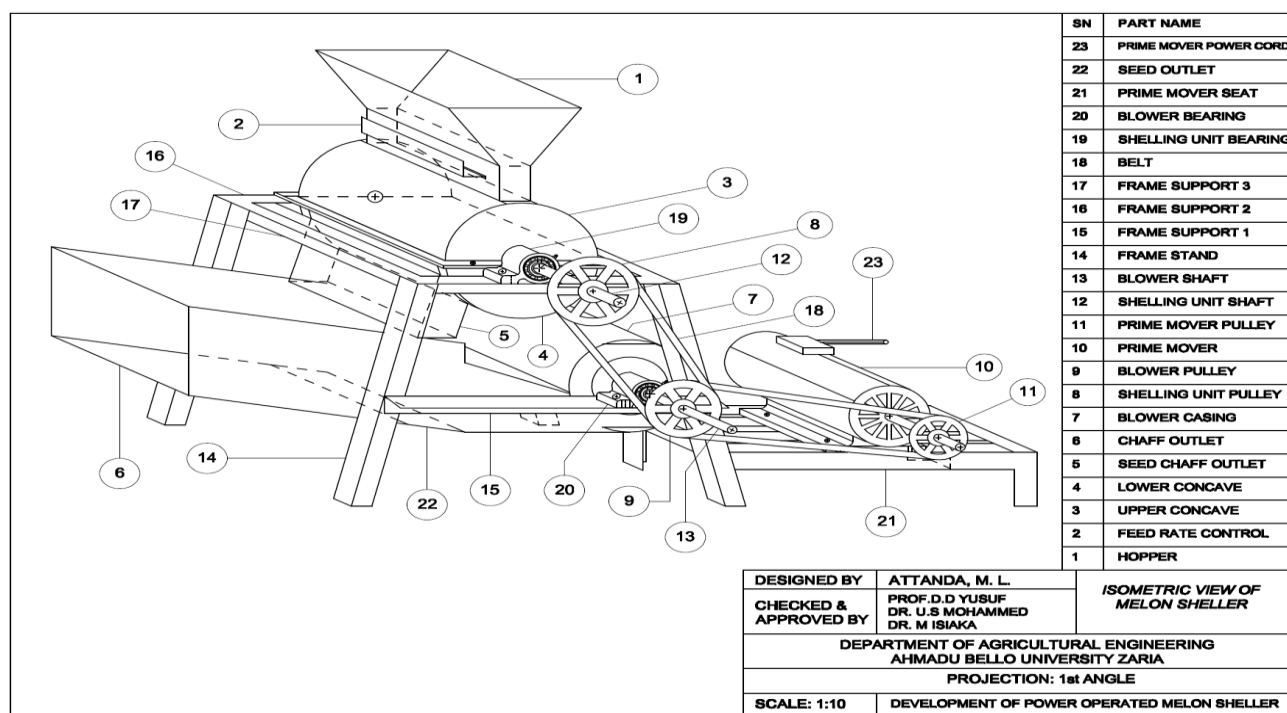


Figure 1: Isometric view of melon sheller

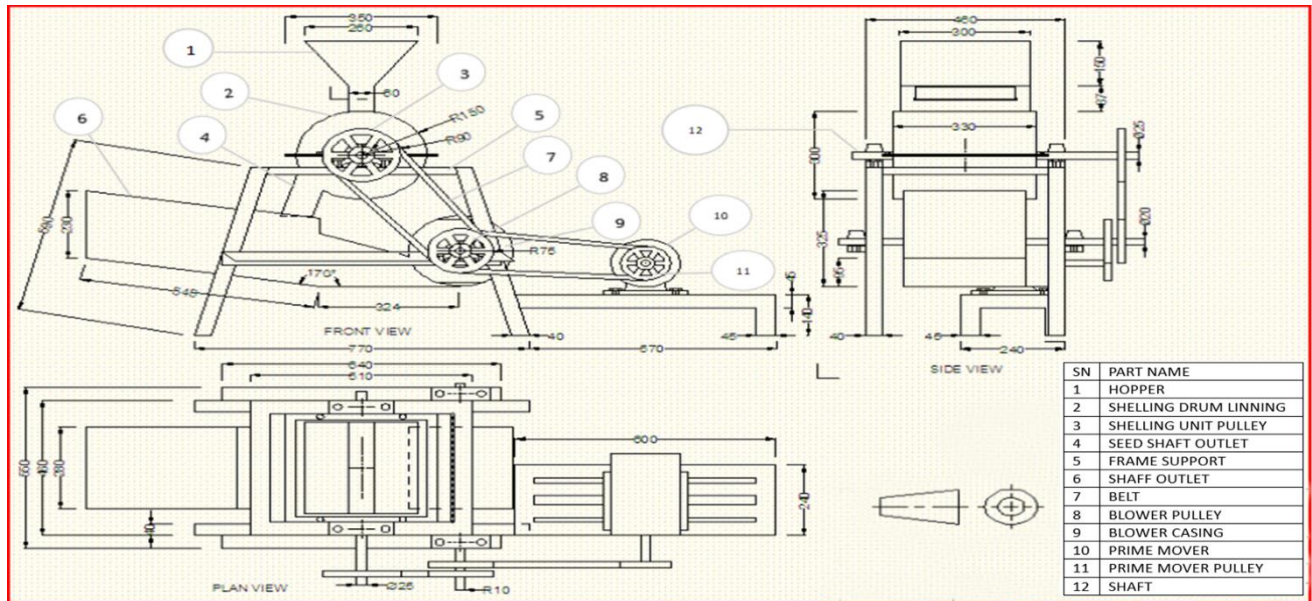


Figure 2: Orthographic projection of melon sheller

2.4.4 Seed loss

The seed loss was calculated as (FAO, 1994):

$$S_L = \left(\frac{W_L}{T_s} \right) \times 100 \quad (15)$$

where: S_L = seed loss %, W_L = weight of seed loss collected, kg, T_s = total seed input, kg

2.4.5 Damaged kernel

The kernel damage was obtained as (FAO, 1994):

$$D_k = \frac{W_{dk}}{W_{sk}} \times 100 \quad (16)$$

where: D_k = damaged kernel, %, W_{dk} = weight of damaged kernel collects at outlet, kg,

W_{sk} = weight of shelled kernel collected at outlet, kg.

2.5 Experimental layout

A layout of the experiment is three speeds (S_1, S_2, S_3), three feeding rate (P_1, P_2, P_3) and three moisture contents (M_1, M_2, M_3) which are arranged in a randomized complete design ($3 \times 3 \times 3$) in 3 replications.

2.5.1 Statistical analysis

The data collected from the experiment were analyzed statistically by using analysis of variance (ANOVA). Software of statistical Analysis Systems, (SAS) Institute Inc., 2007 was used. Duncan multiple range test (DMRT) was used for planned pair comparison between variable means.

2.6 Optimization technique

MATLAB 7.0, R2010a software was implemented using genetic algorithm technique for the optimization of the independent parameters and dependent response variables in this study. Miu and Perhinschi (2001) reported that experimental results indicate that the genetic algorithm is a promising design and optimization tool for solving agricultural machinery related problems for the best approximation solutions and in minimizing the execution time. The following six steps were determined for the use of genetic algorithm in this study: (i) the genetic representation of the chromosome (variables), (ii) the creation of the initial population, (iii)

evaluation function, (iv) selection function, (v) genetic operators making up the reproduction function (cross-over and mutation), (vi) termination criteria. Figure 3 shows the schematic representation of the procedure of optimization using genetic algorithm techniques.

2.6.1 Algorithm development

The optimization problem to be solved in this study was to find an optimum configuration of independent variables combination which constrained by a number of upper and lower boundaries function of inequalities on performance criteria.

The shelling unit of the machine is characterized by:

Vector x of i control parameters,

$$x = (x_1, \dots, \dots, \dots, \dots, \dots, x_i)^T \quad (17)$$

where: x is the independent variables, i is the total number of independent variable

$$\text{Vector } y \text{ of } j \text{ functional criteria, } y = (y_1, \dots, \dots, \dots, \dots, \dots, y_j)^T \quad (18)$$

where: y is the functional criteria of the machine, and j is the total number of performance criteria objectives. The control parameters (x) and functional criteria objectives (y) considered in the decision process in search of optimal solution of this study are:

$$x = (S, P, M) \quad (19)$$

$$y = (SE, CE, DS, LS) \quad (20)$$

where: S = speed of the shelling drum (RPM), P = passes of the feed rate (kg/hr),

M = moisture contents of the seed (%), SE = shelling efficiency (%), CE = cleaning efficiency (%), DS = damage seed and (%), and LS = loss seed (%).

2.6.2 Evaluation function: An optimization problem with more than one objective function such as the case in this study would require a weighting vector. This is simply weighting of all the functional vectors together to form a single aggregate functional response of the form, (William and James, 1980):

$$U[y(x), w] = \sum_{i=1}^m w_i y_i(x) \dots \quad (21)$$

where: U =utility factor relating all the functional vector, $y(x)$ = functional response of the machine, w_i = weighting vector. Therefore, the evaluation function in this study has the expression:

$$EF = w_1 y_1(x) + w_2 y_2(x) - w_3 y_3(x) - w_4 y_4(x) \quad (22)$$

Miu (2001) stated that it is likely the algorithm with equal weights to converge to a local optimum when it does not meet one of the requirements of the weighting vector. In order to avoid the problem of convergence to a local optimal of the algorithm because of equal weight vector, a selective weights vector (Miu, 2001) was also considered as shown in Table I.

Table I: Weighting vector for the performance responses of the machine.

S/N	Parameter	Equal weighting vector	Selective weighting vector
1	Shelling efficiency SE (%)	25	33.3
2	Cleaning efficiency CE (%)	25	33.3
3	Damage seed SD (%)	25	22.2
4	Loss seed LS (%)	25	11.1

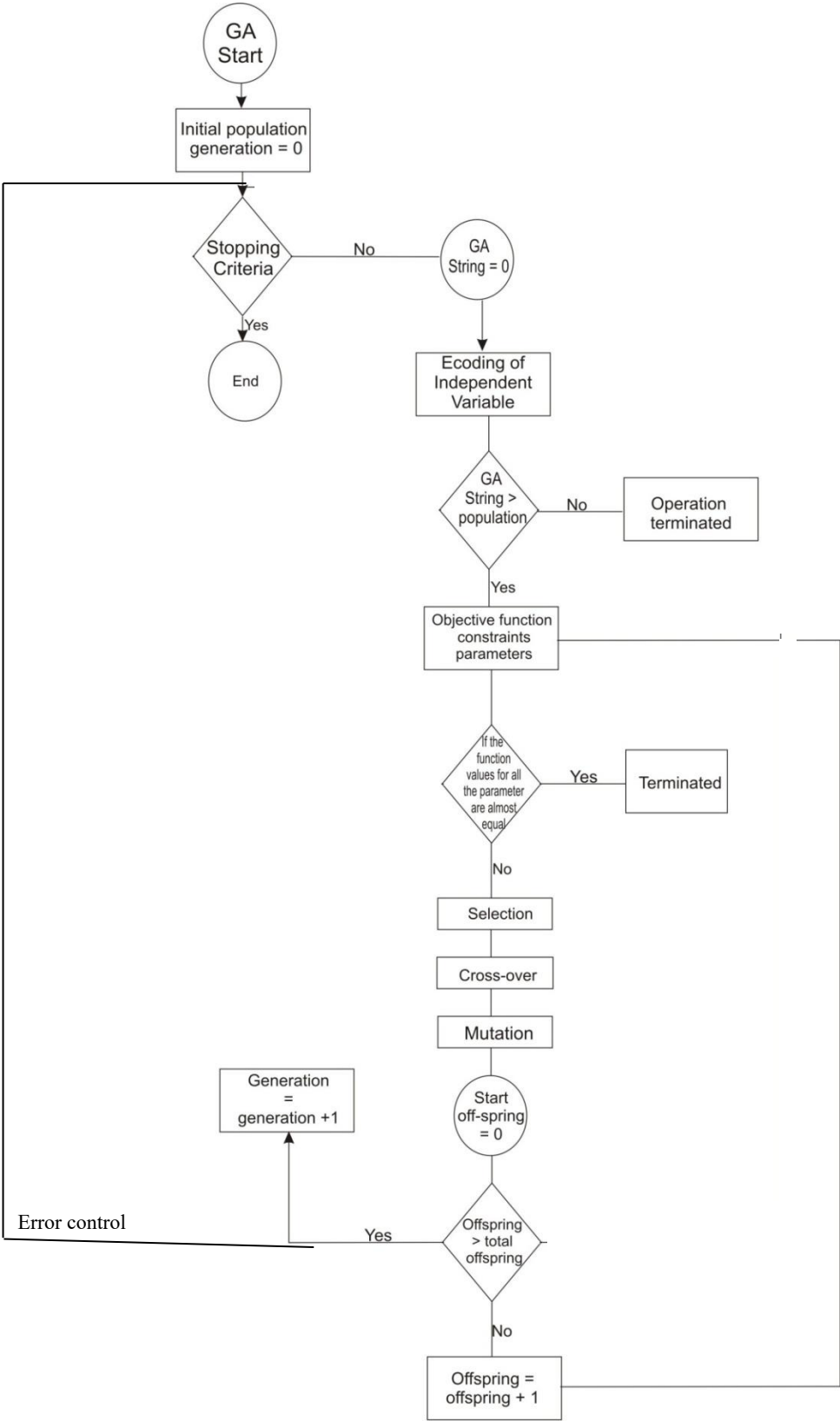


Figure 3: Schematic representation of the procedure of optimization using genetic algorithm techniques.

3.0 Results and Discussion

3.1 Compressive strength: The results of the compressive strength of the melon seed at different moisture contents for both shelled and unshelled seeds of the different seed orientations are presented in Table 2. Compressive forces and stresses showed a continuous decrease with increasing moisture content. Similar observation was noticed with the Young modulus in all the size categories of the melon seed. The least stresses

at yield point occurred at moisture content of 30 % for all size groups with 0.132, 0.146 and 1.53 N/mm² for small, medium and large melon seed, respectively and the corresponding highest values obtained at 10 % moisture content are 0.284, 0.286 and 0.308 N/mm². Young modulus of the seed in the different size categories ranged from 3.35 to 2.65 × 10⁶ Nm⁻², 3.70 to 2.75 × 10⁶ Nm⁻² and 3.85 to 2.90 × 10⁶ Nm⁻² for small medium and large seed, respectively while it ranged from 2.15 to 1.65 × 10⁶ Nm⁻², 2.90 to 2.25 × 10⁶ Nm⁻² and 3.05 to 2.40 × 10⁶ Nm⁻² for kernel. Okon (2008) reported a similar trend of findings for melon seeds.

Table 2: Compressive forces on different size categories of melon seed and kernel at different moisture contents.

Contents:										
Young	Melon	M.C	Small			Medium			Large	
	(%)	Force	Stress	Young	Force	Stress	Young	Force	Stress	
	(N)	(N/ mm ²)	modulus	(N)	N/mm ²	modulus	(N)	(N/mm ²)	modulus	
			(Nmm ²)			(Nmm ²)		(Nmm ²)		
Unshelled	10	6.00	0.284	3,35	7.50	0.286	3.70	9.50	0,308	3.85
	15	6.00	0.244	3.10	6.50	0.248	3.45	8.00	0.260	3.60
	20	5.25	0.213	2.95	7.00	0.267	3.20	6.50	0.211	3.40
	25	4.50	0.162	2.80	4.50	0.162	2.90	5.00	0.210	3.25
	30	3.25	0.132	2.65	4.00	0.146	2.75	4.50	0.153	2.90
Shelled	10	5.00	0.225	2.15	6.05	0.265	2.90	7.00	0.285	3.05
	15	4.00	0.180	2.05	5.50	0.233	2,85	6.25	0.254	2.95
	20	4.25	0.192	1.90	4.00	0.170	2.65	5.50	0.224	2.70
	25	3.00	0.135	1.85	3.00	0.149	2.50	4.25	0.173	2.65
	30	2.00	0.090	1.65	2.50	0.106	2.25	3.50	0.142	2.40

3.2 Shelling capacity

The effects of both speed of the drum, feed rate, and the interaction between the speed of the drum and feed rate were found to be highly significant ($P < 0.01$) on shelling capacity (Table 3). This is because as the speed of the shelling drum increases (Table 4), so the dwelling time of the melon seed reduces in the shelling chamber hence increase output of the machine. There is significant difference in the capacities of the machine at different speeds with machine capacity at 1250 rpm of drum speed higher than the capacity of the machine at both speed of 910 rpm and 860 rpm. Also there exist significant different in the machine capacity at different passes of feed rate with the feed rate at 2 passes having higher machine output than feed rate at 3 and 4 passes (Table 5).

Table 3: Analysis of variance for machine shelling capacity

Source of variation	Degree of freedom	Sum of square	Mean square	f-value
Replication	2	11.1165	5.558270	2.05ns
Speed (s)	2	2300.583800	1199.791900	441.65**
Feed rate passes (p)	2	5692.464486	2846.232248	1047.71**
Moisture content (m)	2	6.157735	3.078693	1.13ns
S*P	4	211.138837	52.784709	19.43**
S*M	4	73.649881	18.412470	6.78*
P*M	4	43.273719	10.818430	3.98ns
S*P*M	8	203.60994	25.451244	9.37**

** = Significant at 1% level * = Significant at 5% level ns = Not significant

Table 4: Duncan Multiple Range Test for comparison of drum speed on machine shelling capacity

Drum speed (RPM)	1250	910	860
Mean ranking	25.76 ^a	17.24 ^b	12.62 ^c
Critical Range	0.9468 0.9002		

Mean with the same letter are not significantly different

Table 5: Duncan Multiple Range Test for comparison of feed rate on machine shelling capacity

feed rate passes	42kg/hr at 2 passes	42kg/hr at 3passes	42kg/hr at4 passes
(kg/hr)			
Mean ranking	30.10 ^a	15.05 ^b	10.48 ^c
Critical Range	0.9468 0.9002		

Mean with the same letter are not significantly different

3.3 Shelling efficiency

Table 6 shows that the effect of drum speed is highly significant on the shelling efficiency of the machine. The shelling efficiency was observed to increase with increase in drum speed. Drum speed of 780, 910 and 1250 rpm at 15 % moisture and feed rate of 42 kg/hr at 4 passes produced 73.50 %, 81.21 % and 90.61 % shelling efficiencies, respectively. There is difference in means of the shelling efficiency of the machine in the descending order of the drum speed (Table 7) as: 1250 rpm > 910 rpm > 860 rpm. Feed rate passes was found to have high significant effect on shelling efficiency ($p < 0.01$). There exist significant different with feed rate at 4 passes having 85.61 % shelling efficiency followed by 3 and 2 passes having 77.0 % and 52.71 % shelling efficiencies, respectively (Table 8).

Table 6: Analysis of variance for machine shelling efficiency

Source of variation	Degree of freedom	Sum of square	Mean square	f-value
Replication	2	193.93580	96.96790	0.96ns
Speed (s)	2	3961.14482	1980.57241	19.52**
Feed rate passes (p)	2	15708.77752	7854.38876	77.41**
Moisture content (m)	2	11538.71124	1769.35562	47.58**
S*P	4	717.88080	179.47020	1.77ns
S*M	4	98.19722	24.54930	0.24ns
P*M	4	1337.60125	334.40031	3.30ns
S*P*M	8	369.68327	46.21041	0.46ns

** = Significant at 1% level * = Significant at 5% level ns = Not significant

Table 7: Duncan Multiple Range Test for comparison of drum speed on machine shelling efficiency

Drum speed (RPM)	1250	910	860
Mean ranking	80.61 ^a	71.21 ^b	63.50 ^c
Critical Range	5.502	5.787	

Mean with the same letter are not significantly different

Table 8: Duncan Multiple Range Test for comparison of feed rate on machine shelling efficiency

passes of feed rate (kg/hr)	42kg/hr at 4 passes	42kg/hr at 3passes	42kg/hr at 2passes
Mean ranking	85.61 ^a	77.00 ^b	52.71 ^c
Critical Range	5.502	5.787	

Mean with the same letter are not significantly different

3.4 Cleaning efficiency

The effect of fan speed and feed rate of the machine is highly significant ($p < 0.01$) on cleaning efficiency (Table 9). The increase in the speed of fan, increased the air flow rate. Effect of interaction of fan speed and feeding rate passes, fan speed and moisture content and feeding rate passes and moisture content are found to be highly significant ($p < 0.01$). However, the combine interaction of fan speed, feeding rate passes and moisture content is significant at 5 % probability level.

Table 9: Analysis of variance for machine cleaning efficiency

Source of variation	Degree of freedom	Sum of square	Mean square	F-value
Replication	2	97.057489	48.528744	5.44 ns
Speed (s)	2	2136.249267	1068.124633	119.83**
Feed rate passes (p)	2	396.023089	198.011544	22.21**
Moisture content (m)	2	70.738422	35.369211	3.97ns
S * P	4	3735.058311	933.764578	104.75**
S * M	4	376.048378	94.012094	10.55**
P * M	4	319.562267	79.890567	8.96**
S * P * M	8	309.999556	38.749944	4.35*

* = Significant at 5% level ns = Not significant** = Significant at 1% level

3.5 Optimization

To compute the optimum values of the independent parameters for the optimum output of the developed machine, a MATLAB optimization programme was performed with an initial population of 90 samples for three (3) different runs of 102nd generation for each version of equal and selective weights evaluation function using the developed model on genetic algorithm application. Figure 4 shows the algorithm interface for the optimization process. The algorithm interface is composed of four interactive; algorithm input, algorithm options, optimal machine input and optimal machine output. The first interface of the algorithm input the constraints for the optimization of the minimum and maximum input. The algorithm option is made of population size and evaluating function of both selective and equal weight functions, and selective weighting coefficient were performed.

3.5.1 Equal weights evaluation function

The genetic algorithm input programme of equal weight relationship and the output at different nth generation are shown in Figs. 5 to 7. The nth generation of the genetic algorithm optimizes various combination of shelling parameters to obtain the fitness individual. Fig. 5 shows the 11th generation of the genetic algorithms. The mean fitness value of any individual to survival to next generation is 24.2316 while the best fitness individual is 26.7867. This implies that any individual sample of the population with minimum genetic value of 24.23 or more would involve in the mutation and cross-over to the n + 1th generation. At 11th generation, the average distance between individuals' population is wide, hence there is the convergence. This indicates that the saddle (optimum point) is not attaining at this generation. On the other hand, Figs.6 and 7 show trends of convergence at 50th and 102nd generations of the genetic algorithm, respectively. The genetic algorithm of 50th generation (Figure 6) shows trend toward convergence with the best fitness value and mean values of an individual to be 31.9129. This suggests that the fitness of each individual is moving toward convergence at this point. The average distance between individual populations is also converging at this generation. At the end of the 102nd generation (Fig. 7) of the genetic algorithm, the algorithm converged with fitness value of 31.9214 and also the average distance between individual's parameter converge to zero. Since the best fitness value of individual is achieved and converged at this generation, the algorithm is terminated.

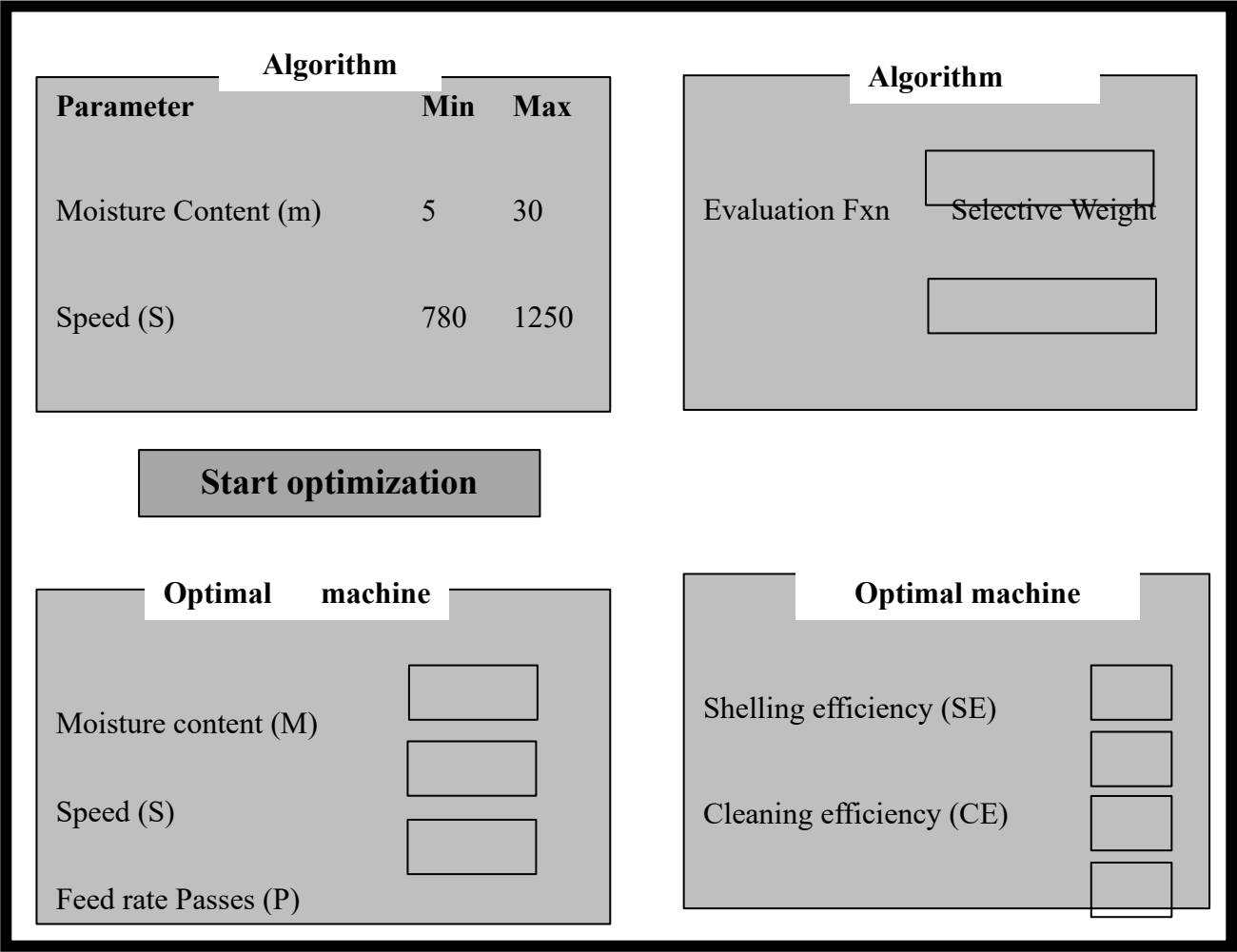


Figure 4: Algorithm interface of the optimization process

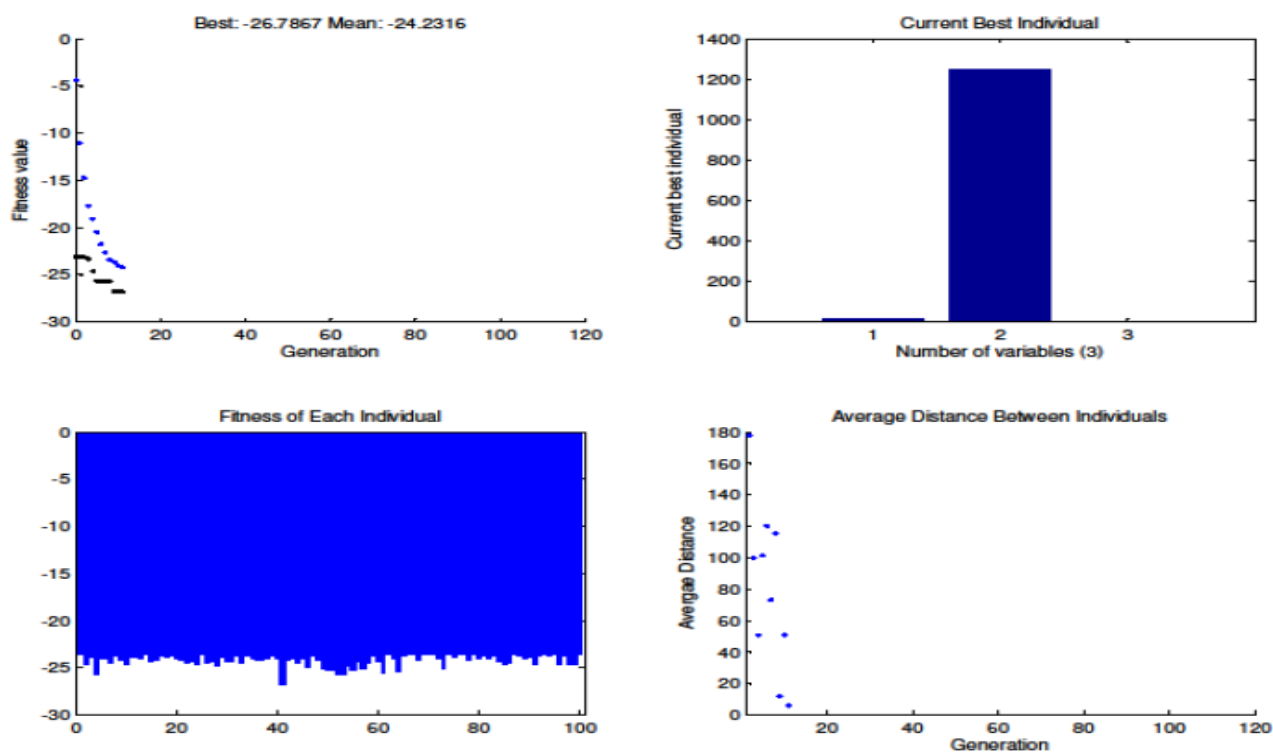


Figure 5: Genetic algorithm at 11th generation for equal weight evaluation function

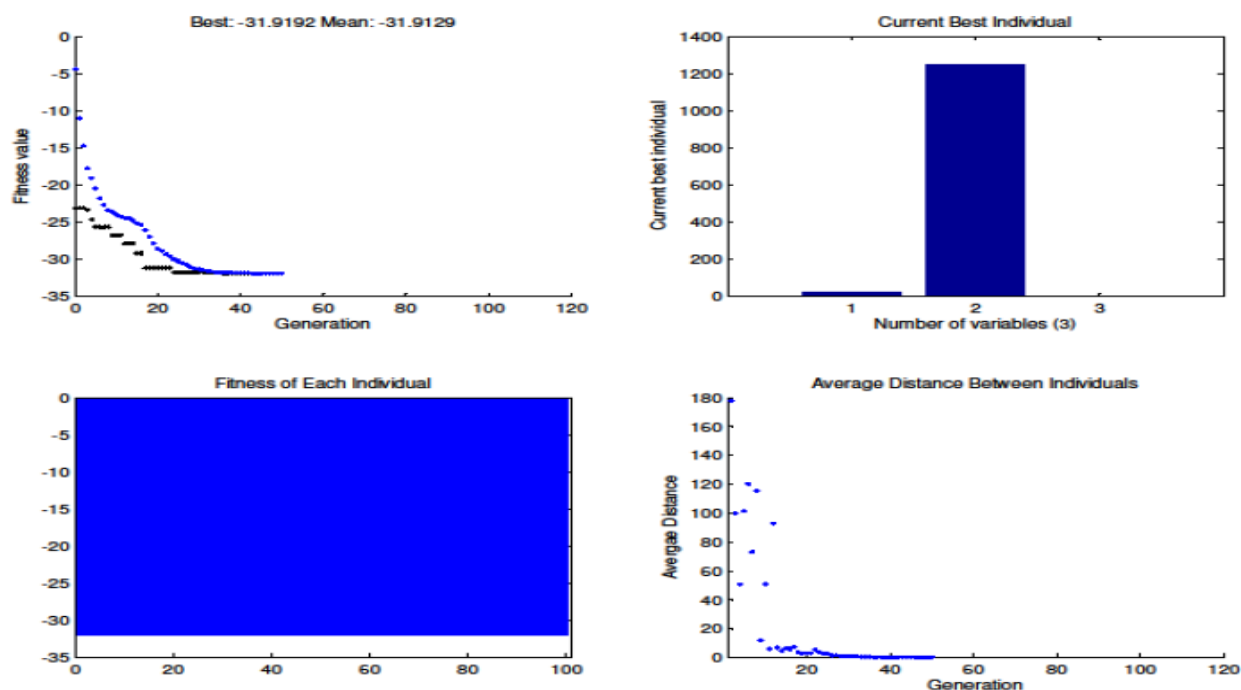


Figure 6: Genetic algorithm at 50th generation for equal weight evaluation function

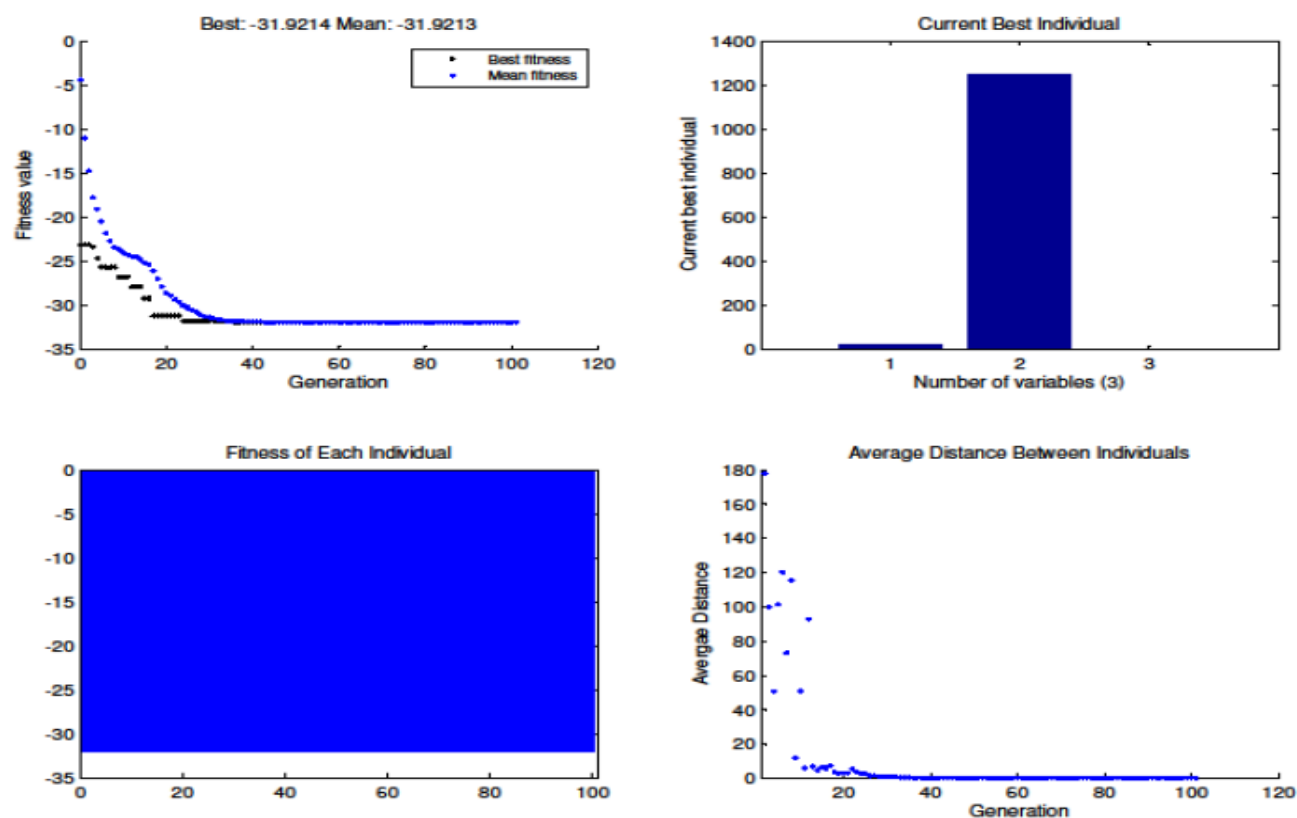


Figure 7: Genetic algorithm at 102nd generation for equal weight evaluation function

3.5.2 Optimal shelling conditions

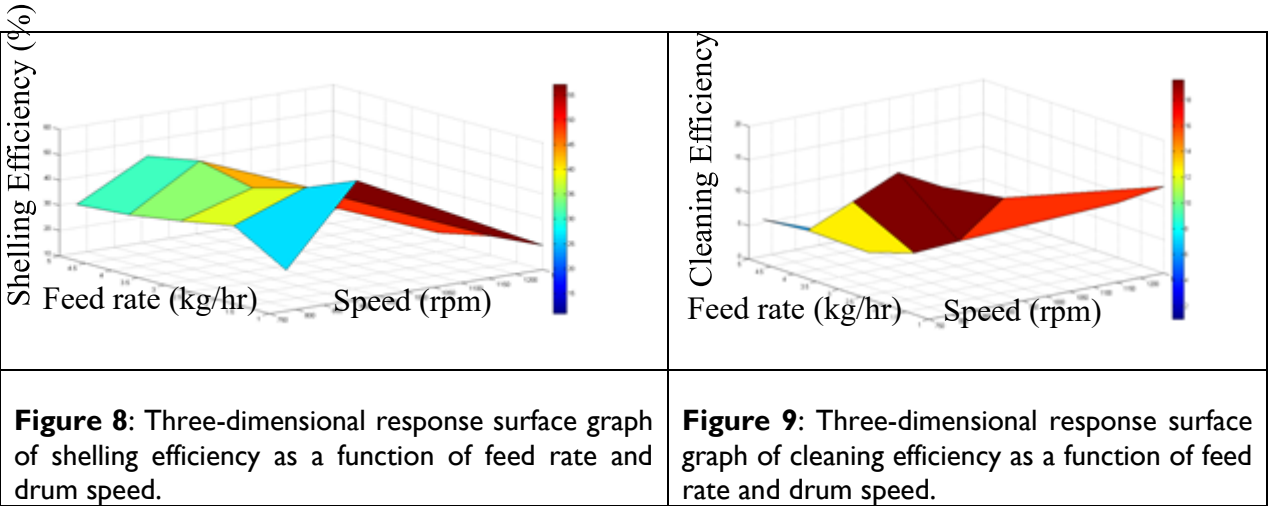
The best individual components of the machine optimum input variables were obtained when using equal weights evaluation function which produced the best performance parameter. The optimum machine inputs are: moisture content (19.9 %), speed (1248 rpm), feed rate (42 kg/hr) at 4 passes and best performance parameters are: shelling efficiency (98.38 %), cleaning efficiency (48.79%), seed loss (8.74 %) and damaged kernel (10.44 %) as shown in Table 10.

Table 10: Equal weight evaluation functions at optimal machine input and output.

Run	Optimal machine input	Optimal machine output
1 st	Moisture content (M) 20.0%	Shelling efficiency: 98.00%
	Speed (S) :1239.34 rpm	Cleaning efficiency: 47.8%
	42kg/hr of feed rate Passes (P): 4.00	Seed loss: 9.83%
		Damage kernel :16.21%
2 nd	Moisture content (M): 20.00%	Shelling efficiency: 97.87%
	Speed (S): 1235.19 rpm	Cleaning efficiency: 47.44%
	42kg/hr of feed rate Passes (P): 3.99996	Seed loss: 10.24%
		Damage kernel :18.35%
3 rd	Moisture content (M): 19.917%	Shelling efficiency :98.38%
	Speed (S): 1248.61 rpm	Cleaning efficiency: 48.79%
	42kg/hr of feed rate Passes (P): 4.00	Seed loss: 8.74%
		Damage kennel :10.44%

3.6 Three-dimensional surface plot on performance criteria of the optimization

Figures 8 to 11 are the graphically search space where the algorithm searches for optimum conditions. These represented the trend of variation in the output parameters for combined variation of the input variables at a constant moisture content of 20 % and constant feed rate of 42 kg/hr at 4 passes, respectively. Optimization parameters are shown on the x and y axes while the variation of the optimization criterion is shown on the vertical z axis with using the color gradient. The visualize mode of shelling efficiency as a function of feed rate and drum speed is also shown (Fig. 8). The small element of deep blue color shows the low level of shelling efficiency and deep red level indicate high shelling efficiency as the drum speed increase in the search space, toward optimum condition. Similarly, at low feed rate passes and fan speed, the cleaning efficiency was increasing in search space toward optimum cleaning efficiency (Fig. 9). Decrease in seed loss (Fig. 10) and damaged kernel (Fig. 11) in the search space, showed minimum seed loss and damage kernel with the deep blue as the minimum element, deep red maximum element and other colors are linearly interpolated.



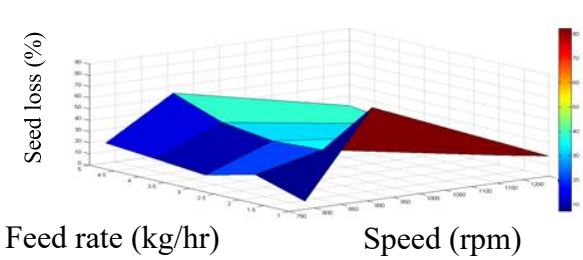


Figure 10: Three-dimensional response surface graph of seed loss as a function of feed rate and drum speed.

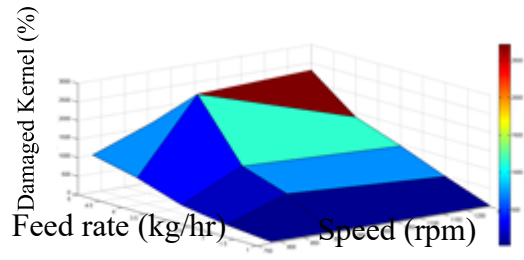


Figure 11: Three-dimensional response surface graph of damaged kernel as a function of feed rate and drum speed.

On the other hand, at constant feed rate of 42 kg/hr and 4 passes, there is increase toward the optimum condition in the search space as the independent variable of drum speed and moisture content increase for shelling efficiency (Figure 12) and cleaning efficiency (Fig.13), respectively. Also, there is increase toward the optimum condition in the search space as the independent variable of drum speed and moisture content increase for seed loss (Figure 14) and damaged kernel (Figure 15).

In order to verify the optimum shelling process conditions obtained, the optimum combination of the machine independent variables (moisture content; 19.9 %, speed; 1248 rpm and feed rate of 42 kg/hr of 4 passes) were tested on sheller. The means of three replication of performance parameters output of the machine when the optimum combination of the shelling process variables were implemented on the sheller, the shelling efficiency, cleaning efficiency, seed loss and damaged kernel were: 96.14, 49.15 %, 9.72 % and 10.52 % respectively. This is very close to the shelling efficiency (98.38 %), cleaning efficiency (48.79 %), seed loss (8.74 %) and kernel damage (10.44 %) obtained from the optimization process, Hence, satisfying nearly all the constraints on the shelling process of the developed machine.

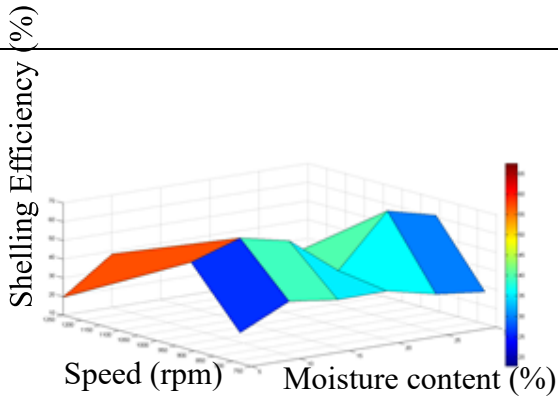


Figure 12: Three-dimensional response surface graph of shelling efficiency as a function of drum speed and moisture content.

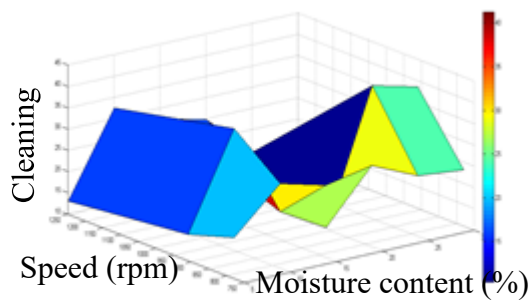


Figure 13: Three-dimensional response surface graph of cleaning efficiency as a function of drum speed and moisture content.

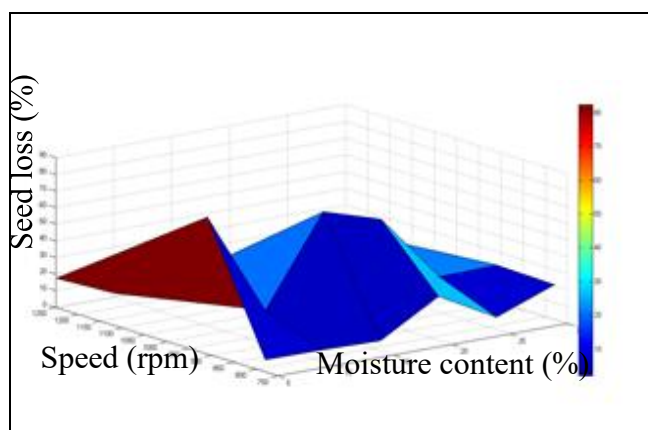


Figure 14: Three-dimensional response surface graph of seed loss as a function of drum speed and moisture content.

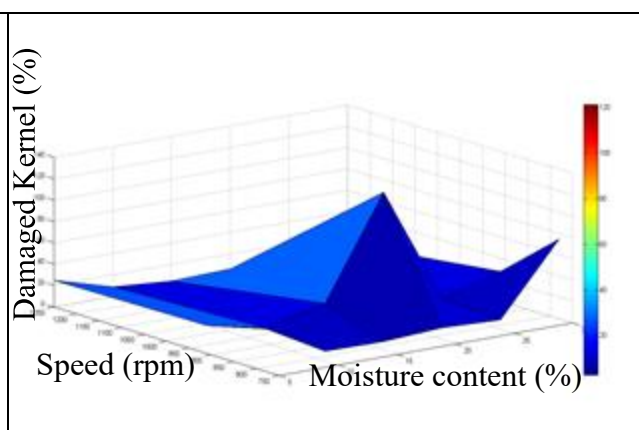


Figure 15: Three-dimensional response surface graph of damaged kernel as a function of drum speed and moisture content.

4.0 Conclusion

The study revealed that the optimum machine inputs are: moisture content (19.9 %), speed (1248 rpm), feed rate (42 kg/hr) at 4 passes and best performance parameters are: shelling efficiency (98.38 %), cleaning efficiency (48.79%), seed loss (8.74 %) and damaged kernel (10.44 %). They are very close to the shelling efficiency (98.38 %), cleaning efficiency (48.79 %), seed loss (8.74 %), and damaged kernel (10.44 %) obtained from the optimization process.

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