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EFFECT OF SELECTED MACHINE PARAMETERS ON PERCENTAGE DAMAGE OF GINGER RHIZOMES

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Abstract: The high rate of mechanical damage on harvested ginger rhizomes which is as a result of some parameters of the machine (ginger harvester) during operation. These had tremendously contributed to the high post–harvest loss experienced by ginger farmers in Nigeria. Thus, there is a need to investigate some machine parameters of ginger harvester such as the digger lengths, speeds and digger spacing as they affect ginger's rhizomes percentage damage (RPD) using response surface methodology. Three levels of speeds (4, 8 and 12km/hr), three levels of digger lengths (25, 30 and 35cm) and three levels of digger spacing (4, 6 and 8cm) were studied as they affect the Rhizomes Percentage Damage of the machine. Results showed that the Rhizomes Percentage Damage (RPD) increased with harvester speed, but decreased with digger lengths and spacing. The linear effects of the speed of the harvester and digger spacing were significant to the Rhizomes Percentage Damage (RPD) of the ginger harvester at 5% probability ($P \leq 0.05$). Also significant are the quadratic effects of speeds, digger spacing, digger lengths and the interaction of the digger lengths and spacing. These factors accounted for about 99.51% for the variation in the Rhizomes Percentage Damage. The lowest and overall best Rhizome Percentage Damage (RPD) of 30.79% was obtained when the digger length was 31cm and the harvester speed was 4km/hr.
Keywords: Ginger, percentage damage, speed, digger length, digger spacing and response surface

1. INTRODUCTION

Ginger (Zingiberofficinalle) is a spicy rhizome of medicinal and culinary importance [1]. Ginger is an essential crop grown for its pungent rhizome which is generally used as cooking spice in Nigeria. It is also been known for its hot and pungent aroma which is due to the oleoresin and essential oils present in it [2]. Ginger is an essential ingredient in the production of beverages and soft drinks. In both conventional and traditional medicine, ginger rhizome has been a functional ingredient in the treatment of indigestion, colic, diarrhoea, and nausea [3]. Moreso, it is believed that ginger can be used to treat influenza–like symptoms and influenza virus [4]. Nigeria's annual fresh ginger production is on an average of 50,000 metric tonnes [5]. Ginger's diverse application and usefulness made it an important article of trade in the world spice market. Thus, about 10% of the produce is processed and consumed as fresh ginger while the other 90% is processed as dried ginger for both local consumption and export. It can be processed as fresh, dried, dehydrated and powdered forms [6]. According to [7], about 20% of dried ginger is locally consumed and further processed for other uses while the remaining 80% is exported. Ginger production in Nigeria started as back as 1927 when an investigation was carried out to find a crop that would generate internal trade for the people of Southern Kaduna, which has now become the traditional home of ginger production in Nigeria [5] and [7].

[8] reported that full agricultural mechanization can only be achieved through the introduction of advanced technologies that reduces drudgery, increase production and enhance the financial growth of the nation. Ginger is usually cultivated annually as a commercial crop which is harvested by digging up the matured rhizomes after 7 to 10 months of planting [9]. The mechanization of ginger production and processing is beginning to receive some attention in Nigeria where there are efforts toward mechanizing the production operations so as to increase ginger production and use [9] and [10]. This is an effort to reduce the manual operations carried out on ginger during planting, mulching, fertilizing, weed control, harvesting and processing [9]. Response surface methodology (RSM) is a statistical tool involving mathematical methods, experimental strategy and statistical inferences which enables the experiment to have an efficient empirical exploration [11] and [12]. RSM uses a sequential experimentation philosophy, where the ultimate goal is to optimize a process. This is carried out using the fewest possible number of experimental runs to achieve the process optimization [12] and [13].

2. MATERIALS AND METHODS

Description of the Ginger Harvester

A two–row ginger harvester was developed [7]. The harvester consists of shafts, pulley, collector, PTO shaft connector, gear reducer, diggers, rake and conveyor. It is coupled to a tractor through the 3–point linkage and the power–takeoff shaft (which is the driving unit). The harvester has two wheels and incorporates a rigid steel framework and a collector. During harvest operation, the diggers dig up the ginger rhizomes which are picked up by the rakes through the conveyor to the collector. The isometric of the two–row ginger harvester are shown in Figures 1 and 2.

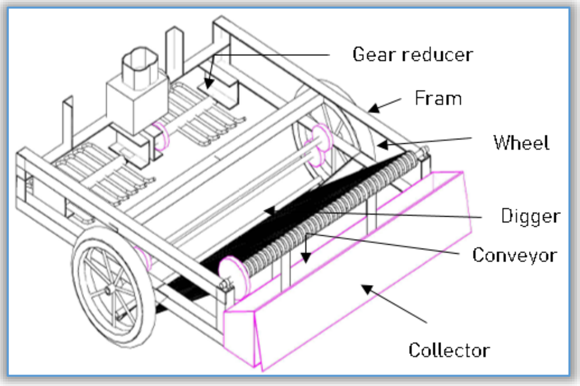

Figure 1: Isometric View of the Ginger Harvester

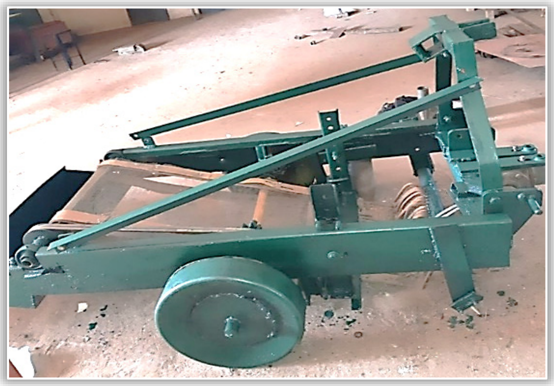

Figure 2: The Developed Ginger Harvester

Experimental Design, Statistical Analysis and Optimization

Response surface methodology was used to investigate the effects of some machine parameters of the ginger harvester like, the speed, digger lengths and digger spacing of the harvester on the Rhizomes Percentage Damage (RPD) of the machine. A central composite design including 20 experiments with 6 centre points of three factors at three levels was used (Table 1). The experiments were conducted with the developed tractor driven two row ginger harvester in a matured ginger farm in National Root Crops Research Institute Umudike. Experimental data used for this study were fitted to a second order polynomial model and regression coefficients were obtained. The generalized second order polynomial model used in the response surface analysis as used by [14] was as follows:

$$Y = \beta_o + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum \sum_{i<j=1}^{3} \beta_{ii} X_i X_j \quad (1)$$

where, β_o, β_i and, β_{ii} are constant coefficients

$X_{i,}$, X_j are coded independent variables linearly related to speed of machine, digger lengths and digger spacing. Evaluation of the mathematical models was carried out for each of the response by means of multiple regression analysis using Minitab16 software. The models includes linear, quadratic and the interaction terms. The significant terminologies in the models for each of the responses were found from the analysis of variance and regression analysis. The response curves were plotted with Matlab R2015 software. In the RSM design the linear, quadratic and interactive effects of speeds of operation, digger lengths and spacing as they affect the response (Rhizome Percentage Damage) were studied. The Rhizome Percentage Damage was obtained by modifying the equation by [15] as:

$$RPD = \frac{M - D}{M} \times 100 \quad (2)$$

where M = Total ginger rhizomes harvested by the machine (kg). D =undamaged or unbruised ginger rhizomes harvested by the machine (kg). The experimental variables that were used in the design, coding and experimental results of the independent variables on the response are shown in Tables 1 and 2.

Table 1: Experimental Variables and Coding Used in the Design

Independent Variables	Variable Levels		
Speeds, X1	4km/hr	8km/hr	12km/hr
Digger Lengths, X2	25cm	30cm	35cm
Digger Spacing, X3	4cm	6cm	8cm
Code Designation	–1	0	1
Dependent Variable (Response)			
Rhizome Percentage Damage (%) Y			

3. RESULTS AND DISCUSSIONS

The experimental variables with the coding are shown in Table1. The experimental results incorporated the independent variables (in coded terms) as shown in Table 2. The estimated regression coefficients for Rhizome Percentage Damage against, speed of operation, digger lengths and spacing are shown in Table 3. The analysis of variance for their regression are shown in Table 4.

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Table 2: Experimental Results of Independent Variables and Response in Coded Terms

Runs	X1	X2	X3	Y%
1	–1	–1	1	66
2	0	0	0	39
3	0	1	0	57
4	0	0	0	38
5	0	0	0	36
6	1	–1	1	70
7	0	0	–1	56
8	1	1	1	64
9	–1	1	1	54
10	–1	0	0	32
11	0	0	0	38
12	1	1	–1	80
13	0	–1	0	60
14	–1	–1	–1	62
15	1	0	0	40
16	1	–1	–1	73
17	0	0	0	38
18	0	0	0	39
19	–1	1	–1	70
20	0	0	1	49

Table 3: Response Surface Regression: Y versus X1, X2, X3

Term	Coef	SE Coef	T	P
Constant	38.4091	0.4894	78.474	0.000
X1	4.3000	0.4502	9.551	0.000
X2	–0.6000	0.4502	–1.333	0.212
X3	–3.8000	0.4502	–8.440	0.000
X1*X1	–3.2727	0.8585	–3.812	0.003
X2*X2	19.2273	0.8585	22.395	0.000
X3*X3	13.2273	0.8585	15.407	0.000
X1*X2	0.6250	0.5034	1.242	0.243
X1*X3	–0.8750	0.5034	–1.738	0.113
X2*X3	–4.1250	0.5034	–8.195	0.000

R–Sq = 99.51% S = 1.42374

The regression equation is:

$$\mathbf{Y} = 38.4 + 4.3\,X_1 - 0.60\,X_2 - 3.8\,X_3 - 3.27\,X_1^2 + 19.23\,X_2^2 + 13.23\,X_3^2 + 0.63\,X_1X_2 - 0.88\,X_1X_3 - 4.13\,X_2X_3$$

where, Coef = regression coefficients, SE Coef = standard error of the regression coefficients, T = Tabulated values of the regression parameters. P = Probability values of the regression terms.
S = Standard error. R–Sq =(R–squared) is a standardized measure of the goodness of fit of the regression model

Table 4: Analysis of Variance for Y (Rhizomes Percentage Damage)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	4143.73	4143.73	460.41	227.14	0.000
Linear	3	332.90	332.90	110.97	54.74	0.000
X1	1	184.90	184.90	184.90	91.22	0.000
X2	1	3.6	3.60	3.60	1.78	0.212
X3	1	144.40	144.40	144.40	71.24	0.000
Square	3	3665.45	1221.82	1221.82	602.76	0.000
X1*X1	1	1312.20	29.45	29.45	14.53	0.003
X2*X2	1	1872.11	1016.64	1016.64	501.54	0.000
X3*X3	1	481.14	481.14	481.14	237.36	0.000
Interaction	3	145.37	145.37	48.46	23.91	0.000
X1*X2	1	3.12	3.12	3.12	1.54	0.243
X1*X3	1	6.12	6.12	6.12	3.02	0.113
X2*X3	1	136.12	136.12	136.12	67.15	0.000
Residual Error	10	20.27	220.27	2.03		
Lack of fit	5	15.44	15.44	3.09	3.19	0.114
Pure Error	5	4.83	4.83	0.97		
Total	19	4164.00				

where, Seq SS = Sum of squares, Adj SS = Adjusted sum of squares, DF = Degrees of freedom, Adj, MS =Adjusted mean squares, P = Probability values of the regression terms and F = Value of the restriction test on the regression model.

4. RESULTS AND DISCUSSIONS

From the regression analysis in Table 3, the Rhizomes Percentage Damage (RPD) increased with harvester speed, but decreased with digger lengths and spacing. This could be attributed to higher speeds causing the harvester to impact so hard on the rhizomes causing more bruises and damages than lower speeds during harvesting operation. The linear effects of the speed of the harvester and digger spacing were significant to the Rhizomes Percentage Damage (RPD) of the ginger harvester at 5% probability ($P \leq 0.05$). Furthermore, the quadratic effects of speeds, digger spacing, digger lengths and the interaction of the digger lengths and spacing are all significant ($P \leq 0.05$). These factors accounted for about 99.51% for the variation in the Rhizomes Percentage Damage. The analysis of variance carried out (Table 4) and [16] confirms this result.

From the response surface diagram in Figure 3, the lowest and overall best Rhizome Percentage Damage (RPD) of 30.79% was obtained when the digger length was 31cm and the harvester speed was 4km/hr. In Figure 4 the lowest RPD of 30.93% was obtained when the digger spacing was 6cm and the speed of the harvester was 4km/hr. Lastly, from Figure 5 the lowest RPD of 42.6% was obtained when the digger spacing was 4cm and digger length was 26cm.

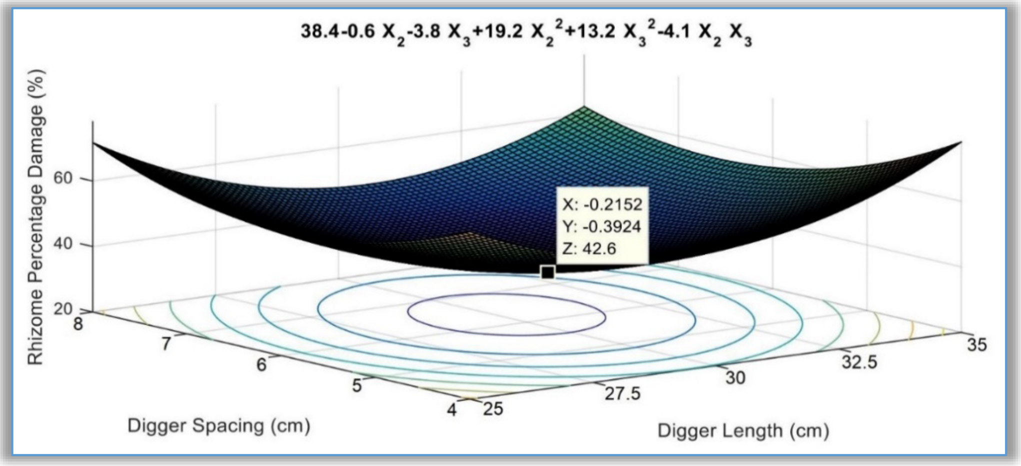

Figure 3: Response Surface Curve of the Effects of Digger Lengths and Speed on the Rhizome Percentage Damage

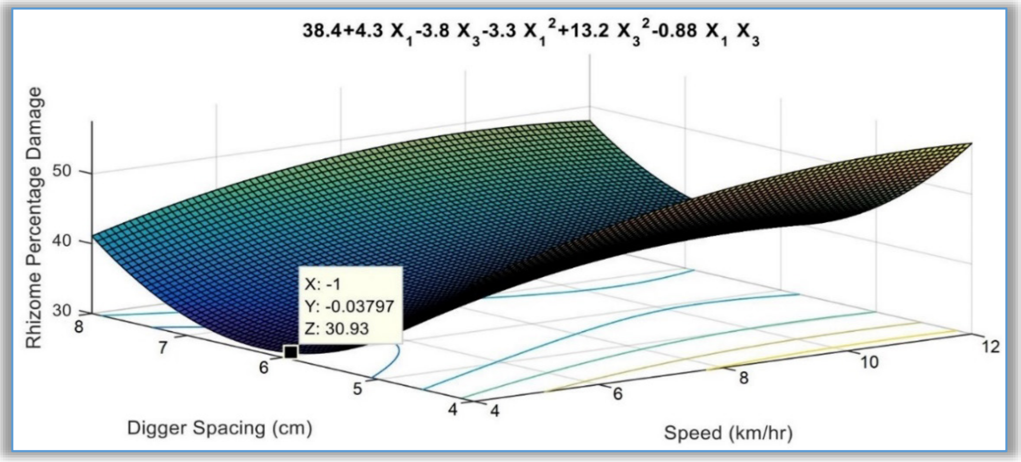

Figure 4: Response Surface Curve of the Effects of Digger Spacing and Speed on the Rhizome Percentage Damage

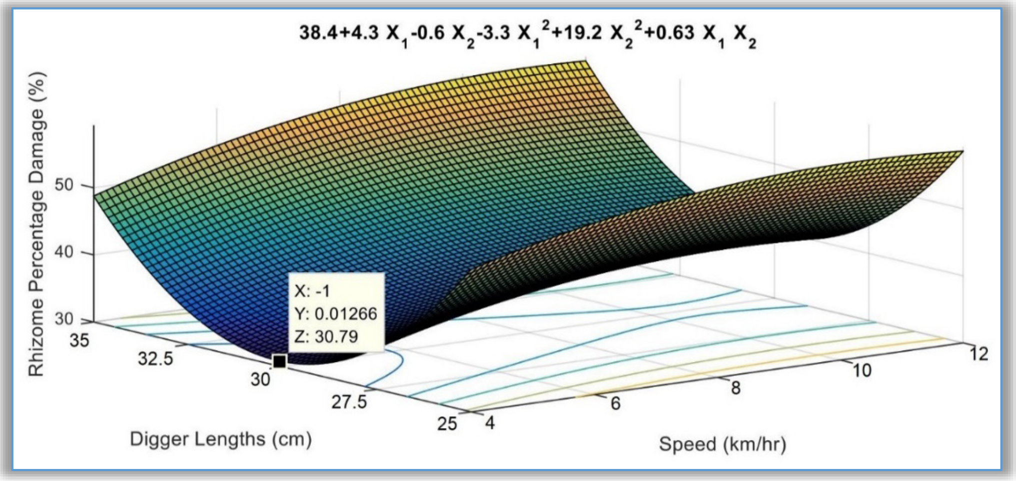

Figure 5: Response Surface Curve of the Effects of Digger Spacing and Digger Lengths on the Rhizome Percentage Damage

5. CONCLUSIONS

The following conclusions can be drawn from this work: The Rhizomes Percentage Damage (RPD) increased with harvester speed, but decreased with digger lengths and spacing. The linear effects of the speed of the harvester and digger spacing were significant to the Rhizomes Percentage Damage (RPD) of the ginger harvester at 5% probability ($P \leq 0.05$). Also significant are the quadratic effects of speeds, digger spacing, digger lengths and the interaction of the digger lengths and spacing. These factors accounted for about 99.51% for the variation in the Rhizomes Percentage Damage. The lowest and overall best Rhizome Percentage Damage (RPD) of 30.79% was obtained when the digger length was 31cm and the harvester speed was 4km/hr.

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