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Comparative Analysis of Cassava Peeling Concept of an Automated System

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Abstract: *An improved cassava peeling machine was developed with the aim of achieving 100% peeling and quality performance efficiencies. The peeling principle is based on impact as tubers spin and came in contact with the cutting tool during linear movement in the direction of auger. This is governed by combining action of auger, tuber monitor and driving force. The mechanism of this principle was mathematically modelled. Performance evaluation was carried out using an improved variety, TMS 30572 harvested in IITA to predict peeling performance of the machine in different locations. Functional parameters at different feed rate and machine speed were determined. These include; throughput capacity (T_C), peeling efficiency (P_E), mechanical damage (M_D), peel retention (P_R) and quality performance efficiency (Q_{PE}). The results showed that T_C ranged from 238.10 to 1351.35 kg/h, P_E ranged from 67.53 to 100.00%, M_D ranged from 0.51 to 1.23, P_R ranged from 32.47 to 0% and Q_{PE} ranged from 67.19 to 98.77%. The result of one way analysis of variance showed that crop parameters and machine parameters had no significant difference ($p = 0.05$) at different locations using the same machine.*

Keywords: *Cassava tuber, peeling prediction, mechanical peeling performance*

1. Introduction

Cassava (*Manihot Esculenta*, Crantz) has fibrous roots, and by the process of secondary thickening the roots develop to tubers which may be up to five or more depending on variety and prevailing soil conditions (Adetan *et al.,* 2003). A transverse division of the tuber shows that it consists of an inner core called the pith. This is surrounded by the starchy flesh that forms the major part of the tuber and main storage region. It is white or cream in colour and is surrounded by a thin cambium layer. Covering the cambium layer is the tuber peel. The peel consists of a corky periderm on the outside which is dark in colour and can be removed by brushing in water as is done in the washers of large factories. The inner part of the peel contains the cortex. The cortical region is usually white in colour and varies in thickness between 1.2 and 4.2 mm (Ademosun *et al.*, 2012). The loosening of the whole peel from the central part facilitates the peeling of the roots. The cork layer varies between 0.5 and 2% of the weight of the whole root, whereas the inner part of the peel accounts for about 8-15%.

The plant is grown for its edible tubers, which serve as a staple food in many tropical countries and are also an important source of carbohydrates. Its nutritional density and value as a famine relief crop have long been recognised and there is an ever-increasing demand for cassava. In parts of the Far East during the Second World War, many people survived on cassava roots, and in Africa, it is a principal food source for workers in mining and industrial centers (Kecham, 1981).

Before the cassava tuber is processed for consumption, the peel has to be removed. Cassava peeling constitutes a major bottleneck in the processing of cassava because of its bewildering variety of shapes and sizes. In all the unit operations involved in cassava processing, peeling constitutes a serious global challenge to food processors. Several prototype peeling machines have been made but with low peeling and quality performance efficiencies. Cassava peeling is still largely done manually. The rate could be as low as 350 kg/day of 8 hours per person (Igbeka *et al*., 1992). The process is slow, labour intensive and arduous in nature, which invariably leads to low productivity.

Olukunle and Oguntude (2008) reported that peeling performance in an automated peeling system is generally influenced by crop, machine and operational parameters. They further reported that soil factors such as soil type, soil moisture, soil fertility, tillage practice and vegetation of the farm would also influence tuber shape and size. The problems posed by tuber size and shape could be reduced by trimming and sorting of tubers.

Asoegwu (1981) studied some breaking characteristics of cassava roots when subjected to bending loads. The loading rate and root diameter were reported to have significant effect on the breaking strength, breaking energy and breaking deformation of the roots.

In order to reduce spoilage by delays in processing of cassava, it is necessary to investigate appropriate crop and machine parameters for optimum performance of mechanical peeling system. This will enhance high peeling efficiency; and quality production of peeled tubers, low mechanical damage to the tuber flesh, low cost of production, provision of industrial material, and to pave the way for food security (Jimoh and Olukunle, 2012). This research discusses theoretical, experimental and statistical analysis of cassava peeling performance of an improved machine using improved cassava tuber harvested from International Institute of Tropical Agriculture (IITA) to predict performance of the machine in other locations. This is important so as to solve the critical problem of peeling and generate an acceptable relationship between crop and machine parameters.

2. Materials and Methods

An improved cassava variety TMS 30572 used for this experiment was harvested from IITA, Ibadan, South-West geopolitical zone of Nigeria. The selection of cassava variety was in accordance with classification of cyanogenic potential (CNP) of cassava cultivars (Ekanayake *et al.*, 1998). Ekanayake *et al.* (1998) further reported that TMS 30572 has low cyanogenic potential with less than 5 mg of hydrocyanic acid/100 g of tuber flesh.

The machine used for this peeling process was developed on the principle of impact between tubers and cutting blades. As tubers spin and come in contact with the blades, peeling is achieved. The interaction between tuber and machine was modeled to generate equations that governed peeling process in different locations. In an experiment the machine was used to peel cassava. Data obtained were analysed to predict the performance in two different locations namely Ibilo in South-South geopolitical zone and Awo-mmama in South-East geopolitical zone of Nigeria. The choice of these locations is as a result of different soil characteristics as reported by Ademosun *et al.* (2012). This theory offers the opportunity to investigate the effect of soil factors at different locations on the peeling performance of the same machine using the same variety of cassava tuber.

2.1. Theoretical Analysis

Theoretical analysis of tuber movement in a mechanical peeling system was idealised, so as to form the basis for 100% peel removal as well as whole tuber flesh recovery. This was accomplished by:

1) Continuous impact between tuber and cutting tool,
2) Linear movement of tubers in the direction of auger,
3) Displacement of tubers during kinetic energy,
4) Circular motion of cylindrical barrel at which cutting blade tract tuber, and
5) Material flow as a result of continuous feeding in the hopper.

The design principle was by impact and tubers spin to reposition themselves in the chamber in all orientations. Thus, peeling was achieved in the process. Figure 1 shows the gravitational attraction between tubers during peeling.

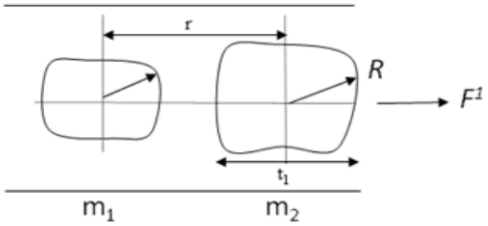


Figure 1. Gravitational attraction between tubers during peeling

Consider two tubers with mass m_1 and m_2 at the two ends of the peeling chamber during the peeling process, under gravitational attraction governed by the inverse square law for forces on bodies at distance (Thompson, 1999), if the universal gravitational constant is γ and the local acceleration due to gravity is g, then mutual attractive force can be modeled as:

$$F^1 = m_1 m_2 \gamma / r^2 \qquad \text{...... (1)}$$

If Figure 1 is re-examined, the distance r could be differentiated so that the equation for the motion becomes:

$$m_1 \frac{d^2 r}{d\ ^2} = \frac{m_1 k}{rt^2} \qquad \text{...... (2)}$$

If define $v = dr/dt$, then the governing equation becomes:

$$v \frac{d}{d} = k/r^2 \genfrac{}{}{0pt}{}{v}{r} \qquad \text{...... (3)}$$

This may be integrated, and the initial conditions applied to obtain (Khurmi, 2009):

$$v^2 = 2k\left[\frac{1}{r} - \frac{1}{r_0}\right] \qquad \text{...... (4)}$$

Where $v(0) = 0$, $r(0) = r_0$. This may also be solved algebraically for r:

$$\frac{d}{d}\frac{r}{t} = v = \pm\sqrt{2g\ ^2 R\left[\frac{1}{r} - \frac{1}{r_0}\right]} \qquad \text{...... (5)}$$

This may be further integrated to obtain:

$$t = \frac{\left[\sqrt{r r_0^2 - r^2 r_0} + \frac{\pi}{4} r_0^{\ 2} + \frac{1}{2} r_0^{\ 3/2} \sin^{-1}\left(1 - 2\frac{r}{r_0}\right)\right]}{\sqrt{2g R^3}} \quad \text{……} \ (6)$$

However, the peeling time *(t)* is inversely proportional to the diameter of the tuber, *R*. In other words, smaller tubers take longer time during peeling and in the process, smaller tubers are broken as a result of prolonged impact with the cutting tool.

2.2. Effect of Velocity of Conveyance on Machine Capacity and Peeling Efficiency

The velocity of conveyance of tubers within the peeling chamber, *v*, is expected to affect the value of machine capacity, T_C, and peeling efficiency, P_E. A close examination shows that the higher the value of *v* is, the higher will T_C be and the lower will be P_E. From Newton's law of motion, it is understood that a higher conveyance velocity implies that the movement of tubers in the peeling chamber would be faster and the peeling time, *t*, would equally be shorter. From a theoretical point of view, processing time is inversely proportional to the throughput, thus when the peeling process is faster, T_C would be higher. Similarly, there will be less time for the cutting tool to penetrate the tuber peel for effective peel removal. Therefore, P_E is expected to be low.

During contact between the tuber and the cutting tool (see Figure 2), consider the separation between peel and tuber flesh, the tuber flesh is surrounded by a thin cambium layer and covering the layer is the tuber peel.

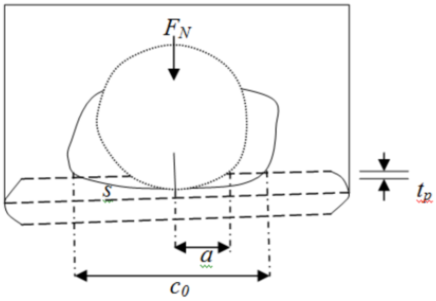


Figure 2. Tuber in contact with cutting tool during peeling process

The separation at the cambium layer between the tuber peel and tuber flesh was analysed using Hertz's theory as given by:

$$t_s = \frac{1}{\pi R}\left[c_1^{\ 2}\left(2 - n^2\right)\sin^{-1}\left(\frac{1}{n}\right) + c_1^{\ 2}\sqrt{1 - n^2}\right] \quad \text{……} \ (7)$$

t_s is the vertical displacement or shear stress at the cambium layer and c_1 is the true length of peel separated within contact area. Knowing that $c_0 > c_1$ and *n* is the ratio between c_1 and apparent length, c_0. From practical experience, the average value of R = 30 mm, c_1 = 25 mm and n = 0.5. Putting these values into equation 7:

t_s = 6.142 N/mm^2

Referring to equation 6, it was deduced that for a given mass of tuber, theoretical peeling time is affected by tuber density (Olukunle and Oguntude, 2008). Thus, the equation it may therefore write as:

$$t = \frac{\left[\sqrt{r r_0^2 - r^2 r_0} + \frac{\pi}{4} r_0^{\ 2} + \frac{1}{2} r_0^{\ 3/2} \sin^{-1}\left(1 - 2\frac{r}{r_0}\right)\right]}{\sqrt{2g R^3}} \ X \ \frac{t_w^{\ 1/3}}{v^2} \quad \text{…..} \ (8)$$

Where *v* is the velocity of conveyance of tubers, *r* is length of peeling chamber and t_w is the weight of tubers.

Theoretically, T_C is defined as:

$$T_C = \frac{t_w}{t} \quad \text{……} \ (9)$$

2.3. Performance Evaluation of the Machine

In the course of the peeling process, it was observed that an accurate length and diameter classification cannot be achieved. Therefore, the weight of tubers was chosen as the constant variable for tuber classification. The machine was evaluated on the basis of weight classification using variable gear motor at speed, S_P: 100, 110, 120, 130 and 140 rpm. The tuber flesh was collected at the tuber outlet while the tuber peel was collected at the peel outlet. The machine's functional parameters such as peeling efficiency, $P_{E,}$*(%);*, mechanical damage, $M_{D,}$*(%);* peel retention, $P_{R,}$*(%);* and quality performance efficiency, Q_{PE}*(%)* were determined using the following expressions (Jimoh *et al.*, 2012).

$$P_E = \frac{w_{pr}}{w_{pr} + w_{prh}} \quad \text{……} \ (10)$$

$$M_D = \frac{w_{tr}}{w_{tr} + w_{tpt}} \quad \text{……} \ (11)$$

$$P_R = \frac{w_{pr}}{w_{pr} + w_{ph}} \quad \text{……} \ (12)$$

$$Q_{PE} = \left\{\left(1 - M_D\right)\left(1 - P_R\right)\right\} \quad \text{……} \ (13)$$

Where W_{pr} is weight of peel removed by machine, W_{prh} is weight of peel removed by hand after machine peeling, W_{trp} is weight of tuber flesh removed along with peel, W_{tc} is weight of tuber flesh completely peeled and t_{aw} is average weight of the tuber.

2.4. Statistical Analysis

One way ANOVA addresses the contribution of each factor variable (independent and dependent) to the statistical fit and whether or not the response can be predicted as well if the variable is removed. The independent variables include: S_P, t_{aw}, w_{bp}, w_{pr}, w_{prh}, w_{trp}, w_{tc} and t while T_C, P_E, M_D, P_R and Q_{PE} were treated as depended variables. The test compared the variation around the model within replicated observations.

The data obtained were analysed using the stepwise method to generate multiple linear equations. In the validation of the model, standard error, SE and coefficient of determination, R^2 were determined. Considering the best equation from each dependent variable in the tubers harvested from IITA, peeling performance of the machine was predicted. Using observed and predicted values, the correlation coefficient (R) and mean bias error (MBE) were generated. The degree to which predicted variables are related to the observed and how scattered are the data points around the fitted straight line were determined.

The regression equations derived are listed below:

$$P_E = 77.373 - 12.508 w_{prh} + 0.626 w_{pr} + 0.060 rpm + 1.564 t_{aw} + 0.053 t \quad \ldots\ldots (14)$$

$$M_D = 22.487 + 3.120 w_{trp} - 3.157 t_{aw} - 0.120 t - 0.031 rpm + 0.552 w_{pr} \quad \ldots\ldots (15)$$

$$P_R = 22.627 + 12.508 w_{prh} - 0.626 w_{pr} - 0.060 rpm - 1.564 t_{aw} - 0.053 t. \quad \ldots\ldots (16)$$

$$Q_{PE} = 76.37 - 81.2004 w_{prh} + 5.303 t_{dw} + 0.03 t. \quad \ldots\ldots (17)$$

$$T_C = 980.504 + 49.482 w_{tc} - 9.394 t - 77.253 t_{aw} + 79.476 w_{prh} \quad \ldots\ldots (18)$$

3. Results and Discussion

The length of peeling chamber r = 2.5 m and from experimental data, t_l varied from 0.125 to 0.492 m: tuber diameter, t_d varied from 0.019 to 0.140 m; and v varied from 1 to 5 ms^{-1}. At a given value of v, t_l increased as t also increased. When peeling tubers within the range of smaller tuber diameter *(t_d)*, t increased from 69 to 89 s as t_l increased from 0.125 to 0.492 m as reflected in Figure 3. When peeling tubers within the range of larger t_d, t increased from 9.4 to 12.1 s as t_l increased from 0.125 to 0492 m as reflected in Figure 4. Thus, smaller tubers stayed longer in the peeling chamber and this prolonged interaction and resulted in higher mechanical damage to the tubers. This justifies the theoretical expression in equation 8 that cassava peeling time is inversely proportional to root square diameter.

The analysis of tuber movement and the investigation of tuber and machine parameters during mechanical peeling produced the desired effects on peeling performance. The observed result in Table 1 shows that as the speed of the machine increased from 100 to 140 rpm; peeling efficiency increased from 67.53 to 100%; mechanical damage increased from 0.51 to 1.23%; peel retention decreased from 32.47 to 0%; and quality performance efficiency increased from 67.19 to 98.77%. During mass production, at a feed rate (F_R) of 10 kg, throughput capacity increased from 238.10 to 454.55 kgh^{-1}; at 20 kg, it increased from 377.36 to 740.74 kgh^{-1}; at 30 kg, it increased from 491.80 to 967.74 kgh^{-1}; at 40 kg, it also increased from 597.02 to 1176.47 kgh^{-1} and at 50 kg, machine capacity increased from 694.44 to 1351.35 kgh^{-1} , as displayed in Table 2.

Results of the stepwise multiple linear regression analysis revealed that as R^2 increased, SE decreased in all cases and this implies that the better the goodness of fit parameters. Plotting of the predicted versus observed functional parameters (such as peeling efficiency, mechanical damage, peel retention, and quality performance efficiency) are shown in Figures 5 - 8 using the same variety in one location to predict peeling performance in other locations. The plots show smooth and good scatter of the data points around the fitted straight line. This indicates that the model describe the functional parameters at different locations which confirms the goodness of the model to estimate the performance of the machine anywhere. The result of one way analysis of variance shows that crop parameters and machine parameters have no significant difference at 5% level at different locations using the same peeling tool (see Table 3). Figures 3 and 4 show the peeling time t (sec) against velocity of conveyance v (ms^{-1}) at various values of t_l (m).

Table 1. Observed **e**xperimental result during peeling of TMS 30572 cassava tuber

Speed (rpm)	Peeling efficiency (%)	Mechanical damage (%)	Peel retention (%)	Quality performance efficiency (%)
100	67.53	0.51	32.47	67.19
110	67.53	0.51	31.24	67.19
120	68.40	0.65	0.21	68.15
130	99.22	0.23	0	98.26
140	100	1.23	0	98.77

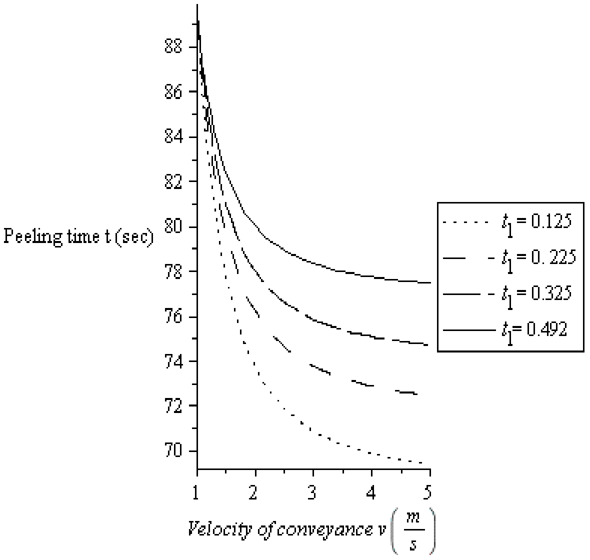
Table 2. Machine capacity at various feed rate during mechanical peeling of TMS 30572

Feed Rate (kg)	Throughput Capacity T_C (kgh^{-1})				
	100 rpm	110 rpm	120 rpm	130 rpm	140 rpm
10	238.10	285.71	333.33	400.00	454.55
20	377.36	454.55	540.54	625.00	740.74
30	491.80	600.00	697.67	833.33	967.74
40	597.02	727.27	851.06	1000.00	1176.47
50	694.44	833.33	1000.00	1162.79	1351.35

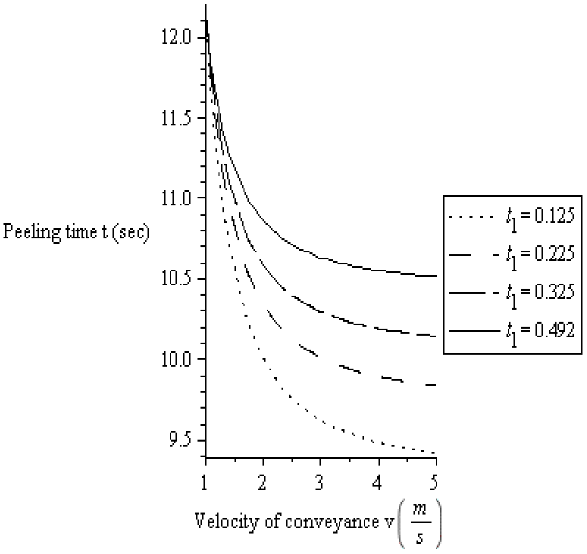
Table 3. Machine parameters at different locations

		Sum of Squares	Df	Mean Square	F	Sig.
T	Between Groups	3.511	2	1.756	.088	.916
	Within Groups	833.467	42	19.844		
	Total	836.978	44			
P_E	Between Groups	12.694	2	6.347	.027	.973
	Within Groups	9741.713	42	231.946		
	Total	9754.407	44			
M_D	Between Groups	.124	2	.062	.039	.962
	Within Groups	67.410	42	1.605		
	Total	67.534	44			
P_R	Between Groups	12.694	2	6.347	.027	.973
	Within Groups	9741.713	42	231.946		
	Total	9754.407	44			
Q_{PE}	Between Groups	15.376	2	7.688	.038	.962
	Within Groups	8407.359	42	200.175		
	Total	8422.735	44			

Where, T is throughput capacity, P_E is peeling efficiency, M_D is mechanical damage, P_R is peel retention and Q_{PE} is quality performance efficiency.



(ms^{-1}) at various values of t_l (m) with t_d= 0.019 m, r = 2.5 m, g = 9.81 ms^{-2}



(ms^{-1}) at various values of t_l (m) with t_d = 0.140 m, r = 2.5 m, g = 9.81 ms^{-2}

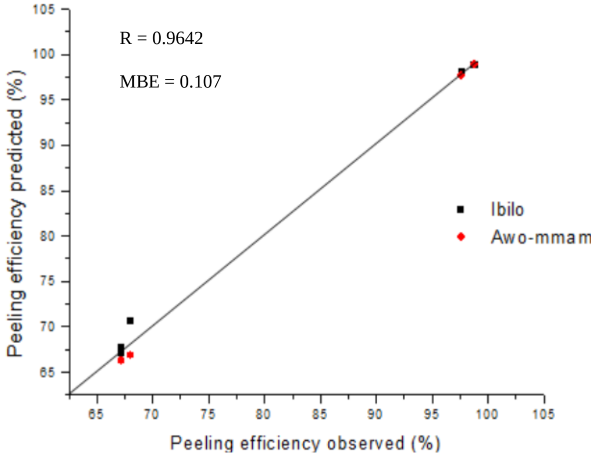


Figure 5. Prediction of peeling efficiency in different locations

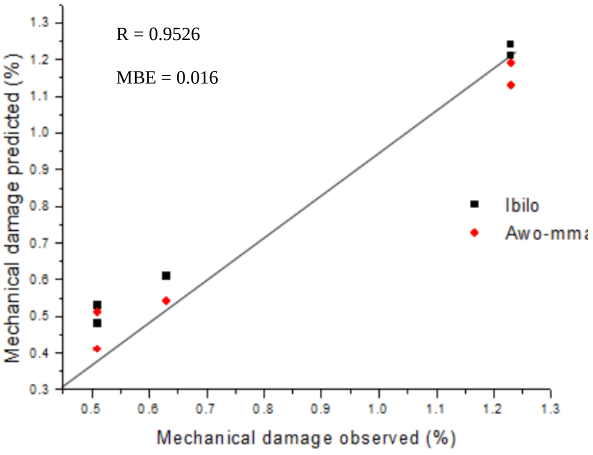


Figure 6. Prediction of mechanical damage in different locations

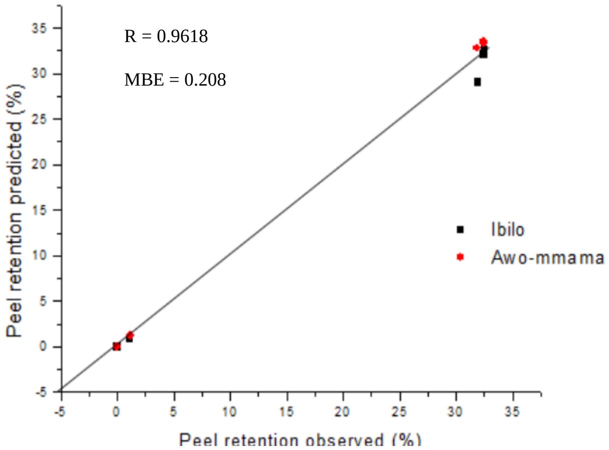


Figure 7. Prediction of peel retention in different locations

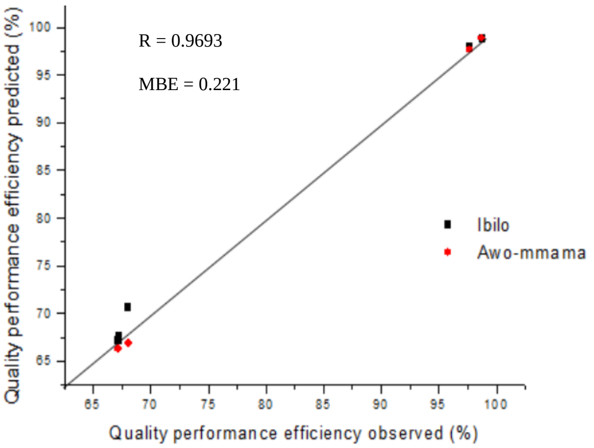


Figure 8. Prediction of quality performance efficiency in different locations

4. Conclusions

Three conclusions could be drawn from the study. These are:

1) The peeling performance of the machine improved at a speed of 130 rpm; this reveals optimum interaction between tuber and machine.
2) Theoretically, mechanical damage was expected to be high in tubers harvested in Awo-mmama because the peel is lighter. However, from the practical results, there was no significant difference with other locations.
3) The model developed is about 96.20% accurate in predicting the peeling performance of the machine in any location using the same variety. It is therefore, a sound scientific basis for developing a machine having a mechanical damage as low as 0% and quality performance efficiency as high as 100%.

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