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A computer-based sensitivity analyses of the performance of an indigenous combine harvester

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ABSTRACT: Harvesting operation using the combine is a precision activity requiring optimum settings based on crop, machine and operational data. The sensitivity of these parameters requires proper investigation due to their impact on the harvesting process and farmer's income. This paper reports development of an interactive computer programme for estimating losses in an indigenous cowpea combine harvester based on regression models developed from previous studies. The programme reads the values of the various input parameters such as crop variety, grain moisture content(GMC), combine forward speed(CFS), stripper speed(RS) and feed rate (FR) and apply the various equations to compute output which include % shatter losses , % unstripped losses, total losses, threshing efficiency, grain damage and cleaning efficiency. The package was tested with values of input parameters on Ife Brown and IT 716 cowpea varieties within the range of values adjudged optimum from field experiments and literatures. Results of typical interface with the programme show that shatter losses were higher in Ife brown than IT 716 cowpea varieties for all the test conditions. At a stripper speed of 100 rpm, grain moisture content of 17.0% wet basis (wb) and forward speed of 3 km/h, shatter losses was 6.64% in Ife Brown, but 4.91% in IT 716. At a feed rate of 600 g/s, concave clearance of 13 mm and grain moisture content of 17.0% wet basis, grain damage increased from 6.43% to 16.50% and from 9.50% to 18.38% in IT 716 and Ife Brown respectively as the cylinder peripheral speed increased from 100 rpm to 500 rpm. The programme is user friendly and offers opportunities to the farmers and combine operators to predict combine performance apriori.

Keywords: Computer programme, losses, combine harvester

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INTRODUCTION

The Combine harvester encounters grain losses in connection with four basic operations, gathering, threshing, separating and cleaning. These losses are usually between 1 and 2 per cent and are lower than losses during manual harvesting which is averagely between 12 and 15 per cent (Nakra, 1990). However, some grains are lost before the harvesting operation, which are known as pre-harvest losses. Machine performance and its operation determine the magnitude of machine losses while weather; stage of maturity and other hazards affect the quantity of pre-harvest losses. The operator cannot control pre-harvest losses because the grain is already lost. However, the farmer can reduce pre-harvest losses by employing better management practices. Corn and soybeans are common crops, which may have large pre-harvest losses (Olukunle, 2002a). Brian (1988) developed an equation relating the percentage of shedding and cutter bar losses (Ys) to the number of days past crop ripeness for combine harvesting (X_2).

$Ys = 2.2 \exp(0.05 X_2)$ (1) (Brian, 1988)

This equation predicts negligible grain loss, which is in agreement with the consistently low level of loss found experimentally. McGechan (1989) reported the estimation of combine harvesting workdays from meteorological data. He opined that estimation of combine workdays

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was a major criterion in determining the size of the combine. He also reviewed the work of various researchers and considered the criterion of Philip and O'Callagan (1974) in Olukunle (2005) as a proper work-hour criterion since it operates on an hourly basis, provided that grain moisture content is below 24% wet basis; no rainfall has fallen in the hour; less than 1.25 mm of rain fell in the preceding hour and less than 2.25 mm of rain fell in the hour prior to the preceding hour.

Header losses occur mainly at the reel and cutter bar. Header losses in direct combining include heads, pods, or ears and free seeds lost during cutting and conveying operations. In windrow combining, total gathering losses for the harvest system include windrower losses as well gathering losses in the pick up and conveying operations. According to Price (1993) combine performance largely depends on the header. Losses with the header are slightly higher than any other part of the machine and are usually between 0.5 and 2.0 per cent (Nakra, 1990). Threshing losses are in the range of 0.5 % to 1 % (Nakra, 1990). These losses include unshelled grains thrown out from the back of the machine and broken kernels. Olukunle (2002a) reported that while harvesting cowpea, angle bar gave the best clearance for rasp bar cylinder as 0.5 to 1.20 cm as measured to the tip of the bar sections; rubber-faced bar did the best work at a clearance of 1.15 to 1.55 cm, whereas a 0.42 cm lateral clearance was best for spike-toothed cylinder. The cylinder peripheral speed of 1.524 to 1.828 m/min was the best for all the three cylinders. Kutzback and Schneider (1997) reported that it was also possible to obtain increased efficiency by additional cylinders and concaves. The basic performance parameters of a threshing unit are threshing efficiency and percentage of seed damage. Lazaro and Simalenga, (1994) reported that threshing efficiency is influenced by the peripheral speed of the cylinder, the number of times the material passes through the concave, concave clearance, number of rows of concave teeth, the type of crop, the variety of crop, the condition of the crop, moisture content of crop, stage of maturity and feeding rate.

The grains, which have not been separated from the straw and find their way out over the straw walker along with the straw, are known as separation losses, straw walker or rack losses. They may be caused by too much straw entering the combine at low cylinder speeds and improper straw walker drive speeds. According to Brian (1988) separation loss rises with throughput of the combine harvester. However they are also influenced by inefficient threshing mechanisms. The convex curve of separation loss (*Yt*) against throughput is related to the ratio of actual throughput, Ca and the rated throughput, Cr such that:

$$Yt = 2\,(Ca/Cr)^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

The major performance parameter of the separating unit is the percentage of seed and pods separated from the straw or pod. (Kepner et al, 1978). Non-grain feed rate and grain/non-grain ratio also influence separation losses. A lot of work has been done in the area of grain harvesting mechanisation especially in Europe and America. Some developing countries such as India and Thailand are also making steady progress in grain harvesting mechanisation. Thepent (2009) reported that the rice combine harvester had been introduced to Thai farmers for a long time. However it is very expensive and unsuitable for field conditions hence the rice combine harvester was not accepted by Thai farmers (Anon, 2006: CIA 2008). The future role of rice combine harvester in Thailand was considered to be based on economic, social and agricultural production systems (Chimchana et al 2008). For the economic aspect, the labour shortage in harvesting, the need in quality improvement of rice and cost reduction led to the utilization of the rice combine harvester (Tahir *et al, 2003,* ASABE 1997: IRRI 2007). In Africa, especially in Nigeria, research into the development of grain harvesters is in progress (Olukunle, 2002; Ademosun and Olukunle 2003; Ademosun *et. al.,* 2003). This paper reports development of a computer programme for estimating losses in an indigenous cowpea combine harvester based on regression models developed from previous studies. This will provide adequate guide for grain farmers as well as combine operators in order to reduce losses during harvesting operations. The programme is user friendly and offers opportunities to the farmers and combine operators to predict combine performance apriori.

MATERIALS AND METHODS

An indigenous combine harvester was designed fabricated and tested as reported by Olukunle (2002a). The machine (Figs. 1a and b) was tested and its performance evaluated using standard combine test procedures. Two varieties of cowpea (Ife Brown and IT 716) were planted at a spacing of 30 cm by 60 cm for two different cropping seasons. The crop varieties were pre-treated with gramozone to effect desiccation at 80% maturity. The effect of day after fumigation (DAF) on seed and chaff moisture content was investigated. Grain losses and machine efficiency were determined at the various stages of the operation of the machine, namely, cutting, threshing and cleaning operation. The effects of varying the forward speed of the machine, peripheral speed of the stripping rotor, the threshing cylinder, fan speed, speed of the reciprocating sieves, crop variety, crop maturity and crop moisture content on the performance of the machine were determined. The data obtained were subjected to statistical analysis using Microsoft Excel, graphs and multiple regression models were obtained between the various parameters such as combine forward speed, rotational speed, and feed rate. Correlation matrices were also produced to ascertain the influence of each independent variable in the multiple regression models on the dependent variable. Based on the multiple regression models a computer model was developed.

Fig. 1a: The Combine Harvester

Model Development

The model (Fig. 2) identifies the crop, machine and operational parameters, reads the values of the various input parameters and using the regression models, calculates output. A computer programme was written in visual basic following the procedure outlined in the flow chart. Thus, a model which relates the effect of the various parameters with the efficiency and losses associated with the combine harvester was developed. The computer programme permits farmers /combine operators to interact with the model and obtain results under various crop, machine and operational conditions. The

Fig. 1b: Internal Structure of the Combine Harvester

package is user friendly and enables the farmer /combine operator to predict crop responses to various combine settings during harvesting operations.

The computer reads the values of the various input parameters and by interaction with the various equations computes output. The input variables include: Crop Variety, Percentage Maturity, Combine Forward Speed (CFS), Peripheral Speed(PS), Day After Fumigation (DAF), Concave Clearance(CC), Feed Rate(FR), Walker Speed (WS) and Fan Speed(FS). The maximum and minimum values of these variables were established based on the findings of many researchers in the area of grain combine harvesting. The output variables were identified as Grain Yield, Stripped Yield, Total Losses(Tols), Unstripped Losses(USL), Shatter Losses(Shls), Seed Moisture Content (SMC), Chaff Moisture Content (CMC), Threshing Efficiency(Th Ef), Functional Efficiency Fn Ef),, Grain Damage(GD), Separation Losses(Spls) and Walker Losses(Wkls). The various equations developed by Olukunle, 2002 were arranged sequentially, from the effect of spray curing to the various unit operations of the combine harvester as follows :

(A) 1. Select crop variety (Ife Brown (1), IT 716 (2); select percentage maturity and determine grain yield from

$$\text{Grain Yield}_1 = 15.12 \times \%\,\text{Maturity} \qquad 3$$

$$\text{Grain Yield}_2 = 11.50 \times \%\,\text{Maturity} \qquad 4$$

2. Pre-harvest Treatment as

$$CMC = -\,0.97\,DAF + 29.465 \qquad 5$$

$$SMC = -\,0.73\,DAF + 25.07 \qquad 6$$

(B) Calculate unstripped losses as

$$USL_1 = 0.921\,CFS - 0.654\,SMC - 1.983\,PS + 23.648 \qquad 7$$

$$USL_2 = 0.976\,CFS - 0.601\,SMC - 1.708\,PS + 19.964 \qquad 8$$

(C) Calculate shatter losses as

$$Shls_1 = 0.868\,PS - 00.606\,CFS - 0.649\,SMC + 15.726 \qquad 9$$

$$Shls_2 = 0.518\,PS - 00.640\,CFS - 0.343\,SMC + 9.805 \qquad 10$$

(D) Calculate total header losses as

$$Tols_1 = USL_1 + Shls_1 \qquad 11$$

$$Tols_2 = USL_2 + Shls_2 \qquad 12$$

(E) Calculate functional efficiency as

$$\text{Stripped Yield} = \text{Grain Yield}\,(1 - (USL / 100)) \qquad 13$$

$$Fn\,Ef. = (\,\text{Stripped Yield} / \text{Grain Yield}\,)\,100 \qquad 14$$

(F) Calculate threshing efficiency as

$$Th\,Ef_1 = 0.282\,FR + 0.225\,PS - 1.71\,CC - 0.357\,SMC + 75.36 \quad 15$$

$$Th\,Ef_2 = 0.272\,FR + 0.186\,PS - 1.51\,CC - 0.152\,SMC + 76.80 \quad 16$$

(G) Calculate grain damage as

$$GD_1 = 0.892\,PS - 0.75\,CC - 0.098\,FR - 1.191\,SMC + 42.44 \quad 17$$

$$GD_2 = 0.785\,PS - 0.63\,CC - 0.096\,FR - 1.496\,SMC + 44.10 \quad 16$$

(H) Calculate walker losses as

$$Wkls_1 = 0.019\,FR + 0.076\,SMC - 0.0505\,WS - 1.10 \quad 18$$

$$Wkls_2 = 0.021\,FR + 0.090\,SMC - 0.0481\,WS - 1.74 \quad 19$$

(I) Calculate separation losses as

$$Spls_1 = 0.175\,FS - 0.032\,FR + 0.13\,SMC - 0.16 \quad 20$$

$$Spls_2 = 0.141\,FS - 0.027\,FR + 0.10\,SMC - 0.12 \quad 21$$

RESULTS AND DISCUSSION

Performance of the Header

The grain yield of cowpea lfe Brown and IT 716 for the test site at 80% maturity was 1,210 kg/h and 920 kg/h respectively. This value is within acceptable average of standard crop data especially for a crop of cowpea in the humid zone of Nigeria between May and August. Pre-harvest loss was calculated as 26,3kg representing 2.16% and 20.4kg representing 2.22% of the yield per hectare of Ife Brown and IT 716 respectively. This could be as a result of activities of birds and rodents and wind characteristics of the site. The performance characteristics of the machine was presented as F3 to F6 and T3 to T6 representing the performance of the machine between combine forward speeds of 3 to 6 km/h for Ife Brown (F) and IT 716 (T) cowpea varieties respectively.

Effect of Maturity on Grain Moisture Contents and Pre-Harvest Losses

Fig. 3 illustrates the effect of maturity on moisture content and pre-harvest losses. Results show that moisture content decreased with increase in percentage maturity. This is due to the growth characteristics of the crop and the relatively low humidity at the harvesting season. Pre-harvest losses also increase with increase in maturity. The grain moisture content decreased from 45% to 13% wet basis (wb) as the maturity increased from 10% to 90%. Pre-harvest losses also increase from 0 to 40% for the same range of maturity. The figure shows that the moisture content of Ife brown is consistently higher than the values in IT 716 variety. This is due to differences in the physical properties of the two varieties. Pre-harvest losses were slightly different in the two varieties between 0 and 70% maturity but 0.9% to 15.0% and 0.7% to 13.0% in Ife Brown and IT 716 respectively between 70% to 95 % maturity. At 50% maturity, grain moisture content is 23% in IT 716 but 31.5% in Ife Brown, pre-harvest losses were however the same in the two varieties at 50% maturity. Between 10% and 60% maturity (range A) grain moisture content decreased from 45%wb to 25%wb in Ife Brown and from 40%wb to 21% wb in IT 716, at this range combine harvesting would be difficult as threshing and other processes of the combine would do more harm to the crop. It would also be difficult and costly to reduce the moisture content from 45% to 13%, which is the safe moisture level for storage. It is however important to note that when cowpea is combined at the upper end of range A, about 40% of the crop harvested would still not be matured. Pre-harvest losses within this range were however low. Between 60% and 80% maturity (range B) the moisture content of the crop was between 23% and 17% wb. The pre-harvest losses were between 0.07% and 0.66% and between 0.02% and 0.57 % in IT 716 and Ife Brown respectively. Harvesting, threshing and other processes of the combine are feasible between 60% and 80% maturity. The moisture content within this range was similar to values of moisture content adjudged optimum for combine harvesting by Baryeh (1987) and Tado et al (1998).

Grain moisture content was between 17% and 10% wb as maturity increased from 80% to 90%. Although the moisture content within this range could permit harvesting and threshing, excessive shattering and natural shedding was observed within this range. The high values of pre-harvest losses within this range would make combine harvesting of cowpea unprofitable.. This was because cowpea matures over a period of time, while some pods were ripe and ready for harvest, flowering and fruiting were still in progress on the same crop. Attempt to wait for higher percentage maturity led to increase in pre-harvest losses. However, at 80% maturity pre-harvest losses was below 1.0%.

Effect of Stripper Speed on Shatter Losses at various Grain Moisture Contents and Forward Speeds

Table 1 and 2 show the effect of stripper speed (RS) on shatter losses in Ife Brown (HSLF) and IT 716 (HSLT) at various grain moisture content (GMC) and forward speed (CFS). Results show that shatter losses were higher in Ife brown than IT 716 for the all test conditions. At RS of 100 rpm, shatter losses was 6.64% in Ife Brown, but 4.91% in IT 716 at the grain moisture content of 17.0% wet basis (wb) and forward speed of 3 km/h. Thus the disturbance caused by the entrance of the stripper on the crop was higher in Ife Brown than IT 716. This was due to the differences in crop physical properties and presentation on the field. At GMC of 17.0% wet basis shatter losses increased from 6.64% to 21.37% and from 4.91% to 13.69% in Ife Brown and IT 716 respectively as the rotational speed increased from 100 rpm to 600 rpm. This was because more disturbances were caused to the crop as the stripper entered the field at higher rotational speed. It was notable however, that the combination of RS and CFS provided similar minimum values of losses under different conditions. At constant RS and GMC, shatter losses decreased with increase in forward speed in the two varieties. At a rotational speed of 600 rpm and moisture content of 17.0% (wb) shatter losses decreased from 21.37% to 20.53% in Ife Brown and from 13.69% to 20.53% in IT 716 as the forward speed increased from 3 km/h to 8 km/h. Increase in forward speed aided the flow of the stripped material into the combine for further processing. Grain moisture content also influenced shatter losses. Natural shedding and shattering caused by rodents and birds were observed on the field as the moisture content decreased. Philip and O'Calaghan (1974) in Olukunle (2002b) in their criterion for determining combine work-days reported that combines should not harvest grains above 24% moisture content. Thus, increase in moisture content should not exceed 24%, such that other processes of the combine would not be adversely affected. It was observed that rotational speed of the stripper (RS) had a positive correlation of 0.782 with HSLT and 0.772 with HSLF. Combine forward speed (CFS) had a negative correlation.

Effect of Cylinder Speed on Grain Damage at varying Cylinder-Concave Clearances, Feed Rates and Grain Moisture Contents

Tables 3 and 4 Illustrate the effects of cylinder speed on grain damage at varying cylinder concave clearance, feed rate and grain moisture content. Results show a very strong influence of cylinder speed on grain damage at constant grain moisture content, feed rate and cylinder concave clearance. Cylinder speed has a direct linear relationship with grain damage. Although it is desirable to increase cylinder speed for higher functional efficiency, grain damage increased with increase in cylinder speed for all test conditions and in the two varieties. In IT 716 and at 100 rpm , grain damage was 6.43%, but it increased to 16.50% at 500 rpm at the same feed rate of 600 g/s, concave clearance of 13 mm and grain moisture content of 17.0% wet basis. In Ife Brown and at 100 rpm, grain damage was 9.50%, but increases to 18.38% at 500 rpm at the same feed rate of 600 g/s, concave clearance of 13 mm and grain moisture content of 17.0% wet basis.

Grain moisture content also has an inverse proportional effect on grain damage. As the moisture content increased from 17.0% to 21.0% wet basis, grain damage reduced. This agrees with the report of Ali et al (1997) and ptasznick et al (1995). Crop variety also had a notable effect on grain damage, results show that grain damage is consistently higher in Ife Brown than IT 716. Increase in feed rate favoured reduction in grain damage in the two varieties and at all test conditions. This is due to the cushioning effect of higher feed rates on the threshing process. Values of grain damage at a feed rate of 100 g/s is consistently higher than values at 300 g/s . At a cylinder-concave clearance of 12mm, cylinder speed of 500 rpm, grain moisture content of 17.0, grain damage was 23.24% at a feed rate of 500 g/s in Ife Brown. At the same conditions as above, grain damage was 21. 48% at feed rate of 500 g/s but 26,45% at a feed rate 400 g/s in IT 716.

Cylinder-concave clearance also influenced grain damage considerably. As the cylinder-concave clearance increased, grain damage increased in the two varieties for all test conditions. A compromise must be reached between high functional efficiency and reduced grain damage. It is important to thresh the crop as much as possible, otherwise, threshing loses would be higher that values obtainable as grain damage. This is undesirable. Results show that functional efficiency is higher between the concave clearance of 6 mm and 8 mm than between 10 mm and 12 mm. Thus, it would not be advisable to thresh between the latter range. Although functional efficiency is higher at the cylinder-concave clearance of 6 mm, grain damage is also too high for all test conditions. Thus, concave clearance of 8 mm would offer a better compromise between grain damage and functional efficiency. A cylinder speed of 400 rpm would also do better as a compromise between grain damage and functional efficiency. Grain damage was lower at 400 rpm but functional efficiency was consistently and acceptably closer to values obtained at 500 rpm. It was observed that cylinder speed (CS) had a positive correlation of 0.46, grain moisture content (GMC) had a negative correlation of –0.43, feed rate (FR) had a negative correlation of –0.5, and concave clearance (CC) had a negative correlation of –0.23 with GDT. Cylinder speed (CS) also had a positive correlation of 0.552, grain moisture content had a negative correlation of –0.243, feed rate had a negative correlation of –0.515 and concave clearance had a negative correlation of –0.391 with GDF.

Table 1: Sample Results Extracts on Header Shatter Losses for IT 716 at Constant GMC and at varying CFS and RS

RS(rpm)	100	200	300	400	500	600
CFS (3km/h) and GMC (17%)	4.91	6.37	7.84	9.30	10.77	13.69
CFS (4km/h) and GMC (17%)	4.73	6.20	7.66	9.12	10.59	13.51
CFS (5km/h) and GMC (17%)	4.55	6.02	7.48	8.94	10.41	13.34
CFS (6km/h) and GMC (17%)	4.37	5.84	7.30	8.76	10.23	13.16
CFS (7km/h) and GMC (17%)	4.20	5.66	7.13	8.59	10.06	12.98
CFS (8km/h) and GMC (17%)	4.02	5.49	6.95	8.41	9.88	12.80
RS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CFS (3km/h) and GMC (19%)	4.22	5.69	7.15	8.62	10.08	13.01
CFS (4km/h) and GMC (19%)	4.04	5.51	6.97	8.44	9.90	12.83
CFS (5km/h) and GMC (19%)	3.86	5.33	6.79	8.26	9.72	12.65
CFS (6km/h) and GMC (19%)	3.69	5.15	6.61	8.08	9.54	12.47
CFS (7km/h) and GMC (19%)	3.51	4.98	6.44	7.90	9.37	12.30
CFS (8km/h) and GMC (19%)	3.33	4.80	6.26	7.73	9.19	12.12
RS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CFS (3km/h) and GMC (21%)	3.54	5.00	6.46	7.93	9.40	12.32
CFS (4km/h) and GMC (21%)	3.36	4.82	6.28	7.75	9.22	12.14
CFS (5km/h) and GMC (21%)	3.18	4.64	6.11	7.57	9.04	11.96
CFS (6km/h) and GMC (21%)	3.00	4.47	5.93	7.39	8.86	11.78
CFS (7km/h) and GMC (21%)	2.83	4.29	5.75	7.22	8.68	11.61
CFS (8km/h) and GMC (21%)	2.65	4.11	5.57	7.04	8.51	11.43

Table 2: Sample Results Extracts on Header Shatter Losses for Ife Brown at Constant GMC and at varying CFS and RS

RS(rpm)	100	200	300	400	500	600
CFS (3km/h) and GMC (17%)	6.64	9.10	11.55	14.01	16.46	21.37
CFS (4km/h) and GMC (17%)	6.47	8.93	11.38	13.84	16.30	21.20
CFS (5km/h) and GMC (17%)	6.30	8.76	11.21	13.67	16.13	21.04
CFS (6km/h) and GMC (17%)	6.13	8.59	11.04	13.50	15.96	20.87
CFS (7km/h) and GMC (17%)	5.96	8.42	10.87	13.33	15.79	20.70
CFS (8km/h) and GMC (17%)	5.79	8.25	10.70	13.16	15.62	20.53
Varying RS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CFS (3km/h) and GMC (19%)	5.34	7.80	10.25	12.71	15.16	20.07
CFS (4km/h) and GMC (19%)	5.17	7.63	10.08	12.54	15.00	19.90
CFS (5km/h) and GMC (19%)	5.00	7.46	9.91	12.37	14.83	19.74
CFS (6km/h) and GMC (19%)	4.83	7.29	9.74	12.20	14.66	19.57
CFS (7km/h) and GMC (19%)	4.66	7.12	9.57	12.03	14.49	19.40
CFS (8km/h) and GMC (19%)	4.49	6.95	9.40	11.86	14.32	19.23
RS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CFS (3km/h) and GMC (21%)	4.04	6.50	8.95	11.41	13.86	18.77
CFS (4km/h) and GMC (21%)	3.87	6.33	8.78	11.24	13.70	18.60
CFS (5km/h) and GMC (21%)	3.70	6.16	8.61	11.07	13.53	18.44
CFS (6km/h) and GMC (21%)	3.53	5.99	8.44	10.90	13.36	18.27
CFS (7km/h) and GMC (21%)	3.36	5.82	8.27	10.73	13.19	18.10
CFS (8km/h) and GMC (21%)	3.19	5.65	8.10	10.56	13.02	17.93

Table 3: Sample Results Extracts on Grain Damage for IT 716 at constant GMC and at varying CS, CC (mm) and FR

Varying CS(rpm)	100	200	300	400	500	600
CC (8), FR (100g/s) and GMC (17%)	31.31	33.83	36.34	38.86	41.38	46.42
CC (9), FR (200g/s) and GMC (17%)	26.33	28.85	31.36	33.89	36.41	41.44
CC (10), FR (300g/s) and GMC (17%)	21.35	23.88	26.39	28.91	31.43	36.46
CC (11), FR (400g/s) and GMC (17%)	16.38	18.90	21.41	23.93	26.45	31.49
CC (12), FR (500g/s) and GMC (17%)	11.40	13.92	16.44	18.96	21.48	26.51
CC (13), FR (600g/s) and GMC (17%)	6.43	8.95	11.46	13.98	16.50	21.54
Varying CS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CC (8), FR (100g/s) and GMC (19%)	30.92	33.44	35.96	38.48	41.00	46.03
CC (9), FR (200g/s) and GMC (19%)	25.95	28.47	30.98	33.50	36.02	41.06
CC (10), FR (300g/s) and GMC (19%)	20.97	23.49	26.01	28.53	31.05	36.08
CC (11), FR (400g/s) and GMC (19%)	16.00	18.52	21.03	23.55	26.07	31.11
CC (12), FR (500g/s) and GMC (19%)	11.02	13.54	16.05	18.58	21.10	26.13
CC (13), FR (600g/s) and GMC (19%)	6.04	8.57	11.08	13.60	16.12	21.16
CS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CC (8), FR (100g/s) and GMC (21%)	30.54	33.06	35.58	38.10	40.62	45.65
CC (9), FR (200g/s) and GMC (21%)	25.57	28.09	30.60	33.12	35.64	40.68
CC (10), FR (300g/s) and GMC (21%)	20.59	23.11	25.62	28.15	30.67	35.70
CC (11), FR (400g/s) and GMC (21%)	15.61	18.14	20.65	23.17	25.69	30.72
CC (12), FR (500g/s) and GMC (21%)	10.64	13.16	15.67	18.19	20.71	25.75
CC (13), FR (600g/s) and GMC (21%)	5.66	8.18	10.70	13.22	15.74	20.77

Table 4: Sample Results Extracts on Grain Damage for Ife Brown at constant GMC and at varying CS, CC(mm) and FR

Varying CS(rpm)	100	200	300	400	500	600
CC (8), FR (100g/s) and GMC (17%)	33.81	36.04	38.25	40.47	42.69	47.13
CC (9), FR (200g/s) and GMC (17%)	28.95	31.17	33.39	35.61	37.83	42.26
CC (10), FR (300g/s) and GMC (17%)	24.09	26.31	28.52	30.75	32.97	37.40
CC (11), FR (400g/s) and GMC (17%)	19.23	21.45	23.66	25.88	28.10	32.54
CC (12), FR (500g/s) and GMC (17%)	14.36	16.58	18.80	21.02	23.24	27.68
CC (13), FR (600g/s) and GMC (17%)	9.50	11.72	13.94	16.16	18.38	22.81
Varying CS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CC (8), FR (100g/s) and GMC (19%)	33.53	35.75	37.97	40.19	42.41	46.84
CC (9), FR (200g/s) and GMC (19%)	28.67	30.89	33.10	35.32	37.55	41.98
CC (10), FR (300g/s) and GMC (19%)	23.81	26.03	28.24	30.46	32.68	37.12
CC (11), FR (400g/s) and GMC (19%)	18.94	21.16	23.38	25.60	27.82	32.26
CC (12), FR (500g/s) and GMC (19%)	14.08	16.30	18.51	20.74	22.96	27.39
CC (13), FR (600g/s) and GMC (19%)	9.22	11.44	13.65	15.87	18.10	22.53
Varying CS(rpm)	**100**	**200**	**300**	**400**	**500**	**600**
CC (8), FR (100g/s) and GMC (21%)	33.25	35.47	37.68	39.90	42.13	46.56
CC (9), FR (200g/s) and GMC (21%)	28.38	30.61	32.82	35.04	37.26	41.70
CC (10), FR (300g/s) and GMC (21%)	23.52	25.74	27.96	30.18	32.40	36.84
CC (11), FR (400g/s) and GMC (21%)	18.66	20.88	23.09	25.32	27.54	31.97
CC (12), FR (500g/s) and GMC (21%)	13.80	16.02	18.23	20.45	22.67	27.11
CC (13), FR (600g/s) and GMC (21%)	8.93	11.16	13.37	15.59	17.81	22.25

CONCLUSION

A computer programme for estimating losses in an indigenous combine harvester based on regression models developed from previous studies has been developed. The programme is user friendly and offers opportunities to the farmers and combine operators to predict combine performance ahead of field operations. Results of typical interaction with the programme show that shatter losses were higher in Ife brown than IT 716 cowpea varieties for the all test conditions. At a stripper speed of 100 rpm, shatter losses was 6.64% in Ife Brown, but 4.91% in IT 716 at the grain moisture content of 17.0% wet basis (wb) and forward speed of 3 km/h. In IT 716 and at a cylinder peripheral speed of 100 rpm , grain damage was 6.43%, but it increased to 16.50% at 500 rpm at the same feed rate of 600 g/s, concave clearance of 13 mm and grain moisture content of 17.0% wet basis. In Ife Brown and at a cylinder peripheral speed of 100 rpm, grain damage was 9.50%, but increases to 18.38% at 500 rpm at the same feed rate of 600 g/s, concave clearance of 13 mm and grain moisture content of 17.0% wet basis. The programme is recommended for cowpea combine operators and farmers.

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