DETERMINATION OF CROP AND MACHINE PARAMETERS RELEVANT TO THE HARVESTING AND POSTHARVEST HANDLING OF *ACHA*

Tanam, U. I.[1] and Olaoye, J. O.[2]
[1]*Department of Environmental Management, Bingham University, Karu, Nigeria*
[2]*Department of Agricultural and Biosystems Engineering University of Ilorin, Ilorin, Nigeria*

Corresponding author's email: isaactanam@gmail.com

ABSTRACT
Acha (Digitaria species) is a cereal crop produced predominantly in Nigeria. Harvesting acha is still being done by traditional methods. Existing regular combines cannot be applied to acha harvesting due to its unique grain characteristics. Appropriate harvesters suited to the characteristics of acha seed are not available. The aim of this study was to determine some crop and machine Parameters (CMPs) relevant to acha harvesting. Machine parameters were determined from the known empirical equations for effective material capacity while standard laboratory investigations were conducted to determine crop parameter (Angle of Repose, Particle Density, Particle Size, Coefficient of Uniformity and Fineness Modulus). Results obtained showed that operating speed (V) (1, 3, 5 km/h), knife speed (S) (300, 400, 500 rpm) and reel index (I) (1.0, 1.25, 1.5) were critical parameters in the design of an acha harvester. Angle of repose, particle density, particle size, coefficient of uniformity and fineness modulus of acha were found to be 32.5°, 0.584 g/cm^3, 0.60 mm, 1.62 and 1.22 respectively. Not considering these parameters in the design of acha harvesting and handling machines results in heavy grain losses. It is therefore recommended that information from this work be adopted in the design of acha handling machines.

KEYWORDS: Crop parameters, Machine parameters, Acha harvesting, Harvester, Grain losses

1. INTRODUCTION

Harvesting is the process of separating mature crop from the stalk and evacuation of cut material from the cutting region. The effectiveness of this operation depends on the appropriateness of the tool used, the settings of the parameters of such tool and the characteristics of the crop. Harvesting can be done manually or mechanically. Manual harvesting is associated with drudgery and loss of timeliness. Large scale harvesting requires the application of mechanical power. Mechanical harvesting is the application of animal or engine powered machines in the harvesting process. Some mechanical harvesters enumerated by Tennes *et al*. (1997) include combines, pulsating air, water jet, rollers, high speed shaker and vibrating tines among others.

As a result of widely varying crop characteristics, no single harvester can be applied to harvesting every crop, and for any harvester selected for any specific crop, the parameters must be properly selected and adjusted for that specific crop (Tanam, 2021). Failure to make this adjustment often result to high harvesting losses (Olaoye, 2004). Machine parameters have been determined and are being used in harvesting cereals such as rice, maize, wheat and sorghum. Nothing is known yet about these parameters as regards *acha*. Wide cultural practices of crops such as weeding operation, planting and crop protection affect the performance of the crop at harvest time (Olaoye and Ariyo, 2020). Olaoye (2012) reviewed challenges of weeding operation in intercropping and mixed cropping systems in Nigeria and enumerated effects of weeding on crop performance.

Acha (Digitaria species) is a cereal produced predominantly in Nigeria with Plateau state, being world largest producer (Tanam, 2021). *Acha* has a variety of uses. It is consumed as a staple food, or forms a major part of it in the producing areas, and is described by Vietnameyer *et al*. (1996), Cruz (2009) and Philip and Itodo (2006a) as the tastiest and most nutritious of all grains. *Acha* can be made into solid food and eaten with soup. It is enjoyed as "*gwete*" by the *Beroms* of Plateau State, and taken as pudding with milk and sugar by some other ethnic groups. Temple and Bassa (2006) and Cruz (2009) have reported different other forms *acha* is consumed in other parts of Nigeria. Jideani *et al*. (2007) reported that medical practitioners in Nigeria have identified and recommended *acha* as a major food suitable for diabetic patients.

Acha is used in the brewing industry to produce malt with very high protein concentration (Hector *et-al*, 1996) and contains a major degrading enzyme similar to barley (Nzelibe and Nwasike, 1995). Nzelibe and Nwasike (1995) added that a blend of *acha* malt and sorghum malt will produce a malt of the same profile as barley malt. *Acha* has been used as a major ingredient in confectionaries with high protein levels (Ayo and Nkama 2004; Jideani *et al*., 2008; Nnam and Nwokocha (2003). A mixture of *acha* and boabab flour has been used to produce milk containing more protein than human and cow milk (Obizoba and Anyika, 1994). Musa *et al.* (2008) reported that the crop is used as binding agent in drug manufacture.

Acha is a popular and important cereal in many communities of West Africa but its production is considered low when compared with other cereals produced in the area. Some factors responsible for this include unimproved seeds husbandry practices, resulting in poor organic performance (Kwon-Ndung, 2006), very tiny grains (Philip and Itodo, 2006a) with 1000 grains weighing approximately 0.44g (Vodouhe *et al.*, 2004), *s*hattering characteristics (Vodouhe *et al.*, 2004), inappropriate harvesting technique (Philip and Itodo, 2006b) resulting in harvest and time losses (Bakare, 2005) and traditional threshing and dehuling methods resulting in poor quality of final product (Vodouhe *et al.*, 2004).

Although *acha* is very popular and is in high demand for its diverse uses, harvesting is still done by manual traditional methods because appropriate machines for harvesting the crop do not exist (Philip and Itodo, 2006a). The result is a poor quality of harvested material as the material has to be spread on bare ground to dry before threshing. This process introduces stones into the crop. Regular combines cannot be used to harvest *acha* because most *acha* fields are small in size and harvester parameters have not been adapted to the unique grain characteristics of the crop (Tanam, 2021). The purpose of this study was to determine the crop and machine parameters (CMPs) relevant to *acha* harvesting in order to develop data necessary for the design of an appropriate machine for *acha* harvesting.

2. MATERIALS AND METHODS

2.1 Determination of critical machine parameters

Effective material capacity of a harvester is a function of the speed of operation of the harvester, effective width of the machine, and the machine efficiency. ASABE (2015), Hunt and Wilson (2016) and Dogra (undated) expressed effective material capacity as Equation 1.

$$C_{mat} = \frac{VWQE}{10} \quad (1)$$

where:

C_{mat} = effective material capacity (kg/h)

V = machine operating speed (km/h)
W = effective width of machine (m)
Q = mass of grain harvested (kg)
E = machine efficiency (decimal)

The expression in Equation 1 was used to determine the machine parameters by looking at the implication of the components. Parameters determined were tested on an *acha* harvester developed by Tanam (2021). Figure 1 is the harvester's material flow block diagram.

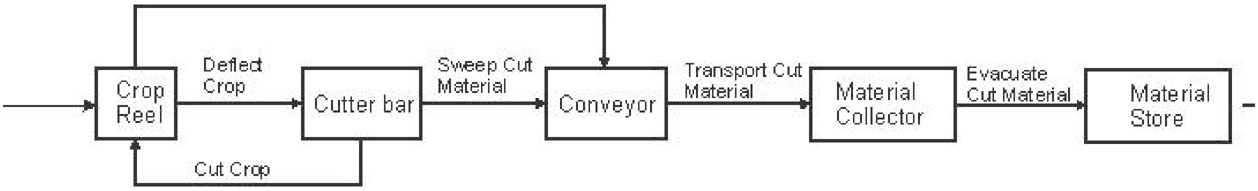

Figure 1: Material Flow Block Diagram

The diagram in Figure shows that while the reel receives and deflects the erect crop toward knife, the knife cuts and reel delivers the cut material to the conveyor. Three parameters (Operating speed (V), Knife Cutting speed (S), Reel index (I)) were therefore considered pertinent to the operation of the harvester. These parameters were combined in a 3^3 Factorial design to produce 27 treatments and replicated once. Table 1 shows the combinations of the parameters. Subscripts 0, 1, and 2 represent low, intermediate, and high levels of each parameter.

Table 1: Factor Level Combinations for a 3^3 Factorial Experiment

Treatments Layout		
$V_0S_0I_0$	$V_0S_0I_1$	$V_0S_0I_2$
$V_0S_1I_0$	$V_0S_1I_1$	$V_0S_1I_2$
$V_0S_2I_0$	$V_0S_2I_1$	$V_0S_2I_2$
$V_1S_0I_0$	$V_1S_0I_1$	$V_1S_0I_2$
$V_1S_1I_0$	$V_1S_1I_1$	$V_1S_1I_2$
$V_1S_2I_0$	$V_1S_2I_1$	$V_1S_2I_2$
$V_2S_0I_0$	$V_2S_0I_1$	$V_2S_0I_2$
$V_2S_1I_0$	$V_2S_1I_1$	$V_2S_1I_2$
$V_2S_2I_0$	$V_2S_2I_1$	$V_2S_2I_2$

The low, intermediate and high levels for operating speed were 1, 3, and 5 km/h respectively, while those for knife speed were 300, 400, and 500 rpm and for reel index, 1, 1.25, and 1.5 respectively.

2.2 Determination *Acha* Crop Characteristics

The Fixed Funnel and the Tilting Box methods, both described by Teferra (2019), were used to determine the angle of repose of *acha* grains. In the fixed funnel method, the material was continuously poured through a funnel to form a cone as shown in Figure 2.

Figure 2: Acha Heap used to Determine Angle of Repose

In order to minimize scattering of the falling grains, the funnel was held close to the growing cone and gradually raised until the base of the cone reached a predetermined diameter of 100 mm. The height of the cone was then measured and the angle of repose (α) determined from Equation 2

$$\propto \ = tan^{-1} \ \frac{h}{r} \qquad 2$$

where:

α = angle of repose (°)

h = height of cone (mm)

r = radius of cone base (mm)

Mehta and Barker (1994) described the Tilting Box method as being appropriate for fine-grained, non-cohesive materials if the particle size is less than 10 mm. The method involved placing the material on a flat horizontal surface and one end of the surface gradually raised until the material just began to slide in bulk. Angle of repose was measured directly at the point this occurred. Each of the above method was performed thrice on two varieties of *acha* (Digitaria Iburua and Digitaria Exilis).

Particle density of acha was determined using two samples collected from two different farmers. The samples were placed in cans, gently compacted and refilled. The dimensions of the cans were measured. Particle density was determined by Equation 3

$$\rho_p = \frac{M}{V} = \frac{4M}{\pi D^2 L} \qquad 3$$

where ρ_p = Particle density (g/cm^3)

M = Mass of compacted material in can (g)

V = Volume of can (cm^3)

D = Diameter of can (cm)

L = Length of can (cm)

During harvest, samples of harvested material were collected from two random locations on the *acha* field. The samples were weighed and oven dried at a temperature of 105 ºC for 24 hours. Equation 4 was used to determine the moisture content of the materials.

$$M_C = \frac{M_W}{M_H} = \frac{M_H - M_D}{M_H} \quad 4$$

where

M_C = Moisture content of material (%) (dry basis)

M_W = Mass of moisture removed (g)

M_H = Mass of harvested material (g)

M_D = Mass of dry material (g)

Sieve method was used to determine the particle size of *acha*. Percentage of *acha* material passing through the sieve was determined from equation 5.

$$P_a = \frac{M_P}{M_a} \times 100 \quad 5$$

where

P_a = Percentage of *acha* material passing through the sieve (%)

M_p = Mass of *acha* passing through the sieve (g)

M_a = Initial mass of *acha* placed on the top sieve (g)

Fineness Modulus, (FM) was determined by Equation 6.

$$FM = \frac{\sum (\text{Cumulative percent finer})}{1000} \quad 6$$

Coefficient of Uniformity, (C_u) was determined using equation 7.

$$C_c = \frac{D_{60}}{D_{10}} \quad 7$$

where

D_{60} = Maximum size of the smallest 60% of the sample

D_{10} = Effective size = Maximum size of the smallest 10% of the sample

3. RESULTS AND DISCUSSION

3.1 Machine Parameters Relevant to *Acha* Harvesting

Table 2 shows the quantity of *acha* grain harvested based on the 3^3 Factorial treatment combinations. Each value represents the average of two runs each combination.

Table 2: Quantity of *Acha* Grain Harvested (kg/ha)

Quantity of grain collected (kg/ha)					
Treatment	Quantity	Treatment	Quantity	Treatment	Quantity
$V_0S_0I_0$	256.2	$V_0S_0I_1$	271	$V_0S_0I_2$	256.0
$V_0S_1I_0$	286.6	$V_0S_1I_1$	272	$V_0S_1I_2$	270.9
$V_0S_2I_0$	274.2	$V_0S_2I_1$	284	$V_0S_2I_2$	266.4
$V_1S_0I_0$	267.4	$V_1S_0I_1$	293	$V_1S_0I_2$	270.4
$V_1S_1I_0$	281.3	$V_1S_1I_1$	302	$V_1S_1I_2$	256.9
$V_1S_2I_0$	282.7	$V_1S_2I_1$	269	$V_1S_2I_2$	202.8
$V_2S_0I_0$	257.2	$V_2S_0I_1$	227	$V_2S_0I_2$	184.6
$V_2S_1I_0$	226.3	$V_2S_1I_1$	253	$V_2S_1I_2$	210.6
$V_2S_2I_0$	227.5	$V_2S_2I_1$	229	$V_2S_2I_2$	200.4

Data presented in Table 2 for quantity grain harvested had mean of 254.8 kg/ha and standard deviation of 30.14. This shows that the variability of the quantity of grain collected with different treatment combination is high. Achieving high field capacity requires operating at high speeds. Although high speed operation will result in high field capacity, it does not necessarily produce high material capacity. Operating at high speeds without a corresponding high speed cutting would produce high field losses due to riding over and leaving behind several uncut crop on the field. Therefore cutting speed of the tool is of critical importance for effective material capacity. Evacuation of cut material from the cutting region requires that the reel be run at an appropriate speed else clogging of cut material may occur. It follows therefore that though other parameters (knife bevel angle, knife clearance, reel height, knife angle, plant morphology and others) may affect material capacity, machine operating speed, knife cutting speed and reel index are the most critical in achieving a good material capacity. Maximum harvest of 302 kg/ha was observed with operating speed, knife speed and reel index of 3 km/h, 400 rpm and 1.25 respectively. Although this value is lower than global average for *acha* reported by Cruz (2009), higher values may be obtained with further adjustments of the machine parameters. Also since an appropriate harvester for *acha* is non-existent (Philip and Itodo, 2006a), it is obvious that the harvest reported by Cruz (2009) were done manually, and the condition under which it was done was not stated. Other factors that could affect the performance of a mechanical harvester include, but not limited to environmental conditions, field pattern and crop yield.

3.2 *Acha* Properties Relevant to *Acha* Harvesting

Results of particle size analysis of *acha* are presented in Table 3.

Table 3: *Acha* Particle Size Distribution

Parameter	Value
Fineness Modulus	1.22
Particle Size (mm)	0.6
Coefficient of Uniformity	1.62

Table 3 shows that the particle size of *acha* is very small, even lower than the 1.5mm by 0.9 mm reported by Philip and Itodo (2006b). The reason for difference is not known. With a fineness modulus of 1.22, *acha* can be regarded and treated as fine material. The obtained coefficient of uniformity of 1.62 indicates the grain are fairly uniform in size. The implication of the tiny size is that a material that must be used for the design of packaging, storage and transporting of the grains from one processing point to another must be such that would prevent the grains from passing through, else heavy grain losses would occur. The tiny size of *acha* grains is probably responsible for the difficulty in mechanisation of the production of the crop. Hulling and winnowing are major challenges faced by *acha* farmers. This property of the crop must also be taken into consideration in the design of planting, harvesting and post harvest handling machines of the crop.

For bulk material with uniform particle size ranges, as is the case with *acha,* angle of repose is a valid estimate of its angle of internal friction (Teferra, 2019) and describes how easily the material would flow by gravity. Table 4 shows the average angle of repose of two varieties of *acha.*

Table 4: Angle of Repose

***Acha* Variety**	**Average (^{0})**	**Standard Deviation**
Digitaria Iburua	32.07	0.38
Digitaria Exilis	32.90	0.38

Both varieties of the crop were observed to have approximately the same angle of repose, with little variation as observed from the standard deviation, which are equal for both varieties. This implies that both varieties can be treat in similar manner, to the extent that a machine developed to handle one can be applied to the other. The observed angle of repose is low compared to most other grains. The implication is that a transport systems such as conveyors used to transport these crops cannot be used for *acha* as *acha* grains would flow freely down. The same is true in the design of hoppers, silos and storage tanks (Al-Hashemi and Al-Amoudi, 2018). This free flow of *acha* grains is enhanced by its low particle density (Table 5), which indicates its degree of looseness. The observed standard deviation for particle density indicates that the means obtained for particle density are a fair representation of the entire data. Unless flights are provided on a conveyor, for instance, the inclination of the conveyor to transport the crop should not be greater than 32^o.

Table 5: Particle Density of *Acha*

Acha Variety	**Average**	**Standard**

	(g/cm^3)	**Deviation**
Digitaria Iburua	0.589	0.003
Digitaria Exilis	0.561	0.001

The moisture content reported in Table 6 is the moisture content at harvest of *acha*.

Table 6: Moisture Content Determination

Sample	Moisture content (% wet basis)
A	24.8062
B	38.5892
Average (wet basis)	31.70%

This appears high when compared with other crops. Harvesting *acha* at lower moisture results in heavy harvest losses (Bakare, 2005) due to its shattering characteristics. This probably explains why *acha* farmer harvest at high moisture content. Unlike combine harvesting of other cereal crops, *acha* is not threshed simultaneously with harvesting. The crop is often spread on bare ground to further dry. This exercise introduces impurities (stones) into the crop thereby reducing its quality and hence, market value. Overcoming this problem may require the use of a combine harvester that must harvest at a safe moisture, which yet to be determined.

4. CONCLUSION

Acha harvesting and processing have continued to be a challenge to *acha* farmers because of its labour intensity. From tests conducted, it was obvious that the variation of operating speed, knife speed and reel index of a mechanical harvester resulted in different quantity of material harvested and could be better if optimised. These parameters must therefore be considered in the design of an appropriate *acha* harvester, or be used for the adjustment of regular combines when *acha* field become larger. The observed crop parameters were generally low, especially the particle size, explaining the difficulty in mechanising its production. These must be given due consideration in the design of an appropriate *acha* harvesting and processing machines to minimise losses. The uniformity of the grains shows that a machine developed for one variety of *acha* may be applied to other varieties

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