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Design and Construction of Improved Yam Storage Structure Using Locally-Available Materials

Shadrack Kwadwo Amponsah[1], Joseph Oppong Akowuah[2], Evelyn Adu-Kwarteng[1], Enoch Bessah[2]

[1]*Crops Research Institute, Council for Scientific and Industrial Research, Kumasi, Ghana*

[2]*Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

ABSTRACT

Yam (Dioscorea *spp.*) is the second most important tropical root crop in West Africa after cassava. Postharvest loss, which has largely been associated with lack of appropriate storage systems, is the most common problem faced by smallholder yam farmers. The high level of yam postharvest losses has become a serious economic and food security threat. Existing yam storage structures have all that is required of improved storage structures but the cost is a great disincentive to farmers, which has greatly affected their adoption over the years. The overall objective of this study was to design and construct an improved storage structure using locally-available materials and expertise to facilitate future adoption by smallholder yam farmers. With dimensions of 3.66 m length, 1.83 m width and a height of 1.83 m, a storage capacity of 5000 tubers for *Pona* yam variety was considered for the structure design. AutoCAD software was used for the engineering design of the structure. Local materials used for the construction included; Borassus *aethiopum* wood used for the structural frame, sawmill waste boards (off-cuts) used for both outside and floor cladding, Ceiba boards used for the shelves and thatch material for roofing. After the design, the improved storage structure was constructed at the Crops Research Institute out-station located at Ejura in the Ashanti Region of Ghana at an estimated cost of US$ 370 as at January, 2014. The improved storage structure has the following features; good ventilation due to the presence of upper openings and side windows, ability to keep a more cooler environment within, water proof using well installed fresh thatch material, protection against rodents with the help of rat guards and raised platform, protection against theft because structure has a gate under lock and key, access for sprout control with the presence of shelves, low cost due to the use of locally available materials and local expertise. By way of recommendation, a field performance evaluation of the structure should be done to assess its storability for different yam varieties. Again, further studies should be undertaken to assess the effect of structure shape on the storability of yam.

Keywords: Design, construction, storage, improved, affordable.

INTRODUCTION

Yams (Dioscorea spp.) are cultivated throughout the tropics and in parts of the subtropics. It occupies a prominent position in West African Agriculture but is also important in South East Asia, Japan, and the Caribbean. The crop is also the second most important tropical root crop in West Africa after cassava and is one of the most important dietary sources of energy produced within the tropics (Okigbo and Ogbonnaya, 2006; Coursey, 1967) as cited in Akangbe et al., 2012. Apart from being a source of food, income, and food supplement for livestock, its production from land clearing to harvest by numerous cultivators have attached high cultural importance (Onwueme and Charles, 1994; Umogbai, 2013). Yam contributes significantly to food security in Ghana and its availability on the market for a considerable part of the year helps prevent food shortages, particularly in the urban communities because it stores relatively longer than other root crops. As a matter of fact, stored yam represents stored wealth which can be sold all year round by farmer to make income (Opara and Nwokocha, 2015).

Address for correspondence:

skamponsah@hotmail.com

Nweke (2005) reported that Nigeria produced about 66.6% (26.6 million Mt) of total world's yam production, with Ghana producing 9.8% (3.9 million Mt) annually. Whereas most yams produced in Ghana are exported, Nigeria produces yams majorly for local consumption and little for the export market. According to Anaadumba (2013), Ghana is the leading exporter of yam, accounting for over 94% of total yam exports in West Africa. In Ghana, yam is produced mostly in the Guinea-Savanna and Forest-Savanna transition zones. However, reasonable production occurs in almost all regions. According to Tetteh and Saakwa (1994), white yam (D. rotundata) is much preferred to the other yam varieties and it constitutes about 80% of total yam produced in Ghana.

Successful storage of yams requires the use of healthy and sound tubers, proper curing if possible combined with fungicide treatment, adequate ventilation to remove heat generated by respiration of sprouts and rotted tubers that develop. Monitoring the presence of rodents and protection from direct sunlight and rain is also necessary. Yams can be best stored in a cool, dry and well ventilated surrounding (Umogbai, 2013). Yam storage structures come in different shapes and sizes depending on the ability of the farmer, locality and cultural practices. The construction materials are usually wood, ropes, palm fronds, guinea corn stalks, and mud (FAO, 2004; Umogbai and Satimehin, 2004).

The most common problems faced by farmers are post-harvest losses. Wastage occurs because the apparent surplus during the harvest season cannot be consumed within a short period. However, few months after the harvest, there is always a diminishing availability of yam produce. Therefore, it becomes imperative that the existing yam tubers are stored in structures for later use (Williams and Raharratham, 1980) as cited in Umogbai (2013). Lack of improved affordable yam storage facilities have left most yam farmers at the mercy of marketers and middlemen, who would usually purchase their produce at relatively cheaper prices. Farmers would usually run at a loss at the end of the farming season, making this situation a great disincentive to yam farmers in Ghana and the sub-Saharan Africa at large. If this problem is not tackled appropriately, soon most farmers would quit yam cultivation and shift their focus to other food crops. This without doubt, would greatly affect the country's food security as far as yam production is concerned.

According to Opara (1999), there are several traditional low-cost storage methods and structures for yam tubers; the most common of them include leaving the tubers in the ground until it is needed, storing under tree shades, yam barns, underground structures such as pits, ditches and mud structures. Umogbai (2013) and Okoedo-Okojie and Onemolease (2009) also reported that there are well ventilated weather-proof, insect and rodent proof strong shelters for storage of yam tubers; unfortunately, the cost of these structures discourages farmers, who are the major producers of yams, from adopting such improved storage structures. There is therefore the need to promote less expensive, improved storage structures using local materials for smallholder yam farmers. This approach will not only increase the incomes of yam producers but also ensure an all-year-round availability of yams, which is critical in achieving sustainable food security in the country.

The objective of the study therefore was to design and construct an improved affordable yam storage structure using local materials to minimize post-harvest losses for improved yam productivity. Specifically, the study sought to:

- Design an improved and affordable structure for yam storage
- Construct the yam storage structure using locally-available materials
- Assess the durability of the local materials used for the construction
- Determine the cost of constructing the improved structure

MATERIALS AND METHODS

Design Calculations

The following design calculations were employed to determine live load, wind load, uniformly distributed load (UDL) and stress as shown in Equations 1, 2, 3 and 4 respectively.

$$\text{Load} = \text{mass} \times \text{gravity} \tag{1}$$

$$Q = 0.013V^2\left(\frac{h}{6.1}\right)^{\frac{2}{7}} \tag{2}$$

Where Q - Wind pressure (Pa)

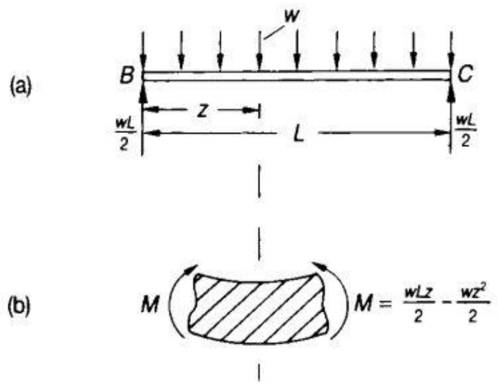
V - Velocity of wind (ms^{-1})

h - Design height (m)

$$\text{Uniformly Distributed Load (UDL)} = \frac{\text{total load (N)}}{\text{length of beam (m)}} \tag{3}$$

$$\text{Stress} = \frac{\text{total load (N)}}{\text{Area } (m^2)} \tag{4}$$

Bending moment of Borassus wood under load was determined as follows:



Where W – Total load exerted

L – Length

Z – Load point

M – Bending moment

Material Selection Criteria

To design an appropriate, less expensive yam storage structure for smallholder farmers in a developing country like Ghana, the following considerations were made in selecting the right material for construction; availability, affordability, workability, cultural acceptability, strength and suitability. The mechanical properties and availability of Borassus palm, Bamboo, sawmill off-cut, woven straw mat (zanna mat) and spear grass thatch in most of the yam growing communities made them appropriate choices for the design.

Durability Test

Durability test was done using the Avery Universal Testing Machine. Three samples of Borassus wood were selected at different moisture content. The moisture content was determined using a moisture detector for wood and building materials (TP-98D). Each wood sample was subjected to a load scale of 10 tons in the Avery Universal Testing machine to record the load at which it will fail.

Construction Materials

Borassus aethiopum wood was selected for the structure frame (including the pillars) because of its high strength and natural resistance to decay and insect attack. Borassus is a local material that is mostly found in the forest-transition and savannah agro-ecological zones of Ghana. Within these communities, Borassus palm is used for other construction purposes but not for yam storage structures. Figure 1a shows the transverse cutting of Borassus palm after felling and Figure 1b shows the Borassus wood longitudinally cut into various sizes for barn construction.

Fig1. *Felling and cutting the Borassus palm for yam barn construction*

Wood slabs from saw mill off-cuts (Figure 2) were used for cladding (structure walls) because they are readily available and relatively cheaper. They are also durable and light weight; thus adds minimal dead load on the structure. In communities where timber sawmills are located, it is common to get this material.

Fig2. *Pile of wood from sawmill off-cuts*

Bamboo can also be used for this same purpose at locations where bamboo is dominant (Figure 3). The availability and very low cost of bamboo sticks makes it suitable for the structure. Bamboo is common in the Forest and parts of the transition and savannah agro-ecological zones of Ghana.

Fig3. *Bamboo used as cladding and floor material for a yam storage barn*

Ceiba pentandra wood was selected for the construction of shelves in the structure because of its durability against weather conditions and availability in most yam growing communities (Figure 4).

Fig4. *Yam storage structure shelves constructed with Ceiba wood*

Woven straw mat locally referred to as Zanna mat is usually made from elephant grass straw. This material is predominantly used in the Northern parts of Ghana and is used as a major covering (cladding) material for some local structures. Figure 5 shows an improved traditional yam storage structure that uses the Zanna mat as the main cladding material.

Fig5. *An improved traditional yam storage structure with Zanna mat as covering material*

Thatch made from partially dried spear grass was used for the roofing because it was less expensive, long-lasting and readily available in all the communities. The individual grass strands are usually bundled together and tied with nylon or fibre ropes Figure 6).

Fig6. *Bundles of spear grass thatch for roofing*

Design of structure

The structure was designed with the aid of AutoCAD 2010 software, taking into consideration all design calculations and estimations. It was also assumed that Pona yam variety would be stored in the improved yam barn.

Construction Process

After the design, the improved storage structure was constructed at the Crops Research Institute out-station located at Ejura in the Ashanti Region of Ghana. Before construction, a suitable site was selected for the construction of the storage structure. A shady area was preferred and precautions were taken to prevent trees from interfering with the prevailing air flow and also to prevent the branches from falling on the structure during storms. The land had a good drainage and the door of the structure was oriented in a direction to provide good ventilation at all times. It was also oriented that way to prevent direct sunlight from entering the structure. The wood used for structure was chemically treated and made to dry out before using them for the construction. Two parts of creosote to one part each of dursban (Chlorpyrifos) and turpentine were mixed together for the wood treatment. Local expertise was used for the entire construction process in other to facilitate adoption of the system.

RESULTS AND DISCUSSIONS

Capacity of Structure

Approximately 5000 yam tubers was used for estimating the structure capacity based on the assumption that smallholder farmers usually produce on the average between 2000 to 5000 tubers of yam per farming season. As an engineering principle, the maximum value is used for design calculations in order to take care of excesses.

The average volume of Pona (D. *rotundata*) was determined using the water displacement method as 1.83 × 10-3 m^3. Therefore at full storage capacity, yam tubers would occupy a total volume of 1.83 × 10-3 m^3/tuber ×5000 tubers = 9.15m^3

Sizing of Structure

The structure should have enough space to accommodate yam tubers at full capacity. To ensure easy entry and free movement of persons in the structure, an average height of man (1.83m) was used for the height of the structure. A bigger volume was needed to ensure there's less congestion during storage of yam tubers. To achieve this volume, dimensions of 3.66 m (length) × 1.83 m (width) × 1.83 m (height) was selected. Therefore the volume for the structure was 12.26 m^3. The remaining space (volume) of 3.11 m^3 (12.26 - 9.15) m^3 would be occupied by the shelves.

It is however important to calculate the number of shelves and area occupied by the shelves in order to know the total number of tubers that can be stored in the structure. From Figure 7, the total number of shelves along the walls of the structure, in the middle and at the entrance section of the structure was estimated to be 50, 35 and 10 respectively with a total area of 22.7 m^2.

Fig7. *Arrangement of shelves in the improved storage structure*

The open space above these shelf columns corresponds to a total area of 4.84m^2 with a total of 12 shelves. An average area of 0.0047 m^2 and 0.0066 m^2 was estimated for Pona and Dente yam tubers respectively. Therefore technically, the structure is capable of storing approximately 5860 and 4173 tubers of Pona and Dente respectively on the shelves.

Design Calculations

- ***Live load***

The average weight of *Pona* yam variety was determined to be 3.32 kg. This value was used in the calculation of the total load yam tubers would exert on the structure at full capacity by employing Equation 1.

$$\text{Load} = \text{mass} \times \text{gravity}$$

Load= 3.32 kg × 9.81 m/s^2 = **32.57 N/tuber**

Therefore, at full capacity of 5000 tubers, the load exerted on the structure was calculated as:

Load=32.57N/tubers × 5000 tubers =**162.85 kN**

- ***Wind Load***

The average recorded wind velocity in Ghana was 2.4m/s and the highest velocity recorded was 20.9m/s. In designing, the highest wind velocity of 20.9 m/s was used in calculating the wind pressure with design height of 1.83m by employing Equation 2;

$$Q = 0.013V^2\left(\frac{h}{6.1}\right)^{\frac{2}{7}} = 0.013(20.9)^2\left(\frac{1.83}{6.1}\right)^{\frac{2}{7}} = \mathbf{1.65\ Pa}$$

- ***Uniformly Distributed Load (UDL)***

Using Equation 3, the uniformly distributed load of yam tubers was calculated as follows;

$$\text{UDL} = \frac{\text{total load}}{\text{length of beam}} = \frac{162.85\,\text{kN}}{3.66\,\text{m}} = \mathbf{44.5\ kN/m}$$

- ***Stress***

Taking the length and breadth of each shelf, the area can be determined and used for the calculation of stress on each shelf or group of shelves by employing Equation 4.

From Figure 7, the total area along the walls of the structure, in the middle and at the entrance section of the structure was 22.7 m^2. Knowing the load per tuber of *Pona* yam variety as 32.57 N and the total number of tubers as 4830 tubers, the stress that would be exerted on that group of shelves (walls, middle and entrance) was calculated as:

$$\text{Stress} = \frac{\text{total load (N)}}{\text{Area } (m^2)} = \frac{157.3\,\text{kN}}{22.7\,m^2} = \mathbf{6.93\ kN/m^2}$$

Again, the open space above the shelf columns corresponds to a total area of 4.84m^2. With a load per tuber of *Pona* yam variety as 32.57 N and approximately 1030 tubers, the stress that would be exerted those shelves was calculated as:

$$\text{Stress} = \frac{\text{total load (N)}}{\text{Area } (m^2)} = \frac{33.54\,\text{kN}}{4.84\,m^2} = \mathbf{6.93\ kN/m^2}$$

From the stress calculations above, it can be realised that stress is same for each shelf column. That means that, as expected, the yam load is evenly distributed on each shelf column.

- ***Bending moment***

The bending moment on the *Ceiba* wood shelves was calculated as follows:

$$M = \frac{wLz}{2} - \frac{wz^2}{2}$$

Where; w – Total load exerted

L – Length

Z – Load point (0.8)

M – Bending Moment

With an average Ceiba wood length of 3.66 m and a total load of 162.85 kN;

Bending moment, $$M = \frac{162.85 \times 3.66 \times 0.8}{2} - \frac{162.85 \times 0.8^2}{2} = \mathbf{186.29\ kN}$$

Comparing the total yam load of 162.85 kN to the bending moment of the *Ceiba* wood shelves (186.29 kN), it means that the shelves would be able to safely hold the yam tubers at full capacity without any mechanical failure.

Durability Test

Each Borassus palm wood sample at different moisture contents was subjected to a load scale of 10 tons in the Avery Universal testing machine to record the load at which it will fail. Table 1 shows the results after the test.

Table1. *Durability test results for Borassus aethiopum wood samples*

Sample type/ Moisture content	**Failing load (kg)**		
	0.48m	**0.60m**	**0.79m**
Sample 1 - Fresh wood (18.3%)	3960	2860	2100
Sample 2 - Partially dried wood (12.8%)	5800	5000	4024
Sample 3 - Very dried wood (8.2%)	7600	6040	5400

From Table 1, the strength of the *Borassus* palm wood varies with length and moisture content. Generally the heavier a wood is the more strength it has, but it was observed that the dry Borassus palm wood which is lighter in weight has more strength than the freshly cut wood. This also justifies the fact that the strength of wood increases with decreasing moisture content.

Borassus palm wood was strongest at a length of 0.48m and moisture content of 8.2%, failing under a load of 3800kg. Therefore at a length of 0.48 m, the force at which the dried Borassus palm wood (sample 3) failed was calculated to be 7600 × 9.81 = 74.56 kN.

The total load exerted on the structure at full capacity of yams was estimated as 162.85 kN. Assuming there are only four pillars of Borassus palm wood holding the entire structure, the combined strength will be 298.22 kN, which far exceeds the entire load of the 5000 yam tubers and the weight of all other structure members altogether. This makes Borassus *aethiopum* palm wood very suitable for the structural frame construction.

Construction of Structure

The rectangular structural frame of the barn was entirely constructed using Borassus palm, held in position at the four corners by burying part of the Borassus columns into the ground (Figure 8). The area dimension (3.66 m × 1.83 m) of the structure was marked out on the ground using line and pegs and holes for the pillars dug at 0.6 metre depth with the help of an earth chisel. The main frame was raised after fixing the side beams and braced for accurate setting before consolidation of the pillar (column) foundation. The bracing allows for better structural stability to facilitate safe climbing of the structure so that the roof frame can be mounted as well. Each of the four corner columns (pillars) was 3.35 metres tall; 0.61 metres as depth in the ground, 0.91 metres as platform height and 1.83 metres as height of the storage area as shown in Figure 8. Again, slope angle for the roof was 33° in other to ensure that rain water doesn't stay long on the roof during and after any downpour.

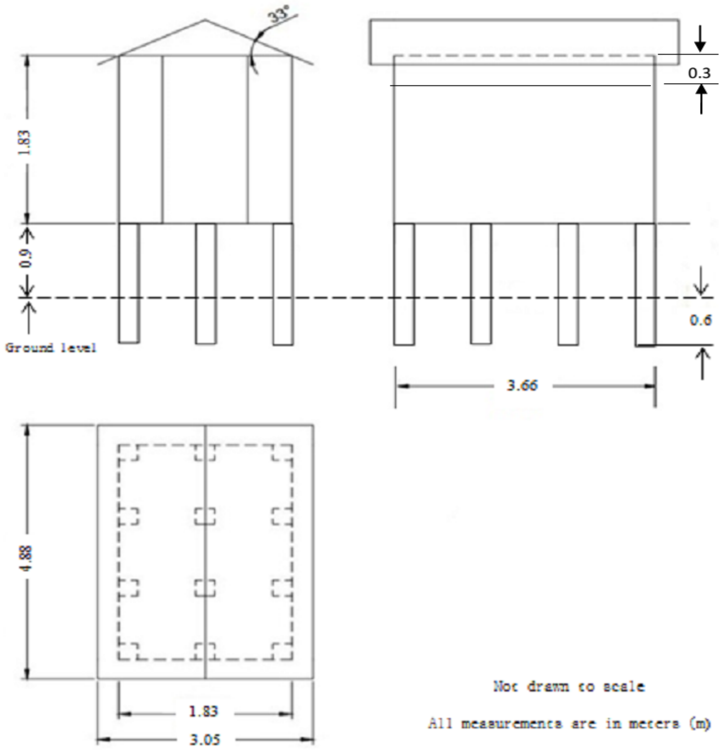


Fig8. *Orthographic view of the improved affordable yam storage structure*

The structure was 3.66 metres in length, 1.83 metres for both width and height; giving a total storage volume of 12.23 m^3. An approximate gab of 0.015 m was left between each cladding (both outside and floor covering) board to facilitate good ventilation within the structure. The gap was sizable enough to allow air to pass through but too small to prevent harmful insects and pests or birds that can attack the yams from entering the store.

After construction, shelves were made within the structure to ensure that yams are well packed to facilitate proper ventilation and to prevent damage and excessive heat generation. Five columns of shelves line were constructed with an average distance of about 0.6 m walk way between them. Each shelve line had five column and five rows divisions and the top part of the shelf left without divisions. The divisions provided stability and strength for the shelves to withstand the load of the yams that will be packed on them (Figure 7).

Again, to facilitate good ventilation within the storage structure, opening of approximately 0.3 m (covered with wire mesh) is positioned along the entire length at the top of structure (Figure 8). Fresh air gets into the structure from underneath to carry away the heated air through the top openings. This ventilation cycle ensures that no heat spots are built up within the storage structure, ensuring a cooler environment for improved yam storage.

To ensure that rodents don't have access into the storage structure, rodent guards, made from Aluminium roofing sheets, are fixed on ground pillars of the storage structure as shown in Figure 9.

Fig9. *The improved yam storage structure with rodent guards fixed*

Cost Estimation of Storage Structure

Table 2 presents the bill of quantity for construction of the improved affordable yam storage structure as at January, 2014.

Table2. *Bill of quantity for improved yam storage structure construction as at January, 2014*

Item	Size	Quantity	Unit Cost (US$)	Total Cost (US$)
Borassus palm wood	3" × 6"	11 pcs	2.00	22.00
Borassus palm wood	2" × 4"	24 pcs	2.00	48.00
Borassus palm wood	2" × 2"	12 pcs	2.00	24.00
Wood slabs		40 pcs	1.00	40.00
Ceiba wood	12" × 1"	24 pcs	4.00	96.00
Wire mesh	¾" × ¾"	½ bundle	40.00	20.00
Thatch		20 bundles	2.00	40.00
Aluminium roofing sheet	4 ft × 8 ft	1 sheet	5.00	5.00
Concrete Nails	4"	2.7 kg	2.50	6.75
Nails	4"	9.5 kg	2.00	19.00
Nails	3"	15 kg	1.50	22.50
Nails	1½"	0.5 kg	1.50	0.75
Hinges		1 pair	2.50	2.50
Hasp		1 pair	3.00	3.00
Padlock		1 piece	4.00	4.00
Turpentine		2 litres	2.00	4.00
Creosote		1 gallon	6.00	6.00
Dursban (Chlorpyrifos)		1 litre	6.00	6.00
TOTAL				**369.5**

The primary assumption for the budget is that local expertise is used for the construction of the storage structure; thus labour is free and therefore not costed. It is also worth noting that in communities where some of the local materials are freely available, the cost may further be slashed down.

CONCLUSION AND RECOMMENDATIONS

In conclusion, design features of the improved traditional storage yam barn include:

- Good ventilation due to the presence of upper openings and side windows
- Ability to keep a more cooler environment within

- Water proof using well installed fresh thatch material
- Protection against rodents with the help of rat guards and raised platform
- Protection against theft because structure has a gate under lock and key
- Access for sprout control with the presence of shelves
- Low cost due to the use of locally available materials and local expertise

It is also worth noting that the structure, because of the durable materials used for its construction, is strong enough to withstand the load of 5000 yam tubers at full capacity without buckling in.

Finally, the use of local materials for the yam storage structure construction will facilitate its future adoption because they are relatively cheaper and easily accessible and allow for the use of local expertise for construction.

It is however recommended that a field performance evaluation of the structure is done to assess its storability for different yam varieties. Again, further studies should be undertaken to assess the effect of structure shape on the storability of yam.

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AUTHORS' BIOGRAPHY

Shadrack Kwadwo Amponsah, holds a Master's degree in Agricultural Machinery Engineering and a Bachelor's degree in Agricultural Engineering from the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi in Ghana. He's currently working with the Crops Research Institute under the Council for Scientific and Industrial Research (CSIR), Ghana as a Research Scientist. His research interests include; machine design and fabrication, integrated agriculture, conservation agriculture, performance evaluation of agricultural machinery, postharvest engineering among others.

Joseph Oppong Akowuah, is a Senior Lecturer at the Department of Agricultural Engineering, KNUST. He has research interest in processing and storage of agricultural products as well as development of renewable energy technologies for food processing. Some current on-going projects include: production and characterisation of briquettes from various biomass feedstock for heating applications; development of improved yam storage systems using local materials; development of solar-biomass assisted hybrid dryer for drying of various agricultural produce.

Evelyn Adu-Kwarteng, is a Senior Research Scientist at Crop Research Institute of the Council for Scientific and Industrial Research in Ghana, where she is Head of Postharvest under the West Africa Agricultural Productivity Program. She holds a B.Sc. (Hons.) in Biochemistry, Nutrition and Food Science from the University of Ghana, Legon, and an M. Phil. in Biochemistry, Food Science and Technology from the Kwame Nkrumah University of Science and Technology, Kumasi. She also holds certificates in Middle-level Management (GIMPA), Quality assessment of non-grain starchy staples (NRI), Cassava cyanogenicpotential determination and Tissue culture techniques (IITA). In 2004 and 2005, she was a Visiting Scholar at the North Carolina State University, Raleigh, and the USDA Agriculture Research Station-SRRC, New Orleans, USA. Her research includes the development and promotion of environmentally sustainable and user-friendly technologies for empowering key actors in postharvest food systems, especially in the areas of storage and processing. Evelyn is keenly interested in the use of renewable energy in improving food and nutritional security.

Enoch Bessah, holds a Master's degree in Climate Change and Adapted Land Use from Federal University of Technology, Minna in Nigeria and a Bachelor's degree in Agricultural Engineering from Kwame Nkrumah University of Science and Technology (KNUST), Kumasi in Ghana. He is currently working with the Crops Research Institute under Council for Scientific and Industrial Research (CSIR), Ghana as a Casual Staff and Research Assistant on three projects. His research discipline includes; integrated agriculture, conservation agriculture, postharvest engineering, performance evaluation of agriculture machinery, soil and land use engineering, climate change assessment and adaptation among others. Enoch is also well vested in the use of ArcGIS and AutoCAD.