Preliminary Evaluation of Guava (*Psidium guajava* L.) Tree Branches for Truss Fabrication in Nigeria

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ABSTRACT

Some physical and mechanical properties of small diameter poles obtained from guava (*Psidium guajava* L) tree branches in relation to their potential use for truss fabrication were determined. The average green moisture content of wood from five replicate samples of debarked tree branches was 84%. The wood samples were naturally resistant to termite attack with and without the bark on. The mean oven-dry density of the wood samples was 674 kg/m^3. This puts it in the density category of the preferred species for rafter and truss fabrication in Nigeria. The mean modulus of elasticity of the air-dried samples (at 50% moisture content) was 2829.1 N/mm^2 while the corresponding mean modulus of rupture was 9.2 N/mm^2. To evaluate the practicality of the proposition, a 2-metre, 4-web Pratt truss was designed and a prototype was successfully fabricated with the poles jointed with nailed plywood gusset plates.

Keywords: Guava branches, density, moisture content, modulus of elasticity, rafter truss fabrication

1. INTRODUCTION

Timber and other wood products have, for ages, remained one of the major structural materials for building construction worldwide due to their renewable nature, availability in various sizes, shapes and colours, affordability, relatively high fatigue resistance and specific strength, ease of joining, durability, and aesthetic appeal. Also, un-serviceable wooden building components are re-cyclable either for their structural properties, e.g., reused permanently as framing or temporarily as form-work, or for their heat content as fuel (Goldstein 1999).

In many parts of Europe and North America, wood products of various types are used in framing, flooring, roofing, siding and even foundation work in single family residences, apartment, commercial and industrial buildings, farm dwellings and service buildings (Willenbrock *et al.* 1998, Breyer *et al.* 1999). In Nigeria, however, the major area of structural utilization of wood is in roof construction, with the building industry alone consuming about 80% of the country's estimated 20 million cubic meters of annual lumber production (Alade and Lucas, 1982, Lucas and Olorunnisola 2002). The various timber species sawn into lumber for use in building construction in Nigeria are shown in Table 1. Other types of wood and wood products currently employed in building construction in Nigeria include:

- Poles used as studs, columns, beams, wall plates, rafters, and purlins largely in farm structures and rural residential buildings, and for scaffolding in multi-storey building construction sites.
- Posts in forms of round, hewn, squared or split wood, used principally for scaffolding, rafting and as columns and wall plates for farm houses, sheds, livestock buildings, storage structures, beams for drying platforms, and generally for fencing.
- Panel products such as plywood, particleboard and fibreboard used for ceiling, flooring, walling, partitioning, decorative paneling, fabrication of doors and windows, furnishing, and as form work material in concrete construction (Mijinyawa and Dahunsi 1996, Lucas and Olorunnisola 2002).

More than 70 % of Nigerians reside in towns and villages with population of less than 20,000 (Hassan *et al*. 2002). Modern wood processing industries (sawmills and plywood mills) are generally located in urban centres throughout the country. Therefore, very large quantities of pole wood is used for framing and rafting in traditional building structures in rural communities due to restricted access to lumber and panel products. However, poles and posts are also used in the construction of temporary sheds, market stalls and food shops in many parts of the country. Hence the use of roundwood timber as well as poles and lumber from fruit trees for roofing has always been very common across the country (Lucas and Comben 1972, Enabor and Olawoye, 1974, Mijinyawa and Dahunsi 1996, Olorunnisola 1998, Lucas and Olorunnisola 2002).

A fruit tree whose trunk is commonly sawn into lumber in the country is oil palm (*Elaisis guiniensis*). A major problem with the use of oil palm trunk for construction in a rural setting, however, is that it has to undergo conversion, a process that requires some level of energy input and thus raises cost of the lumber product. A suitable alternative would be a freely obtained tree in local bushes, whose timber could be used in the round form. Round timber has an advantage of less variation in strength compared with sawn timber, thus facilitating the derivation of allowable stress values. Also, the fibres in round timber are relatively more intact and are therefore unlikely to splinter (Wolfe 1998). The obvious limitations that could be associated with the use of round timber for truss fabrication, i.e., relatively heavy weight, twisted or curved shapes, etc, can be overcome through careful selection of suitable species and proper arrangement of members.

Table 1: Selected Nigerian timber species and their uses in building construction

Building Component	Recommended Timber Species
Carcassing	Afara (*Terminalia superba*),), Albizia (*Albizia spp.*), Alstonia (*Alstonia boonei*), Celtis (*Celtis spp.*), Dahoma (*Piptadeniastrum africanum*), Danta (*Nesogordonia papaverifera*), Ilomba (*Pycnanthus angolensis*), Iroko (*Milecia excelsa*), Obeche (*Triplochiton scleroxylon*)
Door and window frames (external)	Agba (*Gossweilerodendron balsamiferum*), Albizia (*Albizia spp.*), Apa (*Afzelia africana*), Danta (*Nesogordonia papaverifera*), Gedu Nohor (*Entandrophragma angolense*), Iroko (*milecia excelsa*), Lagos Mahogany (*Khaya ivorensis*), Opepe (*Nauclea diderricchii*)
Doors and windows – Solid	Afara- white (*Terninalia superba*), Apa (*Afzelia africana*), Black Afara (*Terninalia ivorensis*), Gedu Nohor (*Entandrophragma angolense*), Iroko (*milecia excelsa*), Lagos Mahogany (*Khaya ivorensis*), Mansonia (*Mansonia altissima*), Sapelewood (*Entandrophragma cylindricum*), Utile (*Entandrophragma utile*)
Flooring and decking	Agba (*Gossweilerodendron balsamiferum*), Albizia (*Albizia spp.*), Danta (*Nesogordonia*), Iroko (*milecia excelsa*), Omu (*Entandrophragma candolei*) (Opepe (*Nauclea diderricchii*), Sapelewood (*Entandrophragma cylindricum*)
Shingles and battens	Abura (*Mitragyna stipulosa*), Black Afara (*Terninalia ivorensis*), Gedu Nohor (*Entandrophragma angolense*), Mangrove (*Rhizophora racemosa*)
Sills and thresholds	Dahoma (***Piptadeniastrum africanum***), Iroko (*milecia excelsa*), Opepe (*Nauclea diderricchii*)
Stair Treads	Guarea (*Guarea spp.*), Mahogany (*Khaya spp.*), Sapelewood (*Entandrophragma cylindricum*)
Roof rafters and purlins	Abura (*Mitragyna stipulosa*), Afara (*Terminalia superba*), Agba (*Gossweilerodendron balsamiferum*), Albizia (*Albizia spp.*), Danta (*Nesogordonia papaverifera*), Iroko (*milecia excelsa*), Obeche (*Triplochiton scleroxylon*), Opepe (*Nauclea diderricchii*), Sapelewood (*Entandrophragma cylindricum*)

Source: Okigbo (1964), 2005 Market survey by the Authors

The branches of guava trees seem to be such a suitable alternative. Justifications for the selection of guava tree branches include their strength and good response to pruning that enhances growth of small diameter poles (Anon. 2000)**.** Besides, guava fruit is mostly eaten raw in Nigeria and it is beginning to loose wide acceptance due to the linkage established between its consumption and the development of a medical condition known as appendicitis. However, there is a dearth of information on the relevant physical and mechanical properties of guava tree branch that may facilitate its utilization as a structural material.

The objective of this study, therefore, was to conduct preliminary evaluation of the physical and mechanical properties of wood from pole-size guava tree branches and to develop a prototype truss.

2. MATERIALS AND METHODS

2.1 Wood Property Tests

Experimental samples were obtained from the branches of two guava trees found on the premises of the Faculty of Technology, University of Ibadan, Nigeria. The trees selected for sample extraction were mature ones, judging by the basal girth which was over 76 cm, since their ages could not be determined. These were preliminary rather than full-blown tests. They were necessitated by the absence of data on the physical, durability and mechanical properties of guava wood. In all, tests were conducted using five branches, two from one tree and three from the other. The property tests carried out included moisture content determination for green samples, density determination for both green and oven dry samples and natural durability against termite, insect and fungi. Static bending tests were also performed.

Moisture content determination (on dry basis) was in accordance with British Standard, BS 812-109:1990, but modified for the material. The modification involved using the complete branches (two in number) in view of the fact that the materials were of very small girth dimension and it would be difficult to take material from their central portions. Taking the whole section indeed gives a more correct value than taking sample from the central portion

Green samples freshly obtained from the trees were debarked and used for green and dry density determination using the water displacement method. For the natural durability test, freshly cut samples from the two mature guava trees were employed. There were eight samples in all, four debarked and four un-debarked. A graveyard test was conducted in accordance with ASTM D 2017-96a to evaluate the resistance of both the debarked and un-debarked branches to termite, insect and fungal attacks. Wood samples obtained from *Acacia species* were used as the control. Test duration was 60 days, with monitoring done at two-week intervals.

Static bending tests were conducted using the three-point test approach to determine the moduli of elasticity and rupture of the samples. In all, ten samples were used, including five samples tested in wet condition and five air-dried samples. All the test samples were prepared in accordance with ASTM D 1037-96a with slight modification due to the size of the test specimens. The tests were conducted at a constant loading rate of 0.1 m/s.

2.2 Design and Fabrication of a Prototype Pratt Truss

A 2-metre span, 4-web Pratt truss was designed in accordance with standard truss design methods. The Pratt type of truss was selected for the targeted low-income earner end-user because its fabrication and assembly is simple and may not require skilled labour, it is economical especially for short to medium span range, and it is appropriate for buildings with or without ceiling (Midwest Plan Service, 1980).

The design was based on the following assumptions and published design data:

(i) A truss centre spacing of 6000 mm.

(ii) Corrugated iron roofing sheet of guage 20 (95.8 N/mm^2) would be used.
(iii) Roofing sheet is to be fastened directly to the top chords.
(iv) The permissible bending strength was taken as 40% of the MOR, while the lowest MOE value experimentally obtained was used.
(v) Wind load for 15^0 slope = 718.2 N/mm^2.
(vi) Estimate weight of truss = 287.3 N/mm^2.
(vii) Top chord gradient = 15^0.

A prototype model of the truss was fabricated with poles extracted from branches of one of the two sample guava trees using simple manual tools. The average moisture content of the air-dried branches at the time of fabrication was 50 % (dry basis). The truss members were prepared using manual tools in accordance with the dimensions derived from previous analysis and generated cutting list. The joints were fabricated using nailed plywood gusset plates. Suitably shaped pieces of 6 mm (1/4 inch) thick plywood was used to cover each joint and was secured by nailing. The size of the gusset and the number of nails were pre-determined for each joint in the truss. Off-cuts were used to reinforce each joint before installing plywood gusset.

Ordinary nailed joints were not employed because nails are generally known to be the least efficient in load transfer capacity and resistance to slip deflection. Also, failures in nailed joints are mostly initiated by splits. The use of gussets was informed by the need to ensure in-plane positioning of components. Aluminum nails of 50 mm length were used to prolong the service life of the joints in view of previous studies by Alade and Lucas (1982) which identified corrosion in service as one of the causes of failure of nailed joints in Western Nigeria. Besides, this method allows the use of relatively small nails so that even the relatively dense woods can be nailed without pre-drilling. To take advantage of the bowed shape of the poles, members were arranged to achieve pre-cambered sections with each member secured with at least two nails.

3. RESULTS AND DISCUSSION

3.1 Green Moisture Content

The average green moisture content of the guava wood samples was 83.6% (Table 2). This relatively high moisture content is an indication that the wood would need to be pre-dried before use preferably below 20 % moisture content to prevent decay and damage by pinhole borers. The degree of drying would depend on the dryness of the locality where the wood would be put to use. Drying would also make the wood stronger, reduce its weight, facilitate impregnation by preservatives and satisfactory gluing with all types of adhesives, and increase its thermal insulation properties.

3.2 Green and Dry Density

As shown in Table 2, the average green density (at 83.6% moisture content) of the guava tree branches was 1092.7 kg/ m^3 while the average oven dry density was 676.1 Kg/ m^3. The mean oven dry density value compares favourably with the dry density of some common timber

Table 2: Moisture content and densities of the guava wood samples

Guava Wood Sample	Green Moisture Content (%)	Density (Kg/m^3)	
		Green	Oven Dry
1	81.8	1181.0	715.0
2	81.8	1052.6	611.1
3	88.4	1066.7	680.0
4	82.3	1129.0	685.7
5	83.5	1034.1	688.9
Mean	83.6	1092.7	676.1
Coefficient of Variation (%)	3.4	5.6	5.7

species used in fabricating rafters and purlins in Nigeria (Table 3), and also suggests that the wood is of medium density. Nailing, the prevailing method of wood fastening in Nigeria, should also not be a problem with the wood since resistance to nailing is commonly associated with high wood density (Alade and Lucas 1982).

3.3 Resistance to Termite, Insect and Fungal Attack

The wood of both debarked and un-debarked samples remained intact at the end of 60 days. They were not attacked by termite, insect or fungi. The *Acacia species* also exhibited a similar form of resistance to termite, insect attack. This finding is another positive indication of the potential use of guava wood as a material for truss fabrication in Nigeria where preservation facilities are quite inadequate in the rural areas in particular and in the country as a whole.

3.4 Moduli of Elasticity and Rupture

The results of the bending strength tests for the green and air-dried samples are presented in Table 4. The mean MOE values for the green and air-dried specimens were 5589.1 N/mm^2 and 2829.1 N/mm^2 respectively, while the mean MOR values were 6.1 N/mm^2 and 9.2 N/mm^2 respectively. MOE is a useful property required in designing trusses. As would be expected the mean MOE of the mean green guava wood was higher than that of the dry wood. This is because wet wood is generally more elastic than dry wood. However, dry wood is often preferred in the design of wood structures to minimize shrinkage associated with *in situ* drying in service.
MOR is also one of the key mechanical properties of wood measured and presented as strength property for design. It is a reflection of the maximum load-carrying capacity of a member in bending and is proportional to the maximum moment borne by the specimen. As would be expected, the mean MOR of the dry guava wood was higher than that of the green wood since the drier a wood material is, the stronger it becomes.

Both the MOE and MOR values obtained for the air dry guava wood samples are comparable with corresponding vales quoted for *Melicia excelsa* (at 18 % moisture content) in the Nigerian code of practice for wood design. However, since this was a pilot study with limited sample size aimed at obtaining baseline information about the bending strength properties of guava wood, no attempt has been made to derive both grade and permissible stress values for guava wood from these results.

Table 3: Densities of selected timber species used in fabricating roof rafters and purlins in Nigeria

Local Names	Botanical Names	Density at 18% M.C. (kg/m^3)
Abura	Mitragyna stipulosa	576
Afara	Terminalia superba	464
Agba	Gossweilerodendron balsamiferum	544
Apa	Afzeliaafricana	864
Danta	Nesogordonia papaverifera	784
Iroko	Melicea excelsa	688
Obeche	Triplochiton scleroxylon	384
Opepe	Nauclea diderricchii	800
Sapele wood	Entandrophragma cylindricum	704
Lagos Mahogany	Khaya ivorensis	528

Source: NPC (1973)

Table 4: Static bending strength properties of wet and dry guava wood

Guava Wood Sample	MOE (N/mm^2)		MOR (N/mm^2)	
	Wet	Dry	Wet	Dry
1	5115.2	2671.9	5.5	8.6
2	7453.1	3128.9	6.0	10.1
3	6222.7	2601.6	6.6	8.3
4	4598.4	3106.5	6.1	9.1
5	4556.3	2636.7	6.1	9.8
Mean	5589.1	2829.1	6.1	9.2
Coefficient of Variation (%)	22.2	9.0	6.4	8.0

3.5 The Prototype Truss

The prototype 2-metre span, 4-web 'Pratt truss' designed and fabricated using guava wood is shown in Figure 1. The average diameter of the component parts was 28 mm. The total cost of fabricating the truss was estimated to be US $ 7.14 (One thousand units of Nigerian currency, the Naira). This is just about 40 % of the cost of producing the same size of truss using sawn timber.

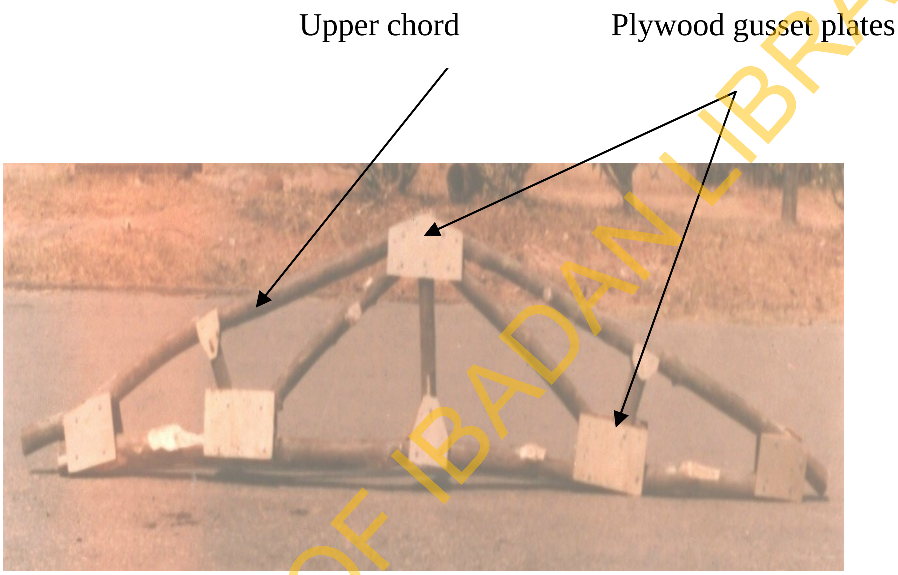

Figure 1: Side view of the fabricated truss

4. CONCLUSIONS AND RECOMMENDATIONS

This study has shown that wood from the branches of guava tree could be used as a suitable and relatively cheaper material for truss fabrication in Nigeria. It is a medium density wood that is very resistant to termite, insect and fungal attack. The bowed shape of the branches which may be considered one of the limitations of poles derived from the tree branches could be of great advantage in cambering as demonstrated in the prototype truss that was fabricated.

Based on the findings of this study, it is recommended that:

(i) Guava wood for truss fabrication should be used with the bark on to enhance its natural resistance against termite attack.

(ii) The wood should be pre-dried before use. However, when wet members are to be used, special rust-proof nails should be employed.

(iii) Truss members should be arranged such that full advantage is taken of any bowed member to facilitate pre-cambering of the truss.

(iv) The joints should be braced with off-cuts to enhance joint rigidity and adequate performance.

(v) Fuller tests should be conducted on the wood properties and the truss fabricated using guava tree branches.

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