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Domestication of *Dacryodes edulis*: 1. Phenotypic variation of fruit traits from 100 trees in southeast Nigeria

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Abstract. A participatory approach to tree domestication is being pioneered by ICRAF and international partners in Cameroon and Nigeria. The domestication of *Dacryodes edulis* offers opportunities to improve the livelihoods of subsistence farmers and to diversify farming systems, such as cocoa farms. The trees produce marketable fruits as well as shade for cocoa and coffee. Twenty-four ripe fruits were collected from each of 100 *D. edulis* trees in Mgbuisi, southeast Nigeria by subsistence farmers. There was continuous and significant tree-to-tree variation in fruit mass (10.2 ± 0.5–71.4 ± 1.3 g), flesh mass (6.8 ± 0.3–62.2 ± 1.2 g) and kernel mass (1.3 ± 0.5–15.1 ± 0.4 g). Mean fruit mass did not differ significantly between different land uses. Flesh mass:kernel mass ratio varied from 0.79 to 29.0. Two trees had fruits without kernels. There was also continuous and significant tree-to-tree variation in fruit length (39.0 ± 0.6–95.1 ± 1.2 mm), fruit width (21.82 ± 0.16–43.75 ± 0.33 mm) and flesh thickness (1.82 ± 0.1–6.39 ± 0.1 mm). Fruit length:width ratio varied from 1.35 to 3.18. Cooked fruits varied in taste with only 14% of trees getting the highest score. Similarly, fruits varied in oiliness with only 3% of trees getting the highest score. Thirteen skin colours were recorded, with the most common being dark blue (31%), greyish violet (29%) and deep blue (9%). Ninety-nine percent of the trees had been planted, with 57% in homegardens, 22% in crop fields, 17% in fallow land and 4% in cocoa. Tree height ranged from 4 to 22 m, and DBH from 9.55 to 63.65 cm. Tree age ranged from 5 to 64 years. Farmers reported first fruiting from age 3 up to 22 years (average of 9.4 years). Most trees originated from seeds bought in markets (63%). Market prices of fruits from different trees, ranged from 2 to 12 fruits for 10 Naira (US$0.07). These quantitative results will help in the identification of elite trees of *D. edulis* for cultivar development through clonal propagation.

Introduction

Dacryodes edulis (G. Don) H.J. Lam. is a traditionally important, indigenous fruit tree of West and Central Africa (Kengue 2002). Increasingly, the species is

becoming commercially important. Its natural range extends from southern Nigeria into western Cameroon, but it is also found extensively in farmland across Cameroon, Gabon, Democratic Republic of Congo, Central African Republic, Republic of the Congo, and Equatorial Guinea. This wider range may result from anthropogenic transfer of planting material (Leakey et al. 2002). Nutritionally, *D. edulis* is the most commonly consumed and grown of the 19 fruit species of the genus *Dacryodes* (Burseraceae) found in the region. Two varieties of this species: *D. edulis* var. *edulis* (cultivated type) and *D. edulis* var. *parvicarpa* (wild type) have been identified by Okafor (1983) on the basis of their fruit size.

Fruits of *D. edulis*, which are commonly know as African pear, African plum, native pear, butterfruit, safou, 'Ube' (in southeast Nigeria) and 'Eleme' (in the southwest Nigeria) are very nutritious (Leakey 1999). The fruits form an important part of the diet of people in West and Central Africa being rich in vitamins and containing 63.5% fat, 24.2% protein and 9.2% carbohydrate (Mbofung et al. 2002). The protein content of *D. edulis* is greater than that of maize (10%), rice (8%), sorghum (11%) or wheat (8–13%), but lower than that in peanut (48%) and soybeans (40%). The fruits are rich in minerals and have some medicinal properties. In addition to the use of safou fruits as a staple food, there is growing interest in preparing fruits into preserves like jams, jellies, and in the extraction of the oil for cooking or use in the margarine, soap and perfume industries (Sonwa et al. 2002). The kernels have been found suitable for use as animal feeds.

Dacryodes edulis trees are also important for the provision of shade. This medium-sized tree is consequently commonly found in homegardens and in smallholder cocoa farms in Cameroon (Leakey and Tchoundjeu 2001), while in Nigeria, trees are predominantly planted in the compound farm and in crop fields. The fruits, which ripen in the rainy season (May–November) are harvested when they change colour from whitish-green to pink to dark blue/purple/black. The fruits have an attractive, oily, slightly sour taste when cooked, but have a relatively short shelf-life when raw, although this can be prolonged by drying using traditional knowledge. In Cameroon, the fruit is typically roasted, but in Nigeria, the fruits are usually boiled in salted water. It is usually eaten with freshly roasted or boiled maize, cassava or plantain. Recent studies have examined opportunities to extend the shelf life of fruits (Kalenda et al. 2002), and to process the fruits into more durable products (Mbofung et al. 2002).

The socio-economic importance of *D. edulis* has recently been documented (Schreckenberg et al. 2002a). Trees are predominantly planted as shade trees in association with cocoa or coffee, where they are also a source of income, as their fruits are widely traded locally and regionally (Ndoye et al. 1997) and even internationally (Awono et al. 2002), with exports from Cameroon estimated at US$2 million in 1999. At the farm level, the estimated value of *D. edulis* fruits is US$161 per tree per year and, on average, producers receive 75% of the consumer price, with weekly marketing margins up to double the minimum wage. This income is particularly important to women as it comes at a time of year when school fees and associated costs have to be paid (Schreckenberg et al. 2002a). Interestingly, the retail trade is dominated by women, while the wholesale trade is dominated by men (Schreckenberg et al. 2002a). The retail trade recognises the tree-to-tree variation in

fruit characteristics (Leakey and Ladipo 1996), while the wholesale trade does not (Leakey et al. 2002). The potential of *D. edulis* to generate income to rural households and to promote food security is supported by work on fruit yield and household benefits (Okafor 1980; Tchoundjeu et al. 2002). There are opportunities to develop *D. edulis* fruits as an oil crop (Kalenda et al. 2002; Kapseu et al. 2002) and to enhance the short shelf life of the fresh fruits, by post-harvest processing (Mbofung et al. 2002), thereby increasing the market demand for fruits.

Although typically propagated by seed, it can be propagated vegetatively by cuttings and by marcotting (air layering) (Mialoundama et al. 2002). Mature marcotts are typically short and bushy in growth, and consequently are planted at $10\,\text{m} \times 10\,\text{m}$ spacing.

In the context of increasing social and economic pressure on forests and natural resources, it is being recognised that *D. edulis* plays an important role in alleviating the threats on food security caused by disturbances to the balance of nature arising from human activities. In this context, it is clear from the number of recent publications and conferences that there is growing recognition of the importance of *D. edulis* (Okorie 2001; Kengue 2002; Kengue et al. 2002a; Schreckenberg et al. 2002b) as an agroforestry tree, which benefits the poor, malnourished and disadvantaged people of West and Central Africa.

As demand for fruits and other non-wood forest products are increasing, the supply of indigenous fruits from Nigeria's forests is threatened by increasing deforestation. This situation of increasing demand and decreasing supply of fruits from the wild provides a considerable opportunity for rural farmers willing to invest in agroforestry technologies and to participate in the selection of elite trees for multiplication as cultivars and planting in the fields. Building on a survey of farmers' species prioritised for agroforestry, which identified *D. edulis* as a priority species for domestication in the humid lowlands of West Africa (Tchoundjeu et al. 2002), this study examines the tree-to-tree variation in fruit characteristics with the aim of providing knowledge on which to base plus-tree selection for cultivar development. It is envisaged that, subsequently, fruit prices are likely to increase in the short to medium term leading to the improvement of rural livelihoods.

Materials and methods

Site selection

The study was conducted at Mgbuisi community (comprising Ilile, Umonu and Umoso villages) near Owerri in southeastern Nigeria located at $5^{\circ}18'$ E longitude, $6^{\circ}55'$ N latitude and 54 m altitude, with an annual rainfall of 2400 mm. The site was characterised by presence of *D. edulis* in the farming system and its nutritional importance in the community. Local farmers were knowledgeable about indigenous fruits and expressed interest in agroforestry and the potential of tree domestication. The area is highly populated ($400\,\text{people}\,\text{km}^{-2}$) and well supported by national agricultural extension systems (NARES) and NGOs.

Almost all the farms in the area were visited in the 1999 fruiting season and all interested farmers with *D. edulis* trees were included in the study. These trees were visited with members of the household and their positions in different farming systems were marked on a sketch map. One hundred trees forming a continuous population from the area were numbered and tagged. These trees were visited weekly throughout the 1999 fruiting season (May–November) to record the phenological changes and determine the peak fruiting season of each tree. Records were kept of changes in fruit colour throughout the season (1 = white; 2 = purple), and fruit fall (E = early; N = normal; L = late).

Fruit collection

The sampling procedures and assessment methods used were based on techniques used in similar studies with *Irvingia gabonensis* (Atangana et al. 2001; 2002; Anegbeh et al. 2003). Twenty-four mature and undamaged fruits were randomly picked among the recent-fallen fruits from four quarters of each tree crown at the peak of the fruiting season. The fruits from each tree were bagged and labelled for assessment later in the day for fruit length (mm), fruit width (mm), and flesh depth (mm) using callipers graduated in 0.1 mm. Fresh fruit mass (g) and kernel mass (g) were determined using portable kitchen scales graduated to 2 g. Flesh mass (g) was determined by the difference between fruit and kernel mass. The taste and oiliness of the fruit flesh was scored using a scale of 1–5 (1 = bitter/not oily; 5 = sweet/oily by a team of five people, three of whom were the same for every tree. Skin colour was assessed on a 3-dimensional basis (hue, tone and intensity) using the Methuen Code of Colour (Kornerup and Wanscher, 1978).

During the study, farmers were asked about age of each tree (years), the age at first fruiting (years), the number of fruiting seasons per year, the seasonality (early; normal; late), the regularity of fruiting years (regular or irregular), and a yield score (1–10). The land use system in which the tree was growing was recorded (H = homegarden; F = fallow; C = cocoa farm; CF = crop field; FOR = Forest). Farmers also identified whether each tree was planted or not planted and, if planted, the origin of its seed (O = own farm; N = neighbour; M = market; E = elsewhere). Trees were measured for height (m), diameter at breast height (cm).

Data were collated in Microsoft Excel and analysis of variance done using SAS (SAS Institute Inc., Cary, NC, USA). With the exception of taste and oiliness scores, standard errors of the mean are presented in the text.

Results

Phenology

In 1999, fruits from the 100 *D. edulis* trees studied ripened between June and November, with the peak (29%) of fruit ripening in the first week of July. No trees were reported to fruit more than once a year.

Table 1. Effects of land use on *D. edulis* fruit, nut and kernel traits in Mgbuisi, Nigeria

Land use system	Fruit length (mm)	Fruit width (mm)	Fruit flesh thickness (mm)	Fruit mass (g)	Fruit fresh mass (g)	Kernel mass (g)	No. of kernel (per fruit)	Fruit taste[1]	Oiliness[2]	DBH[3] (cm)
Cocoa-based	55.0	31.8	4.2	30.5	21.0	9.5	1.1	3.8	2.8	37.0
Crop field	55.3	30.5	3.7	29.7	19.9	9.8	1.0	3.3	2.9	32.4
Fallow field	60.3	31.0	4.0	33.4	23.1	10.3	1.0	2.9	2.4	40.8
Homegarden	58.7	30.7	3.8	31.9	22.7	9.2	1.0	3.2	2.6	32.3
Mean	57.3	31.0	3.9	31.4	21.7	9.7	1.0	3.3	2.7	35.6
CV (%)	18.5	13.0	23.2	34.1	45.7	27.8	18.4	33.5	39.7	37.3
SE (±)	2.71	0.97	0.15	2.64	2.35	0.93	0.06	0.25	0.26	3.80

[1]Scored using a scale of 1–5, 1 = bitter, 5 = sweet.
[2]Scored using a scale of 1–5, 1 = low oil content, 5 = high oil content.
[3]Diameter at breast height.

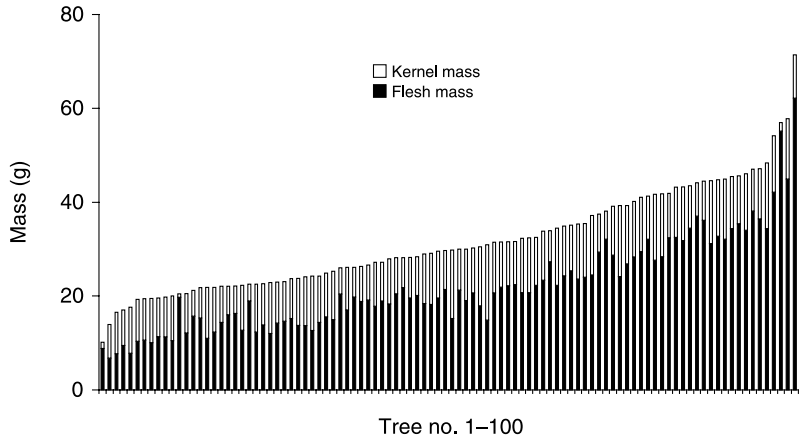

Figure 1. Tree-to-tree variation in fruit mass (flesh + kernel) in *D. edulis* from Mgbuisi, Nigeria).

Land use

The majority of *D. edulis* trees were in homegardens (57%), 22% in crop fields, 17% in fallow land and only 4% in cocoa farms. Fruit and kernel traits did not differ significantly between land uses (Table 1).

Fruit, flesh and kernel mass

There was continuous and significant ($P < 0.001$) tree-to-tree variation in fruit, flesh and kernel mass (Figure 1). Fruit mass varied from 10.2 ± 0.52 g (tree 105) to 71.4 ± 1.3 g (tree 69). Flesh mass ranged from 6.79 ± 0.26 g (tree 59) to

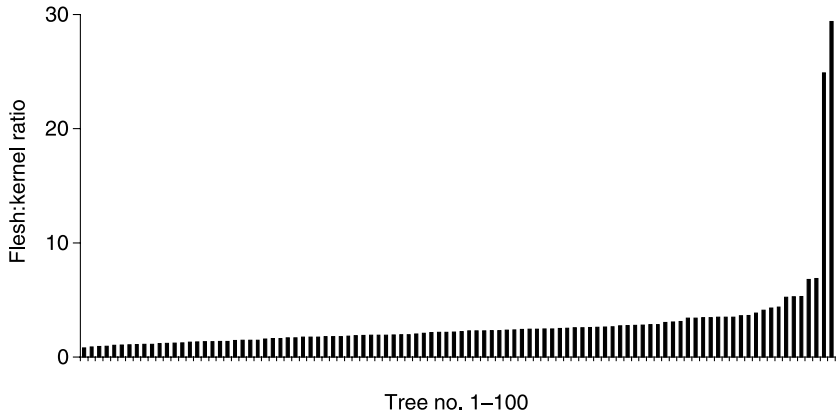

Figure 2. Tree-to-tree variation in fruit flesh:kernel ratio in *D. edulis* from Mgbuisi, Nigeria.

62.21 ± 1.15 g (tree 69) and kernel mass ranged from 1.29 ± 0.5 g (tree 105) to 15.08 ± 0.44 g (tree 81). Mean fruit mass did not differ significantly between different land uses (Homegarden, crop field, fallow, cocoa farm). Flesh mass:kernel mass ratio varied from 0.79 to 29.0 (Figure 2), with two trees possessing very small kernels in fruits which were also small (20.5 g) and large (57.0 g).

Fruit length and width

There was continuous and significant ($P < 0.001$) tree-to-tree variation in fruit length and fruit width. Fruit length varied from 39.01 ± 0.6 mm (tree 105) to 95.09 ± 1.19 mm (tree 92), while fruit width varied from 21.82 ± 0.16 mm (tree 105) to 43.75 ± 0.33 mm (tree 69). Fruit length:width ratio varied from 1.35 to 3.18 (only one tree had value greater than 2.56).

Flesh thickness

There was continuous and significant ($P < 0.001$) tree-to-tree variation in flesh thickness (Figure 3), which varied from 1.82 ± 0.08 mm (tree 93) to 6.39 ± 0.1 mm (tree 68).

Fruit taste

Variability in taste of cooked fruits was considerable (Figure 4) with 14% of trees being scored 5 (trees 3, 13, 14, 20, 32, 34, 37, 46, 47, 77, 82, 84, 100, 102).

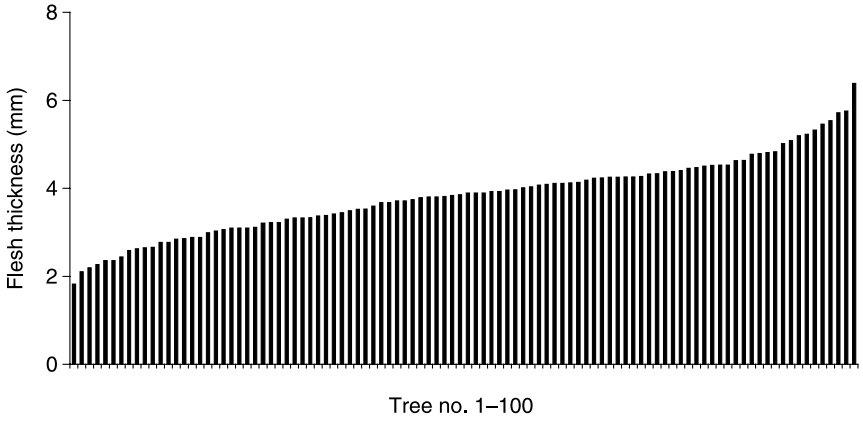

Figure 3. Tree-to-tree variation in fruit flesh thickness *D. edulis* from Mgbuisi, Nigeria.

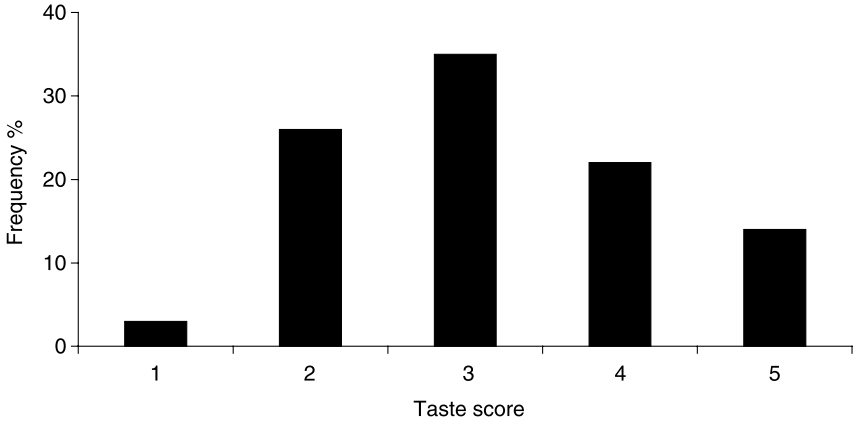

Figure 4. The frequency of fruit taste scores in 100 *D. edulis* trees from Mgbuisi, Nigeria.

Oiliness

Variability in the oiliness of cooked fruit flesh was considerable (Figure 5) but only 3% of trees were scored 5 (trees 92, 46, 100).

Skin and flesh colour

Fruits from different trees varied in skin colour. Of the 13 colours found, the most common were dark blue (21F8) at 31%, greyish violet (18D6) at 29% and deep blue (20D8) at 9%. Other colours were 19B5/19D6/20D6/20C4 = 5%,

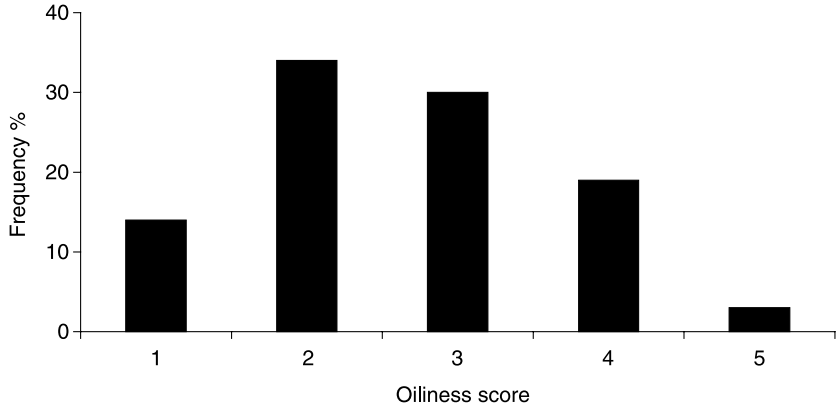

Figure 5. The frequency of fruit oiliness scores in 100 *D. edulis* trees from Mgbuisi, Nigeria.

20C5/19D8 = 3%, 18C4 = 2%, 18B2/18B3/19B4 = 1%. The flesh colour of *D. edulis* was mostly yellow (29A7) at 70%.

Tree history

Nearly all (99%) the trees had been planted by the farmers or their parents. Tree height ranged from 4 to 22 m, and DBH from 9.55 to 63.65 cm, reflecting their age range (5–64 years). Average age was 26.4 years. The farmers reported first fruiting at age 3 (trees 3, 27, 14) to 22 years (tree 65), with an average of 9.4 years. The origin of the seeds planted were: fruits bought in markets (63%), fruits from neighbours (17%), fruits from own trees (11%) and elsewhere (9%). Farmers reported considerable variation in the market prices of fruits from different trees, ranging from two (trees 92 and 101) to twelve (tree 59) fruits for 10 Naira (US$0.07).

Discussion

This study, done in parallel with another in Cameroon (Waruhiu 1999), provides quantitative data on the variability of *D. edulis* and expands on a preliminary study which identified that market price varied independently of a relationship between fruit mass and flesh:kernel ratio (Leakey and Ladipo 1996). Most previous studies have either been descriptive (Okafor 1980, 1983; Okorie 2001) or, if quantitative, have looked at the variability in mean fruit mass between different areas of production (Mbofung et al. 2002), although fruit measurements have been used to look at the frequency of fruits of different size classes and fruit shapes (Kengue et al. 2002b). This study has examined the tree-to-tree variation at a single site and reports 7-fold variation in mean fruit mass per tree, with continuous variation

between that of the smallest and largest fruits. However, trees with larger fruits have been reported from Cameroon (Waruhiu 1999). The evidence of continuous intraspecific variation found in the fruit and nut traits of *D. edulis* and other indigenous trees, such as *Irvingia gabonensis* (Atangana et al. 2001, 2002), probably represents the normal variability arising from out-breeding, and is in contrast with the suggestion of Okafor (1983), who postulated the existence of two varieties with different fruit sizes. This occurrence of continuous variation also questions the validity of categorising fruits into size classes for market studies (Youmbi et al. 1989; Ndoye et al. 1997; Silou et al. 2000), especially when fruit size is not necessarily related to other desirable fruit traits likely to affect market price (Leakey and Ladipo 1996; Waruhiu 1999; Leakey et al. 2002).

The variation in fruit flesh:kernel ratio reported here supports earlier evidence from Cameroon that a few trees produce kernel-less fruits (Kengue 2002) especially those trees that fruit late in the season (Kengue 1990). It is not known whether this incidence of fruits without seeds indicates that they are parthenocarpic or the result of poor pollination (Kengue 2002; Kengue et al. 2002b). Since the kernel is generally considered to be of little interest, seedless fruits could be a desirable market trait.

In 1999, the peak of the fruiting season was in the first week of July in Mgbuisi, while in the same year, further east in Cameroon the peak was in June in Chop Farm, near Limbe on the south coast, and in August in Elig Nkouma, north of Yaoundé (Waruhiu 1999), concurring with a reported phenological gradient associated with declining rainfall and increasing altitude (Kengue et al. 2002b) that ranges from May to October, with a few trees fruiting out of season. This range of fruiting times offers opportunities through cultivar development to greatly enhance the productive season, as has been demonstrated by the cultivar 'Nöel' in Cameroon which fruits at Christmas (Tchoundjeu personal communication).

The analysis of taste and oiliness in this study was less detailed than an organoleptic study done the following year in Cameroon (Kengni et al. 2001), although it covered a wider range of overall variability. It is clear from these studies, however, that a detailed study of tree-to-tree variation in taste and other qualitative traits is required, especially as cultivars are developed for their morphological attributes (Leakey et al. 2002). Such studies should be linked to others examining the tree-to-tree variation in nutritional qualities and to oil content to meet the food and industrial markets, respectively. Some studies on oil content and quality have identified variation between different fruit origins in Central Africa (Kalenda et al. 2002; Kapseu et al. 2002; Mbofung et al. 2002), but the likelihood is that an expanded study of tree-to-tree variation would find a considerable range about these means.

Two lines of study have suggested that local people in Cameroon, and to a lesser extent Nigeria, have already made a good start to the domestication of *D. edulis*. Regarding the history of domestication and planting, the first study has shown that the number of indigenous trees in the farmers of subsistence households is considerable and that *D. edulis* is the dominant species (Schreckenberg et al. 2002a). This concurs with the high level (99%) of *D. edulis* planting found in Mgbuisi.

There was however, a difference in the preferred landuse for planting as 57% of the trees in Mgbuisi were planted in homegardens compared with 10% in Cameroon (Waruhiu 1999), where most of the trees (67%) were found in cocoa farms. The other evidence for farmer domestication comes from the analysis of the frequency distributions of different fruit traits with reference to a hypothesis on the impact of domestication on fruit mass and flesh thickness (selected traits) relative to kernel mass (a trait of low, if any, selection importance). This analysis suggests that Cameroon farmers have made a 67% gain in fruit mass through truncated selection, while in Nigeria the population seemed to be virtually wild and unselected (Leakey et al. 2004).

A programme of Participatory Domestication in a number of villages is already underway for *D. edulis* in both Nigeria and Cameroon (Tchoundjeu et al. 2002). The results of this study indicate that there is considerable intraspecific variation in a number of fruit traits with importance for genetic selection and that through the development of cultivars from the best trees in a village population it should be possible to make substantial improvements to the quality of the marketable products. When implemented on a wider scale, it is foreseen that this approach to agroforestry should have positive benefits on the livelihoods of the people and on the sustainability of the farming systems (Leakey 2001).

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