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Farmers' Knowledge on Macadamia Genetic Diversity in Kenya as a Means for *in situ* Conservation

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ABSTRACT

Macadamia, a member of the family *Proteaceae*, is widely grown in Kenya as an alternative cash crop to tea and coffee, but varieties adapted to different agro-ecological zones are still lacking. Macadamia breeders require high genetic diversity to select and recombine favorable traits through cross-breeding and hence the need for *in situ* conservation of existing germplasm. A survey was done to assess the variability that exists in farmers' field and how well they can differentiate between different macadamia types and to locate valuable germplasm for further evaluation and conservation. A total of 185 farmers were interviewed using a semi-structured questionnaire and descriptive statistics was done using statistical package for social sciences (SPSS). The survey results indicated that only 10.3% of the respondents could differentiate Macadamia types, by species, among them only 2.8% could do so by varieties, indicating a limited knowledge on Macadamia morphology. Nut characteristics (97.3%) followed by leaf characteristics (88.0%) and yield (88.0%) were the morphological markers mostly used by farmers. Detailed morphological and molecular characterization of some selected promising accessions is ongoing. Hence, there is a need for farmers' training on morphological markers that could be used to select valuable Macadamia germplasm for conservation *in situ*.

Keywords: Agro-ecological zones, Farmers' knowledge, Genetic diversity, Germplasm, *in situ* conservation, Macadamia, Morphological markers, *Proteaceae*, Kenya.

INTRODUCTION

Genetic diversity forms the basis of agriculture and the usefulness of a genetically diverse gene pool in plant breeding cannot be overemphasized (Center for Genetic Resources, 2005). Moreover, genetic diversity within and among populations is the backbone of conservation of plant genetic resources for both present and future use (Quedraogo, 2001).

Two decades ago, scientists generally believed that the best way to conserve plant biodiversity was to collect samples from farmers fields and preserve them in national and international gene banks (Cromwell, 1999), a method usually referred to as *ex situ* conservation. Only a few countries especially in sub-Saharan Africa are able to construct and run expensive gene banks with refrigeration systems because of the unreliable supply coupled with the high cost of electricity. Moreover, some species are recalcitrant and cannot survive under such storage conditions (International Plant Genetic Resources Institute, 2001), while for vegetatively propagated species, seeds may not be viable or they may not represent the original accession due to heterozygosity in out-crossing species. Gene banks cannot also store the farmers' indigenous technical knowledge and experimentation that creates and maintains agricultural biodiversity. It may also be difficult for ordinary farmers to obtain seeds from gene bank collections due to the limited volumes of seeds that are stored, and also the distance between farmers and the gene banks (Cromwell, 1999). Therefore, many people are now promoting *in situ* or on-farm conservation.

In situ conservation is the continuous cultivation and management by farmers of a diverse set of populations of a crop in the environment where the crop has evolved (IPGRI, 2000). The International Convention on Biological Diversity (CBD) also indicated that *in situ* conservation of biological diversity is one of the most important issues for the conservation and utilization of biological resources (CBD, 1992). *In situ* approach allows for conservation of diversity at ecosystem, species and genetic levels and ensures that the ongoing processes of evolution and adaptation of crops to their environments are maintained (IPGRI, 2001).

Effective conservation requires a clear understanding of the extent and distribution of genetic diversity and how it is changing over time (IPGRI, 2001). Scientists have relatively little knowledge of the effect of farmers' practices on agricultural diversity and of whether there are any opportunities for making these practices more effective for agricultural biodiversity (Cromwell, 1999).

Macadamia (*Macadamia* spp.), an ever-green spreading semi-hard wood is a crop of economic importance in Kenya. It belongs to the *Proteaceae* family (McConachie, 1995) and the tree can grow up to 20 meters (Duke, 1983). The genus consists of ten species but only two; *M. integrifolia* and *M. tetraphylla* are cultivated. Growing countries include Australia,

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USA (Hawaii and California), South Africa, Kenya, Malawi, Zimbambwe, Guatemala, Brazil, Costa Rica and Fiji. The first introduction of Macadamia in Kenya was in 1946 when a farmer, Bob Harries brought six seeds of *Macadamia tetraphylla* from Australia and planted them in his farm in Thika in Central province. Later in 1964 more seeds of *M. integrifolia*, *M. tetraphylla* and hybrids between them were imported from Australia, Hawaii and California (Harries, 2004). These two seed sources were used to propagate seedlings that were distributed to farmers in Central and Eastern highlands of Kenya as an alternative cash crop to tea and coffee (Harries, 2004).

In 1968 scion material from superior *M. integrifolia* varieties were imported into the country from Hawaii including HAES 246, HAES 328, HAES 333, HAES 508, HAES 660 and HAES 669 and grafted seedlings were produced. The grafted Hawaiian varieties were planted in different agro-ecological zones. Selection breeding has been going on in Kenya since 1977, culminating in selection of promising varieties for commercial planting which are either *M. integrifolia* or (*M. integrifolia* x *M. tetraphylla*) hybrids. In 1986, a Macadamia improvement programme was initiated through a technical cooperation between the government of Kenya and the government of Japan for further selection of adaptable cultivars and appropriate propagation methods and agronomic packages. Since Macadamia is 75% out-crossing (Ondabu *et al*., 1996), grafting scions of the selected cultivars on to seedling rootstocks was recommended as means of propagating true-to-type clones for distribution to farmers.

For further improvement of Macadamia, breeders require high genetic diversity from which to select and recombine favorable traits through cross-breeding (McHargue, 1996) to develop varieties that are adapted to Kenyan conditions. However, most of the original introductions and subsequently selected superior quality trees are still in farmers' orchards. With selection of superior commercial varieties, farmers have continued to uproot or top-work old trees with the new selections. Hence, although population size of the Macadamias grown by farmers has been increasing, there is risk of losing trees with high genetic potential thus leading to loss of genetic diversity.

An understanding of the level and structure of genetic diversity allows identification of populations that are worthy of conservation because of their diversity or distinctiveness (Chamberlain, 2001). Conservation of clonally propagated plants demands more complex and expensive procedures. If they are to be maintained on-farm *in situ*, their existence is endangered by several factors, including the introduction of alternative improved varieties such as the case with Macadamia. Conservation efforts thus need to be based on solid knowledge of clonal diversity (Vicente *et al*., 2006). A challenge undertaken by the *in situ* conservation is to quantify the effects of social, cultural and economic factors on farmers' actions with regard to crop genetic diversity (De Carlo *et al*., 2000) as it is affected by various aspects of farmer decision making (Cromell, 1999). This study was done to assess farmers' knowledge and perceptions on different Macadamia genotypes and the parameters they used to differentiate between genotypes, gather baseline information on the economic importance of Macadamia, and locate valuable germplasm for further evaluation and conservation.

MATERIALS AND METHODS

A survey was done in macadamia growing areas of Kenya. These are Central province (Muranga, Nyeri, Kiambu and Kirinyaga districts), Eastern province (Embu, Meru and Machakos districts), Western province (Bungoma), Rift Valley province (Kisii and Koibatek) and Coast province (Taita Taveta district) covering 27 administrative divisions and 61 sub-locations.

In the field, structured interviews were conducted with individual farmers to fill out a semi-structured questionnaire. The survey questionnaire was developed and formulated in consultation and reference to other questionnaires previously developed for Macadamia and also according to guidelines as outlined by Malhotra (1996). It was validated after two pretests in two districts. The target population was purposively selected to include the farmers growing at least one tree of the original Macadamia introductions. Purposive sampling technique was also used to arrive at the various sampling units which were the households that were growing Macadamia. Sampling elements were either the male or female of the households growing Macadamia. A total of 185 respondents were interviewed from 11 districts which covered 27 divisions, 64 locations and 71 sub-locations.

Key data that was gathered included respondents general information such as gender, age, education and occupation, farm characteristics such as location, distance from all-weather roads and nearest source of agricultural information. Information on Macadamia included farmers' knowledge on the age and the number of the trees they had, knowledge about macadamia differences in terms of species and variety, and the morphological parameters they used to assess differences. Macadamia production and marketing information included the source of planting materials and their status (grafted or ungrafted), tree characteristics such as yield and status and their perceptions of their best and worst trees. Information on income was based on sales of the year 2005 including the channels they used to reach market. Other information included farmers' perceptions on whether or not to increase macadamia hectearage and other land use enterprises. After appropriate coding of the collected data, analysis consisted of descriptive statistics using SPSS Version 12.0 and Excel.

RESULTS

General socio-economic information of farmers growing Macadamia

The respondents consisted of 85.9% full-time farmers while 14.1% had other occupations besides farming mainly in formal employment and business. Most (87.7%) were within 5 kilometers of all-weather roads and 52.4% within 5 kilometers radius of an agricultural extension office. Male respondents accounted for 65.4% of the respondents while 34.6% were female and in all the districts more males were interviewed than females (Fig. 1). In the Western Kenya region no females were interviewed.

The respondents were from different age groups ranging from very young (21-30) to over 70 years. Majority (59.0%) of the respondents were and over 50 years of age (Fig. 2).

Majority of the respondents had some level of education with only 8.3% having no education at all. However, majority (55.3%) had primary education with the rest having attained secondary (22.7%) and tertiary (13.3%) education. The level of education was largely dependent on age of respondents (Chi- square -$\times^2$ for P = 0.05 and 15 degrees of freedom = 47.138). Respondents below 60 years had at least some level of education especially secondary and tertiary (university or other institutions of higher learning) as shown in Figure (3).

Macadamia production by farmers

The number of macadamia trees planted by the farmers ranged from 1-800 trees per farmer but the majority (84.1%) had 1-30 trees while 3.1% had 100 or more trees with only one farmer with a plantation of 800 trees. Among them, 48.1% of the farmers had grafted seedlings. All the grafted seedlings were planted after 1976 with most (67%) being planted after 1990. About 87% of the farmers also had un-grafted seedlings ranging from 1-600 trees per farmer with most (87.6%) being planted before 1990. The most important distribution sources for grafted seedlings included the coffee factories (40.5%), the Kenya Nut Company Nursery (16.7%), The Kenya Agricultural Research Institute (15.5%) and The Farmers Training Center at Wundanyi in Coast Province (11.9%) while for un-grafted seedlings, coffee factories accounted for 65.6% followed by other farmers/neighbours (10.8%) and the Bob Harries nursery (7.6%).

Among trees that farmers rated as their best, yield ranged between 7 and 400 kg, of which 64.5% yielded 50 Kg and above. These trees were either grafted (21.8%) or ungrafted (76.5%), and according to enumerators' assesment, 38.2% were *M. tetraphylla*, 40.6% were *M. integrifolia* and 21.2% hybrids. The poorly rated trees yield ranged between 2 and 80kg and were either grafted (19.2%) or ungrafted (79.1%) and most of them were *M. tetrapylla*.

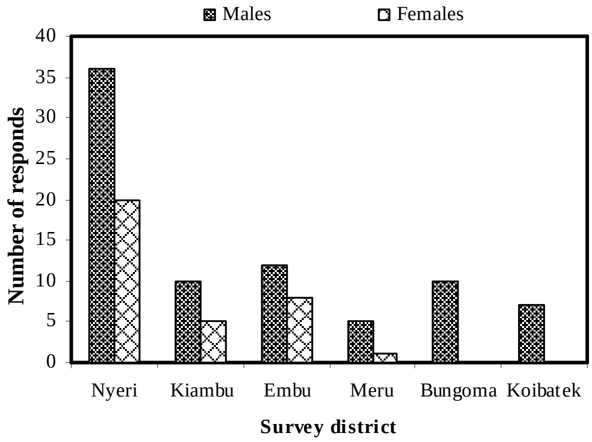

Figure (1): Number of male and female respondents in some districts.

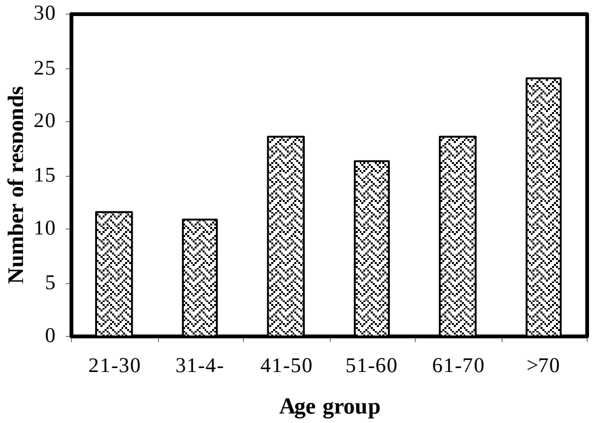

Figure (2): Percentage of respondents interviewed in the different age groups.

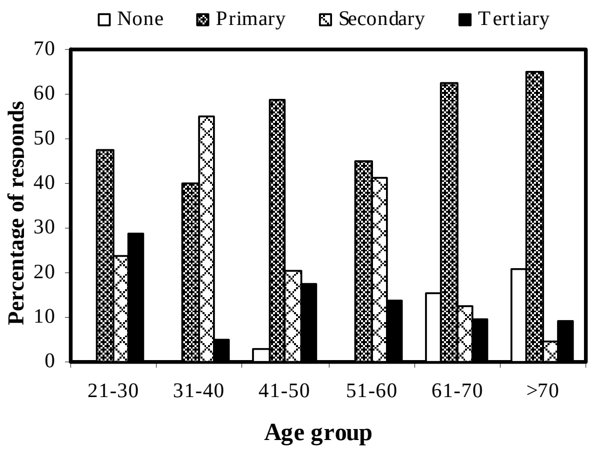

Figure (3): Percentage of respondents with different levels of education for each age group

Macadamia was ranked the 2nd as the most important cash crop after coffee followed by Avocado and Banana and 68.9% of the respondents intended to increase their Macadamia acearage because of the good returns they were getting from selling it. Marketing channels included either 'farmer directly to processor' (49.7%) or 'farmer to processor through agent/broker' (46.9%). Among the most important benefits from Macadamia proceeds were; paying school fees (40.6%), buying food (32.6%) and purchase of farm inputs (10.9%). About 15.8% wished to increase acreage on Macadamia but were limited by the small land size, lack of money to buy seedlings, the high cost of seedlings and farmer's age. Grafted seedlings were more preferred (91.9) than un-grafted ones (2.4%) for new plantings. Among the most important constraints in macadamia growing, pests and diseases, and poor prices by brokers were rated highest.

Differentiating between Macadamia genotypes

It was noted that farmers used some parameters, though not to precise detail, to differentiate between the Macadamia species and varieties. Some of these parameters were similar to those used by researchers for selection for agronomic traits (Table 1).

Table (1): Morphological markers used by both researchers and farmers for differentiation and selection of Macadamia.

Morphological marker	Used by researcher	Used by farmer
Tree characteristics		
Tree shape/habbit	√	√ (Farmers used either upright of spreading growth habits)
Tree yield	√	√
Leaf characteristics		
Number of spines per leaf	√	√ (farmers only differentiated types by whether leaves were serrated or not and not the actual number of serrations)
Leaf length	√	√
Leaf width	√	√
Leaf length/width ratio	√	
Leaf color	√	√
Petiole length	√	√ (farmers used either sessile or petiolated summarized as leaf attachment)
Color of new shoots	√	√ (used by one farmer)
Nut characteristics		
Nut shape	√	√
Shell surface texture	√	√
Shell color		√
In-shell nut diameter	√	
In-shell nut weight	√	
Shell thickness	√	
Twin nut ratio	√	
Flower characteristics		
Flowering habit	√	√
Flower color/time of bloom	√	
Kernel characteristics		
Kernel shape	√	
Kernel color	√	
Kernel recovery ratio	√	
Kernel diameter	√	
Kernel weight	√	
First grade ratio	√	

Using these markers, only 10.3% of the respondents could differentiate the Macadamia species they had planted. Some could differentiate all the three including *M. integrifolia*, *M. tetraphylla* and the hybrids while others could differentiate either one or two of them as shown in Figure (4). Among those who could differentiate between species only 2.8% could differentiate between varieties which included KMB-3 and MRG-20.

The most important markers that were used by farmers to differentiate the genotypes were nut characteristics, followed by leaf characteristics; yield and growth habit (Fig. 5). In-shell nut characteristics included size (plate 1A), fruit surface texture and husk color (plate 1B). Leaf characteristics included length and width (plate 1C), marginal serrations (plate 1D) and leaf attachment (plates 1 E & F) and color. Yield was rated by the number of kilograms harvested per tree per season and tree growth habit was assessed as upright or spreading. Flower characteristics were based on color or length of racemes while new flush was basically on color of sprouting shoots (plates 7 and 8).

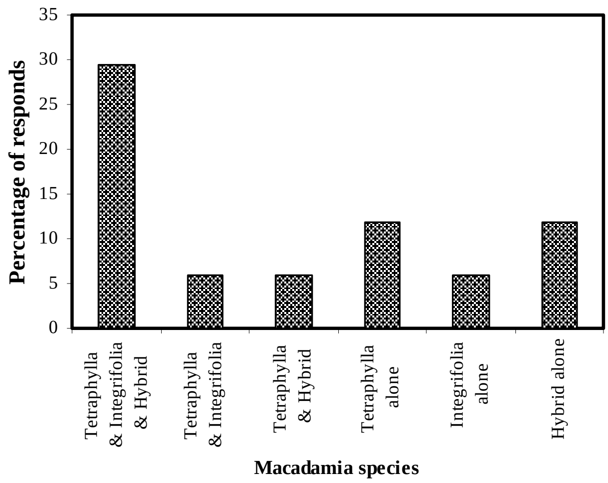

Figure (4): Percentage of respondents who could differentiate between species.

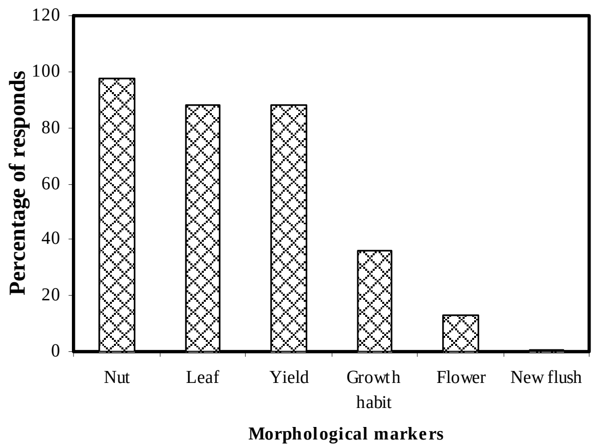

Figure (5): Percentage of respondents that used different morphological markers to differentiate Macadamia.

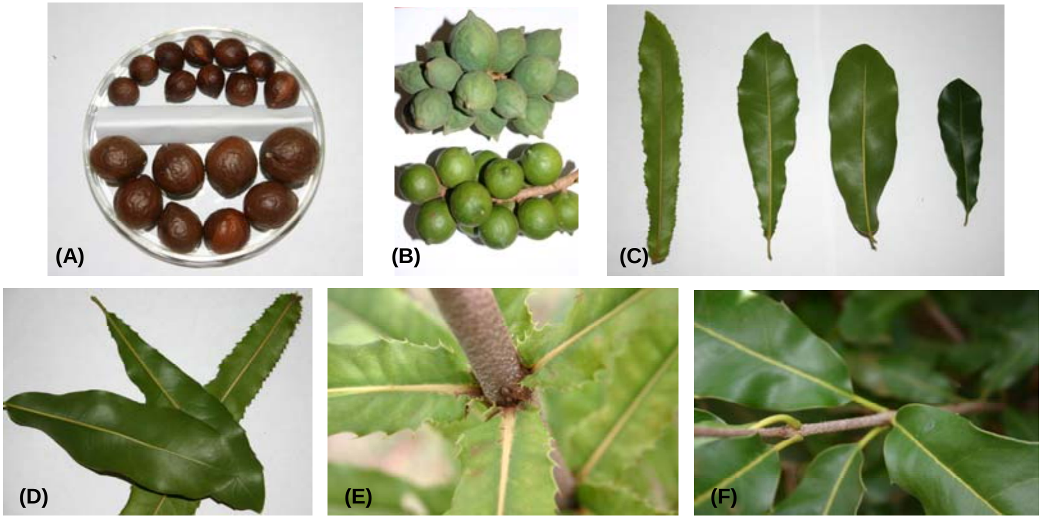

Plate (1): Morphological Diversity: **(A)** Variability in in-shell nut size, **(B)** Difference in fruits surface texture and color, **(C)** Differences in leaf length and width, **(D)** Variability in leaf marginal serrations, **(E)** Sessile leaf attachment, and **(F)** Petiolate leaf attachment.

Table (2): Local names given by the respondents in different regions.

Region	Local names	Interpretations
Central	*Makandamia, Mikandamia, Ngandania Ngimbo, Nguta, Mbegu cia maguta*	The first three names are the vernacular forms of the name Macadamia. The crop was introduced with the notion that the kernels would be used to make a cooking fat brand Kimbo® hence the vernacular name *ngimbo*, nguta meaning fat and *mbegu cia maguta* (seeds of fat)
Eastern	*Makandamia, Mikandamia, Ngandania Nkandania*	
Western & Coast	*Makandamia*	

Among the nut parameters, size was most prevalently used while leaf marginal serrations were mostly used among leaf characteristics and flower color among flower characteristics. Farmers also assigned local names to Macadamia which differed slightly according to ethnicity (Table 2).

DISCUSSION

In this study on genetic diversity of Macadamia in Kenya, males accounted for 65.4% of the respondents while 34.6% were females indicating the important role, responsibility and decision-making of male farmers in Macadamia production and conservation. Although most of the respondents located within 5 kilometers to all-weather roads and Agricultural Extension office, this did not seem to influence the number and source of Macadamia trees they had planted, marketing or even their ability to differentiate between the types of Macadamia.

Most of the interviewed farmers were over 50 years of age. This is explained by the fact that the old trees had been planted in the 60s. These farmers are expected to have a wealth of indigenous knowledge about the trees they have that could be useful in conservation decision-making. Though the level of education of the respondents was largely dependent on age, with the younger farmers being more educated than the older farmers, it did not influence the ability of the younger farmers to differentiate the genotypes. On the contrary, the level of knowledge of younger farmers (21-40 years) of 2.2% matched that of farmers over 70 years, probably due to the accumulated indigenous technical knowledge over the years.

Majority of the farmers that were interviewed (84.1%) had 1-30 trees with only 3.1% having big plantations of 100 trees and above. This is probably due to the fragmented land parcels owned by small-scale farmers. This may explain the low ability of the farmers to differentiate between species and varieties due to low variability that may exist within farms. The most important distribution sources for grafted seedlings included the coffee factories (40.5%), (which was the main distribution centers for agricultural inputs in the 70s due to the presence of a cooperative union), the Kenya Nut Company Nursery (the only private nursery propagating Macadamia at that time), and the Kenya Agricultural Research Institute (15.5%), (which initiated the Macadamia improvement programme and propagated limited numbers of grafted seedlings).

Among trees that farmers rated as their best, yield ranged between 7 and 400 kg, indicating a high variability of this marker. Of these, 64.5% yielded 50 Kg and above which is regarded as economically adequate (Ondabu *et al*., 1996). These trees were either grafted (21.8%) or un-grafted (76.5%). The high percentage of un-grafted trees (hence original seedling trees) indicate untapped genetic potential. According to enumerators' assessment, 38.2% were *M. tetraphylla*, 40.6% were *M. integrifolia* and 21.2% hybrids also indicating untapped genetic potential within the three Macadamia species. The yield of the poorly-rated trees ranged between 2 and 80 kg and were either grafted (19.2%) or un-grafted (79.1%) and most of them (69.4%) were *M. tetraphylla* according to enumerators' assessment also indicating genetic diversity among the two species.

Farmers used a number of morphological markers (yield, nut, leaf and flower characteristics) that were also used by researchers for selection of superior materials, indicating a level of reliability of such markers. Moreover, these markers are highly heritable further increasing reliability. However, using these markers, only 10.3% of the respondents could differentiate the Macadamia species they had planted. Some could differentiate all the three including *M. integrifolia*, *M. tetraphylla* and the hybrid, while others could differentiate either one or two of them. Among those who could differentiate between species only 2.8% could differentiate between varieties which included KMB-3 and MRG-20. This percentage is quite low despite the number of years the farmers had farmed the crop (82.2% of the farmers had planted them between 1960 and 1990) indicating a limited knowledge on Macadamia. This is further supported by the fact that farmers had local names only of the crop itself (which only differed slightly with locations due ethnic differences) and not the individual varieties indicating that they had not mastered differences among the genotypes well enough to assign different names. Although the farmers had a wealth of knowledge about the individual trees on their farms including source of planting material, age, yield and other tree characteristics, there is need to educate farmers on differentiation methods both for species and varieties if they are to be the custodians of the germplasm conserved on-farm. Bearing in mind that Macadamia was ranked second most important cash crop, and farmers were willing to increase hectarage on Macadamia suggest a level of popularity of the crop and hence greater expectation that farmers would be willing to learn characterization techniques for conservation purposes. There is need also to validate farmers' knowledge through empirical measurements of morphological characters as a way of arriving at an understanding of farmers' perceptions of the traits that are used to recognize and distinguish between varieties.

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