Comparative Analysis of Selected Factors Affecting Fruit Phenotype and Yield of *Sclerocarya birrea* in Tanzania

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Abstract

Knowledge of fruit physical properties and yield is imperative for trees with commercial domestication prospects like Sclerocarya birrea. This study assessed individual fruit weight and diameter as well as yield per tree for the three subspecies of Sclerocarya from two types of land use (farmland and wild). Ten female trees were randomly selected from on-farm and wild sites for each subspecies. From each tree, diameter and weight of 50 randomly selected fruits were measured during a peak fruiting while all fruits per tree were counted and recorded throughout the entire fruiting season for two consecutive years. Results showed that subspecies multifoliolata had significantly heavier fruits and more yield than subspecies birrea and caffra (p < 0.001) Fruits from subspecies birrea were significantly larger than those from the other two subspecies (p < 0.001).Trees from the wild population yielded more fruits that were also heavier that those from on-farm but the difference was only significant for subspecies multifoliolata (p < 0.001) Fruits from on-farm population of subspecies birrea were significantly the largest in diameter (p < 0.001). There was a strong relationship between fruit properties with crown diameter &dbh; and between yield and crown diameter while a decline in rainfall reduced fruit yield across the species and land use. Our results indicate that fruit physical properties and yield have allometric relationship with tree size structure and they vary with rainfall, type of subspecies and probably pollination intensity but not with farmers' selection pressure and intervention.

Key Words: *Sclerocarya*, Yield, Land-use, Tanzania

Introduction

Sclerocarya birrea is a prime species for commercialisation in sub-Sahara Africa (Teklehaimanot, 2005; 2008), and also outside of Africa (Hillman *et al.,* 2008). Good yield and appearance are among important factors in fruit trade to ensure supply to markets and fulfil consumers' desire for properties such as size, weight and texture (Seymour *et al.,* 2002). Various factors are said to affect fruit properties and yield performance of trees in dry areas. Some of the factors are soil water and nutrient availability, herbivory, competition and fire (Bofa, 1999; Murray and Gill, 2001; Wolfe and Denton, 2001); pollination intensity and degree of isolation among trees (Waites and Ågren, 2004; Kunin, 1993; Ghazoul 2005; Elliot and Irwin, 2009); fruit biophysiological properties (Lawes *et al.,* 1990); genetic make-up (Tanksley, 2004); weather fluctuation (Ågren *et al.,* 2008b); and domesticated vis-à-vis wild condition (Bofa, 1999; Shackleton *et al.,* 2003; Tanksley, 2004; Leakey *et al.,* 2005; Emanuel *et al.,* 2005; Hillman *et al.,* 2008). Also within trees, yield and properties of fruits can be affected by tree features such as height and DBH (Peters *et al.,* 1988; Leishman *et al.,* 1995, Wolfe and Denton, 2001; Shackleton *et al.,* 2003). Big trees provide good mechanical strength to support heavy fruits (Wolfe and Denton, 2001). Also a study by Leakey *et al.* (2005) found the weight of subspecies *caffra* fruits to be largely contributed by the flesh rather than kernel.

Despite the mounting interest in commercialisation of *Sclerocarya birrea*, Shackleton, (2003) warns that the data on rates of fruit production and fruit properties remains scanty; much of it being anecdotal. Many are informal observations or records of one or two accessible trees, and do not represent a good sample. Quin (1959) reported a yield between 21,667 and 91,272 fruits from four trees in South Africa with an average weight of 550 kg per tree. In comparison, Shone (1979) reported on one tree from the same area as producing 9,601 fruits or 270 kg. In the drier areas of North western South Africa, and Botswana, Peters (1988) reported a yield of 2,000 fruits (one tree) and 36,550 fruits (11 trees) or 550 kg per tree. Lewis (1987) measured fruit yield over a single month from 111 trees in the Luangwa valley (Zambia), and reported a total 226,000 fruits, or just over 2,000 fruits per tree. A figure of approximately 70,000 fruits per tree, or 570 kg is provided by Roodt (1988). Walker (1989) reported a yield of 6,900 to 12,100 fruits per year from a single tree over five years from the Matobos in Zimbabwe. Holtzhausen *et al.* (1990) provide a figure of an average of one ton of fruit per tree. The ratio of number of fruits to mass of fruits differs widely between these reports, indicating either extremely wide differences in the mass of individual fruits, or relatively crude extrapolations of mass (Shackleton *et al.,* 2003).

However, the work by Lewis (1987); Shackleton *et al.* (2003); McHardy (2003) and Leakey *et al.* (2005) present clear scientific methodologies. Their work on subspecies caffra in South Africa and Namibia reports more yield and heavy fruits from on farm than wild environment. They attribute the findings to the influence of farmers' selection pressure which is based on preference for high productivity traits. Their findings are in line with Tanksley, (2004) who says that fruit from domesticated species often have been tremendously enlarged over that normally found in the progenitor wild species

Since the three subspecies of Sclerocarya birrea occur together in Tanzania, this study had an ideal opportunity for a concurrent measuring, comparison and contrasting the fruit properties and yield from field materials. The study collected field data on fruit yield and assessed fruit properties in relation to the subspecies, land use, tree sizes and seasonal weather variation. The information contributes to the basic understanding as well as comparing and contrasting the three the subspecies. Future domestication plans will benefit from this information as basic guidance for silvilculture, breeding and postharvest processes including marketing.

Methodology

Study Area

Three sites namely Holili in Rombo district, Kilimanjaro region, Kiegeya in Morogoro urban district, Morogoro region and Malinzanga in Iringa rural district, Iringa region were used. The three sites are at least 400 km apart and at most 1100km from each other by road. The sites were selected in such a way that each covered one of the three subspecies of *S. birrea. S. birrea* subspecies caffra was found in the northern part of the country (Holili); *S. birrea* subspecies *Birrea* in the east-central region of the country (Kiegeya) and *S. birrea* subspecies *multifoliolata* in the southern region of the country (Malinzanga).

Holili lies at latitudes 3°21'3.6"S and longitude 37°36' 43"E. The mean rainfall ranges from 500mm in the lowlands to over 2000mm in areas over 1600 m.a.s.l. Mean temperature is 21.7°C but ranges from 10.2°C to 43.7°C. The hot season lasts between October and March. Holili (part of the Taita-Taveta vegetation) is covered by mainly arid and semi-arid land vegetation, grassland, woodlands and shrub lands with savanna species (*Acacia* sp, *Commiphora* sp.). Where the groundwater table is high, riverine/ permanent wetland vegetation types occur with *Acacia xanthophloea*, *Miliciaexcelsa, Albizia* sp, *Ficus* sp. etc. (Krhoda, 1998).

Malinzanga village is located near Ruaha National Park in Iringa region in the Southern highlands zone of Tanzania. The village is located at latitude 6°41'24"S and longitude 37°44'53"E. It receives a mean annual rainfall of 650mm with mean temperatures ranging from 8°C to 30°C. May to September is the driest period in the area. The vegetation of Malinzanga site is dominated by Acacia woodland/bushland, *Acacia/Commiphora* bushland, Brachystegia woodland, *Commiphora – Combretum* bushland, *Acacia tortilis* thorn scrub, and Acacia induced woodland modified by human activities, *Hyphaene* and *Acacia tortilis* riparian vegetation, Combretum woodland and riparian *Acacia-Ficus* vegetation (MBOMIPA 2006)

Kiegeya is a village located approximately 20 km north of Morogoro municipality. The village is located at latitude 7°35’45’’S and longitude 34°59’20’’E. The mean annual rainfall ranges from 600mm in the lowlands to 1200mm in the highlands. Mean temperatures vary greatly with altitude ranging from 17.5^{o}C in the high elevations to 31.3^{o}C in river valleys. Kiegeya has fairly open woodland, though considerable parts of it, particularly on ridges and in valleys, would be better classified as wooded grassland. *Brachystegia, Isoberlinia* and elements of the miombo are present, but admixed with species more characteristic of Gillman’s bushland and thicket. Many of the trees are leafless during the dry season but other species lose their leaves, until the flush begins, and the thickets contain a number of evergreen elements. Fires burn the grasses, usually in June, July and August, but these fires, being early, tend to be very patchy, with many areas left unburnt (Welch, 1960).

Materials and methods

Dendrometric measurements

For each tree included, dbh, height to the top of crown and height to the first branch were measured. Crown diameter was derived by measuring two diameters perpendicular to each other (at 90^{o}) through the crown vertical projection. The mean of the two crown measurements was then used as crown diameter value for each tree.

Fruit phenotypic characterisation

Ten female trees from each land use type i.e. on farm vis a vis wild; for each subspecies were used to assess fruit phenotypic characteristics and yield per tree. From each of the ten female trees, 50 fruits were picked during peak fruit dropping for assessment of diameter and weight. Fallen fruits were usually plentiful beneath the tree crown, and so ripe, unblemished fruits were collected at random, sampling from 5 quadrants (10 fruits per quadrant), following the procedures described by Leakey *et al.* (2000) and used by Shackleton *et al.* (2003). Fruits from each tree were separately bagged and labelled. As soon as possible; usually the same day, the fresh fruits were weighed using an electronic balance. In the same period diameter of the fruits were measured in centimetres using Veneer callipers. With the exception of few, the *Sclerocarya* fruits are not perfectly roundish, so 3 diameters were taken for each fruit and an average was taken to be the mean diameter value.

Fruit yield

During fruit fall; fruits were picked up and removed from under the ten trees and then counted at irregular intervals of days depending on frequency of fall until the end of fruit fall. Data on fruit yield was collected for two seasons, 2007/08 and 2008/09. Although randomly selected, it was ensured that female trees assessed were at least 30 m away from the nearest female neighbour to avoid mixing of fruits.

Data analysis

Data on weight, diameter of individual fruits and number of fruits per tree was analysed to obtain range, mean and standard error of mean using Minitab program which in turn was used to develop bar graphs using Excel program. Number of fruits per tree was also used to estimate fruit weight yield per tree by multiplying with the mean weight of individual fruits. Since fruit weight was not assessed in the 2008/09 season, fruit yield per tree for that year was estimated using the mean obtained in the previous season. One way ANOVA was done to assess the differences between means by subspecies while student t-test was used to assess the differences in means by land use (on farm and wild) conditions. Paired t-tests were used to compare means of yield between the two seasons, 2007/08 and 2008/09. Regression and/or correlation analysis was done to establish the relationship between the fruit properties and yield with tree size parameters (crown diameter, tree height and diameter at breast height).

Results

Weather

Data on monthly rainfall and mean monthly temperature for the three sites in two years were obtained from a nearest weather station to each site. The weather data for the three study sites is shown in Figure 1. For Malinzanga site where subspecies *multifoliolata* was assessed it shows that during the two years, the pattern was similar where the months of May to September were the coldest with temperatures below 20^{o}C. In terms of rainfall, the months of January and February 2008 received more rainfall, almost twice as much; than the rainfall received in the same months in 2009.

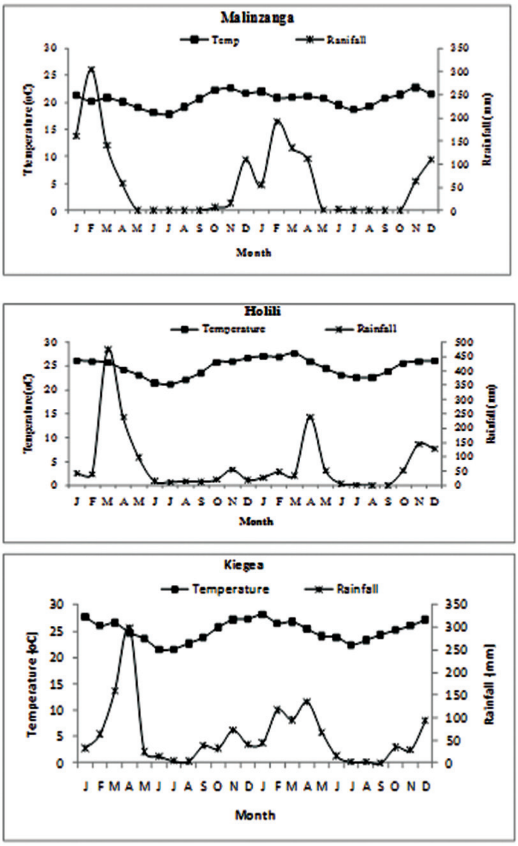

Figure 1: Mean monthly temperature (^{o}C) and monthly total rainfall (mm) from January 2008 to December 2009 for the three study sites

The wet months were from November to April with the months of May to October receiving zero rainfall. The months with no rainfall were also the coldest months. For Holili (subspecies *birrea*) and Kiegea (subspecies *caffra*) the rainfall and temperature patterns were similar. Temperatures were in most of the months above 24^{o}C. In the two sites almost each of the dry months in 2008 recorded some amount of rainfall. The dry months were May to October in the two sites but Holili had a drier spell between January and February compared to Kiegea. In all sites there was a decline in rainfall in 2009, especially in the peak months of March and April.

Fruit phenotypic characteristics

Fruit weight

Results showed that fruits produced by subspecies *multifoliolata* were the heaviest with mean weight for an individual fruit of 28.941 ± 0.269 g. Mean weight for individual fruits of subspecies *birrea* and *caffra* was 25.71 ± 0.23 g and 24.01 ± 0.22 g respectively (figure 2). ANOVA showed that the differences between the means by subspecies was significant at $p < 0.001$ ($F = 107.60$; $\alpha = 0.001$; $DF = 2$).

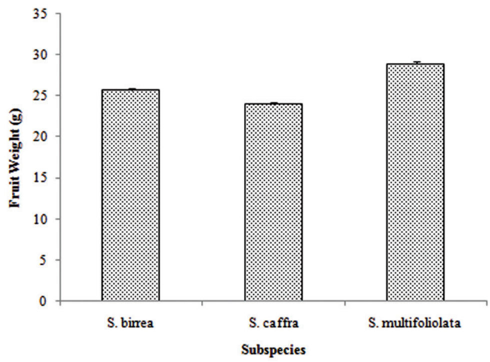

Figure 2: Mean and error bars for fruit weight for the subspecies of *Sclerocarya birrea*

The results in Figure 3 shows the mean weight and standard error of the mean for on farm and wild fruits of the three subspecies. Mean weight for on farm fruits of subspecies *multifoliolata* was 27.77 ± 0.61 g (range = 11.34 - 41.13 g) while those from the wild population had a mean weight of 30.11 ± 0.42 g (range = 12.80 - 47.70 g). Independent t-test showed that fruits from wild trees were significantly heavier than those from the on farm environment ($p < 0.001$, $t = 4.43$; $DF = 498$; 95% CI = -3.373 to -1.300). There was a slight difference between on farm and wild fruit weight for subspecies caffra. Figure 3 shows that mean weight for on farm fruits was 24.03 ± 0.33 g (range = 11.70 – 36.42 g) and mean weight for wild population fruits was 24.00 ± 0.29 g (range = 12.67 – 35.00 g). Independent t-test showed that the difference in the means was not significant ($t = 0.07$; $\alpha = 0.95$, DF = 498; 95% CI = -0.84 to 0.9) for subspecies *caffra*.

Mean weight of fruits of subspecies *birrea* indicates that fruits from on farm trees were heavier than fruits from trees in the wild environment (figure 3). Mean weight of fruits from on farm trees was 26.03 ± 0.33 (range = 14. 69 - 38.85 g) and for fruits from the wild population was 25.39 ± 0.24 g (range = 13.71 - 38.13 g. Independent t-test revealed no significant difference in weight between on farm and wild fruits (t = 1.37 α = 0.170 DF = 498; 95% CI = -0.274 to 1.546).

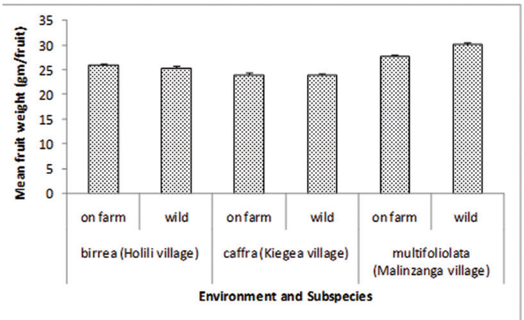

Figure 3: Mean fruit weight and standard error for *Sclerocarya birrea* by subspecies and environment

Fruit diameter

Mean fruit diameter for subspecies *caffra* was the smallest (2.886 ± 0.013 cm) compared to mean fruit diameter for *multifoliolata* (3.19647 ± 0.017 cm) and birrea (3.208 ± 0.017 cm) (figure 4). Analysis of the means using one way ANOVA showed the differences were significant at $p < 0.001$ (F = 134.33; DF = 2; α = 0.001).

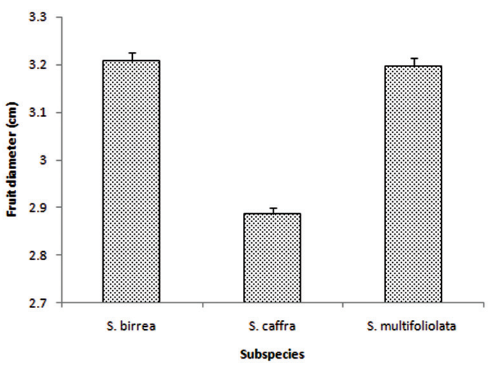

Figure 4: Mean and error bars of fruit diameter for the subspecies of *Sclerocarya birrea*

Mean diameter and error bars for on farm and wild populations are presented in Figure 5. For subspecies *multifoliolata* mean diameter of fruits from on farm population was 3.12 ± 0.03 cm (range = 2.33 - 4.20 cm) and that of fruits from the wild population was 3.27 ± 0.02 cm (range = 2.50 - 3.93 cm). Independent t-test showed that for subspecies *multifoliolata*, fruits from the on farm population were significantly smaller ($p \leq 0.001$) than those from trees in the wild environment (t = -4.46; α = 0.001; DF = 498; 95% CI = -0.2169 to -0.0842.).

For subspecies *caffra* mean diameter of fruits from on farm population was 2.85 ± 0.02 cm (range = 2.26 - 3.47 cm) while mean diameter for fruits from trees in the wild population was 2.92 ± 0.02 cm (range = 2.17 - 3.52 cm). Independent t-test showed that the difference between the means was significant at $p < 0.05$ (t = -2.51; α = 0.012; DF = 498; 95% CI = -0.1117 to -0.0136), with wild fruits bigger than on farm fruits. For subspecies *birrea* mean fruit diameter for fruits from on farm trees was 3.29 ± 0.03 (range = 2.50 - 4.17 cm) while the mean diameter of fruits from wild trees was 3.12 ± 0.02 cm (range = 2.63 - 3.90 cm). Independent t-test showed that the differences in the means was significant ($p \leq 0.001$) with wild fruits smaller than on farm fruits (t = 5.20; α = 0.001; DF = 498; 95% CI = 0.1079 to 0.2388).

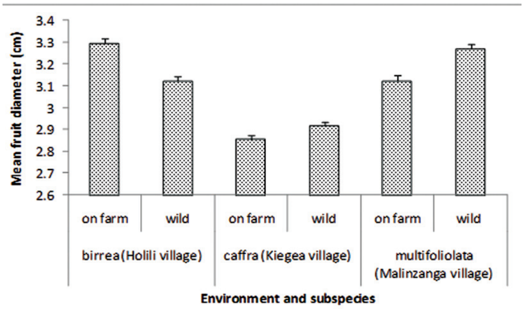

Figure 5: Mean fruit diameter and standard error (cm) of *Sclerocarya birrea* by subspecies and environment

Fruit yield

In general it was found that there were more fruits and weight (kg) per tree in the wild than on farm population (Table 1). The table also shows that number and weight of fruits was less in 2009 (when there was less rainfall – figure 1) than in 2008. Mean and range of fruit yield per tree in the wild was 5924 ± 742 fruits/tree; range = 673 – 13046 fruits/trees; while mean and range of fruits/trees for on farm trees was 4395 ± 609 fruits/tree; range = 528 - 11891 fruits/tree for year 2008. In year 2009 mean and range of fruits/tree was 3660 ± 503 fruits/tree; range = 424 - 9384 fruits/tree for trees in the wild and 2733 ± 402 fruits/tree; range = 229 – 8435 fruits/tree for trees on farms.

Mean and range of fruit weight produced by individual trees in the 2008 season was 163.48 ± 22.02 kg; range = 16.15 - 392.79kg and 116.46 ± 16.73 kg; range = 13.74 - 330.22 kg for wild and on farm populations respectively. For the 2009 season the mean and range of weight was 100.72 ± 14.88; range = 10.17 - 282.54 kg and 72.14 ± 10.87 kg; range = 5.50 - 219.55kg for wild and on farm populations respectively.

Using analysis of variance (one way ANOVA) we found a significant difference ($p < 0.01$) in fruit yield per tree between the three subspecies ($F = 10.68$; $\alpha = 0.001$; $DF = 2$) with subspecies multifoliolata and caffra having the highest and least number and weight of fruits per tree respectively. Independent t test (two tailed) showed that the only significant difference between the means was in terms of fruit weight in year 2008 ($p < 0.1$; $t = -1.70$) where wild populations had more fruit weight/tree than on farm populationi.e comparison between land use. However t-test (paired) showed that both number and weight of fruits per tree for year 2008 were significantly higher ($p< 0.001$) than the 2009 yield i.e comparison between seasons. Table 1:

Yield for subspecies caffra

For subspecies *caffra* the number and weight of fruits per tree for wild population was higher than that for on farm population and number of fruits and weight per tree was more in 2008 than in 2009 as shown in figures 6 and 7. The mean and range of number of fruits per tree for the 2008 season was 2173 ± 357 fruits/tree (range = 724 - 3958 fruits/tree) and 3021 ± 814 fruits/tree (range = 673 - 8391 fruits/tree) for the on farm and wild populations respectively. For the 2009 season fruit production declined to 1309 ± 199 fruits/tree (range = 229 - 2254 fruits/tree) and 2029 ± 519 fruits/tree (range = 424 - 5130 fruits/tree) for the on farm and wild populations respectively.

Mean and range of weight of fruits in 2008 season was 52.21 ± 8.57 kg/tree (range = 17.40 - 95.10 kg/tree) and 72.49 ± 19.54 kg/tree (range = 16.15 - 201.36 kg/tree) for on farm and wild populations respectively. For 2009 season the mean weight declined to 31.46 ± 4.78 kg/tree (range = 5.50 - 54.16 kg/tree) and 48.68 ± 12.46 kg/tree (range = 10.17 - 123.11 kg/tree) for on farm and wild populations respectively. Using independent t-test it was found that the differences in number and weight of fruits per tree were not significant between the different land use settings. Paired t-test showed that number and weight of fruits per tree was significantly different between the two seasons ($p < 0.001$)

Yield for subspecies *multifoliolata*

Fruit production in terms of number and weight per tree for subspecies *multifoliolata* is also presented in figure 6 and 7. In the 2008 season mean number of fruit produced was 6026 ± 1119 fruits/tree (range = 1296 - 11891 fruits/tree) and

Table 1: Mean, standard error and range of fruit counts and weight per tree for a combined data for all subspecies of *Sclerocarya birrea*

Variable	Environment	Mean + SE by year		Range by year	
		2007/08	2008/09	2007/08	2008/09
Fruits per tree (counts)	On farm	4395 ± 609	2733 ± 402	528 - 11891	229 - 8435
	Wild	5924 ± 742	3660 ± 503	673 - 13046	424 - 9384
Fruit weight per tree (kg)	On farm	116.46 ± 16.73	72.14 ± 10.87	13.74 - 330.22	5.50 - 219.55
	Wild	163.48 ± 22.02	100.72 ± 14.88	16.15 - 392.79	10.17 - 282.54

9192 ± 1030 fruits/tree (range = 4237 - 13046 fruits/tree) for on farm and wild populations respectively. In the 2009 season there were 3226 ± 693 fruits/tree (range = 815 - 5608 fruits/tree) and 5551 ± 915 fruits/tree (range = 1346 - 9384 fruits/tree) in on farm and wild populations respectively.

Fruit weight was 167.36 ± 31.08 kg/tree (range = 35.99 - 330.22 kg/tree) and 276.75 ± 31.00 kg/tree (range 127.57 - 392.79 kg/tree) for on farm and wild populations respectively in the 2008 season while in the 2009 season fruit weight was 89.58 ± 19.25 kg/tree (range = 22.63 - 155.74 kg/tree) and 167.14 ± 27.54 kg/tree (range = 40.53 - 282.54 kg/tree) for on farm and wild populations respectively.Therefore the mean number and weight of fruits per tree for subspecies *multifoliolata* was high for wild populations than on farm populations and was also high for the 2008 season than the 2009 season. Independent t -test showed a significant difference in the means for yield and weight of fruits per tree between the land use setting ($p< 0.1$ for yield and $p < 0.05$ for weight). Paired t-test showed a significant difference ($p < 0.001$) in the means for yield and weight of fruits per tree between 2008 and 2009 seasons.

Yield for subspecies *birrea*

Fruit production data in terms of number and weight per tree for subspecies *birrea* is presented in figure 6 and 7; showing more fruits and weight from the wild than on farm populations and season 2008 than season 2009. In the 2008 season mean number of fruit production was 4987 ± 1152 fruits/tree (range = 528 - 10218 fruits/tree) and 5562 ± 1210 fruits/tree (range = 815 - 11619 fruits/tree) for on farm and wild populations respectively. In the 2009 season there were 3401 ± 799 fruits/tree (range = 741 - 8968 fruits/tree) and 3664 ± 834 fruits/tree (range = 492 - 8435 fruits/tree) in on farm and wild populations respectively.

Fruit weight was 129.80 ± 29.97 kg/tree (range = 13.74 - 265.96 kg/tree) and 141.22 ± 30.73 kg/tree (range 20.69 - 295.03 kg/tree) for on farm and wild populations respectively in the 2008 season while in the 2009 season fruit weight was 95.38 ± 21.70 kg/tree (range = 12.81 - 219.55 kg/tree) and 86.34 ± 20.29 kg/tree (range = 18.82 – 227.71 kg/tree) for on farm and wild populations respectively. Independent t-test revealed that the mean values for yield and weight per tree for subspecies *birrea* were not significantly different between the two environments. But paired t-test showed a significant difference ($p < 0.01$) in mean values of yield and weight per tree between 2008 and 2009 seasons.

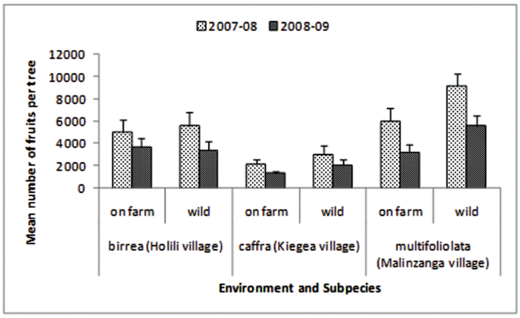

Figure 6: Mean and standard error of number of fruits per tree for *Sclerocarya birrea* by subspecies, environment and year

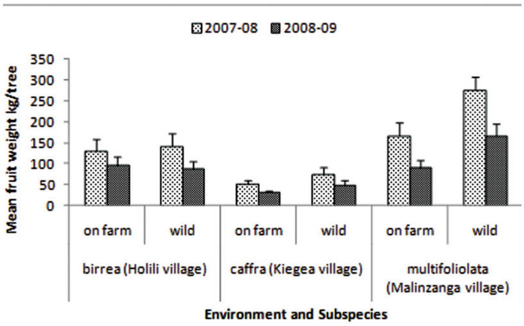

Figure 7: Mean and standard error of weight of fruits per tree for *Sclerocarya birrea* by subspecies, environment and year

Relationship between fruit yield and allometric properties

Fruit yield was related to crown diameter, tree height and diameter at breast height (DBH) and results are shown in figure 8. Crown diameter showed the strongest positive relationship with number of fruits produced; $R^2 = 0.72$ for the 2008 season, and $R^2 = 0.62$ for the 2009 season. Tree height and DBH also showed positive relationship with fruit yield per tree although this was weak. Regression analysis gave the following relationship between fruit yield and the various fruit parameters:

$$Y = 33x + 737w - 14.8z - 2211$$

Where; Y = Fruit yield; x = tree height; w = crown diameter; z = tree DBH

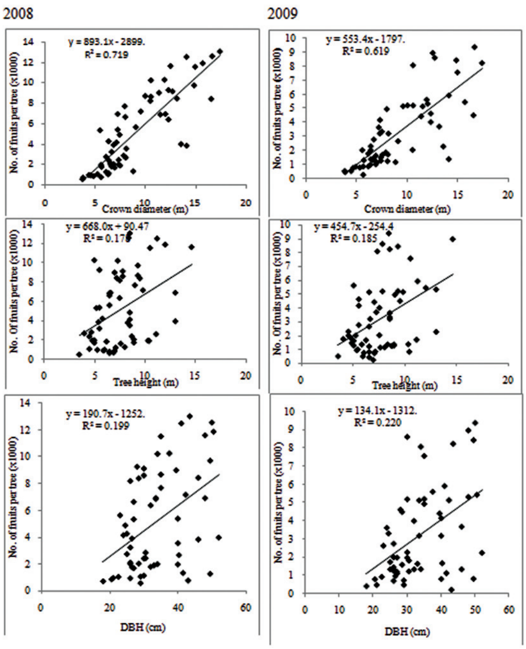

Figure 8: Relationship between number of fruits per tree with crown diameter, height and DBH of *Sclerocarya birrea* trees

Discussion

Fruit phenotype

Fruit weight

A comparison between the subspecies showed that subspecies *multifoliolata* produced significantly the heaviest fruits followed by birrea and the lightest were fruits from subspecies caffra. It has been reported that fruit properties can vary within an individual, between individuals within a population and between populations of a species (Roach and Wulff, 1989). Various factors, biotic and abiotic; influences the variation of fruit properties usually in complex interactions, needing long term studies to unravel particular causes for variation. Among the factors are genetical (Richings *et al.,* 2001; Tanksley, 2004) and allometric (Thompson and Rabinowitz, 1989; Leishman *et al.,* 1995; Cornelissen, 1999) properties. Subspecies *multifoliolata* trees were the biggest in size compared to *birrea* and *caffra*; and allometric analysis between crown diameter and DBH with fruit weight showed strong correlation - with crown size ($r = 0.66$; $p < 0.001$); with tree DBH ($r = 0.63$; $p < 0.001$). Big tree height, which normally influences crown diameter; and DBH have been found to relate to heavy weight of individual fruits in tropical drylands because of mechanical reasons (Peters *et al.,* 1988; Wolfe and Denton, 2001; Murray and Gill, 2001). However the impact of variability in genetical properties among the subspecies on fruit size should not be ruled out.

On farm fruits for subspecies birrea and caffra were heavier than the fruits from wild populations but the difference was not significant. However for subspecies *multifoliolata* it was the fruits from the wild population which were heavier and the difference was significant. Leakey *et al.* (2005) found that subspecies *caffra* trees on farm were significantly heavier than those from the wild in South Africa while tree in Namibia showed no significant difference by land use. Our results show one subspecies only (subspecies *multifoliolata*), with significant difference in fruit weight; and actually it was the wild fruits which were heavier. On farm fruits for *Sclerocarya birrea* are expected to be heavier than wild fruits due to farmers' selection pressure (Shackleton *et al.,* 2003; Leakey *et al.,* 2005); a phenomenon which have also been observed in fruits from other species (Tanksley, 2004). At the moment, the level of domestic utilisation and trade of *Sclerocarya* fruits is less in Tanzania compared to South Africa and Namibia, hence probably less influence of on farm trees from farmers' selection pressure. On farm fruits are expected to be big not only due to selection pressure but also due to less competition and general care received from farmers (Bofa, 1999). However other factors such as intensity of pollination due to more tree hence pollen abundance (Kunin 1993; Ghazoul 2005), herbivory selection pressure (Wheelright, 1993) and soil water retention (Wolfe and Denton, 2001) which are superior in the wild environment as well as differences in biochemical processes within fruits (Richings *et al.,* 2001) may play an important role in giving opposite results.

Mean weight per fruit for the Tanzanian populations of *Sclerocarya birrea* was in the range between 30.11 ± 0.42 and 24.00 ± 0.29 g which were recorded from wild populations of subspecies *multifoliolata* and *caffra* respectively. The minimum (11.34 g) and maximum (47.70 g) fruit weight were both recorded from subspecies *multifoliolata*. With the exceptionof a Namibian tree described as a'wonder tree'by Leakey *et al.,* (2005) and a clonal establishment in Israel (Hillman *et al.,* 2008); the mean fruit weight obtained for subspecies *multifoliolata* and *birrea* in Tanzania are higher than the previous records which are based on subspecies *caffra* from other countries. In an experimental stand established in Israel 34.41 ± 0.91 to 56.74 ± 1.65 g/fruit have been reported (Hillman *et al.,* 2008). Shackleton *et al.* (2003) reported mean fruit weight of 20.9 ± 0.18 g/fruit from on farm trees and 24.9 ± 0.19 g/fruit from wild trees of subspecies *caffra*. Leakey *et al.* (2005) report a mean weight of 26.7 g/fruit and 20.1 g/fruit for subspecies *caffra* in Namibia and South Africa respectively but also recorded a record breaking weight of 69 g/fruit from a tree he described as a 'wonder tree' in Namibia of which its lightest fruit weighed 47 g.

Leakey *et al.* (2005) found that the main contributor of fruit weight for subspecies *caffra* is flesh, although several other factors interplay in the whole process of fruit development (Murray and Gill, 2001). For Sclerocarya birrea, fruit weight is an important factor in development of cultivars because it relates to flesh and kernel mass (Leakey *et al.,* 2005). The unique genetic variation for Sclerocarya in Tanzania (Kadu *et al.,* 2006; Mouk *et al.,* 2007) and the high fruit weight recorded from subspecies multifoliolata (also endemic to Tanzania) may spark more interest in research, domestication and conservation. There is a need for a long term monitoring of the properties and analysis of various factors affecting these properties. Tanzania present an ideal and unique opportunities due to availability of study materials i.e. the only place where all the subspecies occurs.

Fruit diameter

There was a significant variation of fruit size between the subspecies and between the land use settings. Subspecies birrea had the largest fruits followed by subspecies *multifoliolata* and the smallest fruits were from subspecies *caffra*. Pearson's correlation of fruit diameter and fruit weight was 0.239 ($P < 0.001$) meaning that the relationship was not so big and therefore a large fruit was not necessarily heavier than a small fruit. If the main contributor of fruit weight for the Tanzanian populations is flesh as is in South Africa and Namibia (Leakey *et al.,* 2005) it may imply that variable kernel sizes were responsible for irregularities in the relationship between weight and diameter. Fruit size is important because it relates to quality and appearance and hence influences the market and consumer satisfaction (Seymour *et al.,* 2002). For development of suitable cultivars it is therefore important to take both weight and size of the fruit into consideration. Fruit size, and not weight; has been mentioned as among farmers selection criteria for superior *Sclerocarya* trees (Woiso, 2011), hence when working with farmers this criteria needs to be modified to include weight.

For subspecies *birrea* on farm fruits were larger in diameter than wild fruits while for subspecies caffra and *multifoliolata* fruits from the wild populations were larger than those from on farm populations. Subspecies *birrea* (on farm) recorded the biggest mean size of 3.29 ± 0.03 cm while the smallest were subspecies *caffra* (on farm) with a diameter size of 2.85 ± 0.02 cm. Fruits from subspecies *multifoliolata* which were the heaviest were not the biggest probably because of the weak relationship between fruit weight and diameter as reported above. Most of the factors mentioned above which affect the variation of fruit weight between on farm and wild populations would be expected to also affect size in situations where normally fruit diameter and weight relates. But also in areas with frequent fires trees tend to produce small fruits in order to save energy to use for vegetative regeneration (Murray and Gill, 2001). This theory may also hold true for *Sclerocarya* because the site were subspecies *caffra*, whose fruits were smallest; was studied experiences frequent fires (Woiso, 2011), highlighting the probability of its influence on fruit development. However these findings only shed some lights on the influence of fire on sizes of fruits from *Sclerocarya* trees, long term and wider area studies are necessary before a conclusion is made.

Fruit Yield

There was a significant difference in yield per tree between the subspecies but the difference in yield per tree between the two land use settings was only significant for subspecies *multifoliolata*. Subspecies *multifoliolata* and *caffra* recorded the highest and lowest yield respectively. Using data from the wild population in 2008 which recorded the highest yield per population; subspecies *multifoliolata* and *caffra* produced on average 6026 ± 1119 fruits/tree and 3021 ± 814 fruits/tree respectively. Across all the populations; the minimum yield was 229 fruits/tree (recorded from subspecies caffra on farm population in 2009 season) while the maximum yield was 13,046 fruits/tree (recorded from subspecies *multifoliolata* wild population in 2008 season). While there is no previous record on yield for subspecies *multifoliolata* and *birrea*; yield records for *caffra* from countries like Namibia and South Africa shows huge fluctuations between populations and seasons although most of the data is questioned for the scientific methods used (Shackleton *et al.,* 2003). Yields of 21,667 to 91,272 per 4 trees or 550 kg/tree (Quin, 1959); 9,601 fruits/tree or 270 kg/tree (Shone, 1979);. 2,000 fruits/tree or 550 kg/tree (Lewis 1987; Peters, 1988); 70,000 fruits/tree or 570 kg/tree (Roodt, 1988); 6,900 - 12,100 fruits/tree (Walker, 1989); 3,896 – 21,885 fruits/tree (MacHardy, 2003); 3,500 – 17,000 fruits/tree and 1,753 ± 343 fruits/tree or36.8 ± 7.8 kg/tree (Shackleton *et al.,* 2005); and 6–45 kg/tree from clonal stands in Israel deserts (Hillman *et al.,* 2008) have been reported. The relationship between fruit yield and DBH was weak (R2< 22) similar to findings by Shackleton *et al.,* (2003), but there was a strong relationship between yield and crown diameter (R^2> 60). Bigger trees are expected to produce more fruits but also environmental conditions such as soil properties, herbivory, pollination success and seasonal rainfall fluctuation affects yield of fruits (Bofa, 1999; Wolfe and Denton, 2001; Shackleton *et al.,* 2005).

There was more yield from the wild than on farm populations but the difference was not significant with the exception of subspecies *multifoliolata*. The production of more fruits in the wild than on farm population found on *multifoliolata* may relate to the availability of more pollinators in the wild and the high degree of tree isolation on farms (Lobo *et al.,* 2003; Waites and Ågren 2004). In presence of more pollinators, more flowers stand a high probability chance of fertilisation and therefore more fruits. Pollination intensity and pollination success increase with increasing population density and decrease with degree of isolation (Kunin 1993; Waites and Ågren 2004; Östergård and Ehrlén 2005; Singer and Wee 2005; Ward and Johnson 2005; Ghazoul 2005). However the previous single available data on yield by land use for subspecies *caffra* in S. Africa and Namibia by Shackleton *et al.,* (2003); McHardy (2003) and Leakey *et al.,* (2005) shows that on farm population produce significantly more fruits (17, 000 fruits/tree) than wild populations (3,500 fruits/tree). They attributed the findings to availability of more care by farmers and lack of competition from other plants on farmlands. Selection pressure by farmers is another factor they pointed out to be responsible for fruit production (Leakey *et al.,* 2005; Emanuel *et al.,* 2005) although it may not be reflected in this study because of the lack of selection pressure in Tanzania. However these findings highlights a need for more specific studies on the influence of competition, domestication care, selection and other factors on yield of *Sclerocarya birrea*.

Resource availability such as rainfall affects productivity of trees and forests (Chiarucci *et al.,* 1993; Ceballos *et al.,* 2004; Ågren *et al.,* 2008a; Zunzunegui *et al.,* 2010). This was reflected in these results. With less rainfall in 2009, all the populations produced significantly less fruits compared to the previous year where rainfall was higher. Limited rainfall can result into abortion of flowers or fruits at their early stage in order allocate enough resources for few selected fruits (Winsor 1986, Sutherland 1986; Lobo *et al.,* 2003; Ågren *et al.,* 2008b). Data on fruit yield is likely to vary from year to year in relation to the amount of rainfall available in particular years and especially during reproduction phase. Monitoring of yield may need to be done for several years in order to cover a wider range of rainfall fluctuations from year to year in a longer span.

Conclusion

Subspecies *multifoliolata* fruits were heavier and many than those produced by subspecies birrea and caffra. In terms of fruit size, subspecies *birrea* produced the largest compared to the other two subspecies.The trees in the wild produced more and heavier fruits than the ones in on farm environment. Fruit phenotype and yield showed allometric relationship with tree size structure as well as rainfall and subspecies. Phenotype and yield did not relate to farmers‘ selection pressure and intervention probably because at the moment there is no any form of domestication in Tanzania

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