Research Reports

Rootstock Propagation Methods Affect the Growth and Productivity of Three Improved Cultivars of Ber in Mali, West Africa

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SUMMARY. The adaptation of three improved cultivars of ber (*Ziziphus mauritiana*) from India to farming conditions in the Sudanian zone of the Sahel region was tested in Mali. The three cultivars used as scions were Seb, Umran, and Sotubata. The use of coppices of local ber resulted in a significantly better growth and higher fruit production on all the grafts of the three cultivars when compared with nursery seedling rootstocks. The cultivars also performed significantly better in the South Sudanian zone than in the more-arid North Sudanian zone. The highest fruit yield of 38 kg per tree was achieved on coppices in the South Sudanian zone. It was concluded that the high success of this experiment offers a great opportunity for adoption of the three improved cultivars of ber using coppice shoots as rootstock to optimize their use in parkland agroforestry systems in the South Sudanian zone of the Sahel region of West Africa.

Ber, also called jujube, is found throughout tropical and subtropical regions of the world (Saran et al., 2006). It belongs to Rhamnaceae family. The species is one of the most ancient indigenous fruits domesticated in India. It is now extensively cultivated in the Indian subcontinent (Pareek, 2001; Williams et al., 2006). The main attraction of

ber lies in its fruit production (Sidibé, 2010; Sidibé et al., 2012). Ber is popular due to high economic returns, low cost of cultivation, and wide ability to withstand drought (Pareek et al., 2007). Tarai and Ghosh (2010) reported that the good productivity of ber and its ability to stand transport and storage makes the tree more popular for commercial cultivation than other fruit crops.

The ripe fruit are mostly consumed fresh, but they are also eaten dried or prepared into candy. The ripe fruit are also crushed and mixed with water and sugar to form a ready-to-serve drink. Nutritionally, the ripe fruit is richer than apple (*Malus × domestica*) in protein, phosphorus, calcium, carotene, and vitamin C (Pareek, 2001; Williams et al., 2006). Ripe fruit pulp provides 20.9 kilocalories/100 g. It is a rich source of vitamin C (70–165 mg/100 g pulp), the majority being in the form of ascorbic acid (66–133 mg/100 g pulp), and contains 1.03% to 1.18% protein and 4.9% to 12.4% sugars (Pareek, 2001; Williams et al., 2006). The leaf is consumed by camels (*Camelus dromedarius*), goats (*Capra hircus*), and cattle (*Bos taurus africanus*) and is highly nutritious (Ngwa et al., 2000).

Ber is one of the most highly valued tree species by local people in Mali because of its fruit. Local people consume the fruit either fresh or dried (Gustad et al., 2004). Despite its importance, it has never been domesticated in Africa. One can find it growing naturally in farm fields, fallows, alongside roads, and watercourses. In its wild form, the tree can reach up to 10 m in height and 5 m in crown width. A survey carried out in Burkina Faso, Mali, Niger, and Senegal revealed that ber is among the farmers' 10 most preferred tree species (Bonkougou et al., 1998). However, because of the small size of fruit (1–2 g per fruit) and its sensitivity to parasitic attacks, its use for optimizing the productivity of parkland agroforestry systems is limited (Ouédraogo et al., 2006).

It has been demonstrated in West Africa by Sahel Regional Program of the World Agroforestry Center that it is possible to graft improved cultivars of ber from India onto rootstocks of local ber to produce much bigger and sweeter fruit. The aim of this study was, therefore, to investigate the adaptation of some of these

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
4.1868	kilocalorie(s)	MJ	0.2388
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵

Table 1. Mean survival rates of three cultivars of ber trees grown on two rootstocks in Aug. 2006 at two sites (South Sudanian and North Sudanian zones) in Mali, West Africa, assessed 2 years after grafting.

Site	Cultivar	Survival rate [mean $\pm$ SE (%)]	
		Seedling rootstock	Coppice rootstock
Massala	Seb	50.00 $\pm$ 15.27	66.67 $\pm$ 3.33
	Sotubata	50.00 $\pm$ 5.77	43.33 $\pm$ 12.02
	Umran	40.00 $\pm$ 10.00	53.33 $\pm$ 6.67
	Mean	46.67 $\pm$ 5.77	54.44 $\pm$ 5.29
	Significance-cultivars	NS ^a	NS
Siramana	Seb	63.33 $\pm$ 3.33	60.00 $\pm$ 0.01
	Sotubata	56.67 $\pm$ 6.67	66.67 $\pm$ 3.33
	Umran	40.00 $\pm$ 23.09	50.00 $\pm$ 0.01
	Mean	53.33 $\pm$ 7.82	58.89 $\pm$ 3.89
	Significance-cultivars	NS	NS
	Significance-sites	NS	NS

^aNot significant at $P < 0.05$ according to Tukey's pairwise comparisons.

improved cultivars of ber from India to farming conditions in Mali to optimize their use in parkland agroforestry systems.

Materials and methods

The trials were established in 2006 in two agro-climatic zones of Mali: the South Sudanian zone in Siramana village where the rainfall is 900–1100 mm, and the North Sudanian zone in Massala village with 700–850 mm of rainfall. In each village, three farmers were selected according to their willingness to participate in the research. The trials were performed on the lands of participating farmers. Selection of the villages was done according to the accessibility of the sites. This research involved two types of rootstock, three cultivars of ber, and six farms in two agro-climatic zones. The rootstocks were shoots from coppices and nursery-grown seedlings. The coppices were tree young shoots that regenerate from cut stump on farmers' fields that were left fallow for not more than 2 years after crop cultivation. The tree had already well-developed roots. These plants would have been clear-felled at the end of this fallow period to convert the fields for crop cultivation. By grafting some of these trees, before they are clear-felled, with improved cultivars, it was envisaged that an improved agroforestry parkland system would be created that would consist of widely spaced and high-yielding improved trees of ber and associated food crops.

In each farmer's field, 30 well-developed coppices were randomly selected. Scions from three improved

cultivars were taken from the Research Station of the World Agroforestry Center, Bamako, Mali. The cultivars were Seb, Umran, and Sotubata. Ten coppices were grafted per cultivar in each farm using the procedure of top cleft grafting (Lee, 1994). The average diameter of the coppice at the grafting point was 1 cm. The average size of the scions used was 8-cm long and 1-cm diameter. After grafting, the entire union of graft and scion was covered with a plastic bag to avoid desiccation. The plastic cover was removed 3 weeks after grafting. The second type of rootstock was nursery-grown seedlings that were raised in nurseries run by the six selected farmers on their farms after receiving training on nursery and grafting techniques. Seeds of the local cultivar of ber were pretreated by soaking in water overnight. The seeds were sown in plastic bags containing a mixture of local soil, sand, and compost in equal proportion. The seedlings were watered once per day. The scions of the three improved cultivars of ber were grafted onto the seedling rootstocks after 4 months of growth in the nursery, following the same procedure as applied on coppices. The scions used were also of the same size as the ones grafted onto coppices. The average diameter of the nursery rootstocks was 1 cm. The average size of the scions used was also 8-cm long and 1-cm diameter. The grafted seedlings were watered once per day and protected against animal browsing through fencing. Three weeks after grafting, the plastic cover around the scions was removed and 10 grafted seedlings of

each of the three cultivars were planted out on 2 Aug. 2006, on each of the six farmers' fields. To make sure that the technique applied was similar, grafting of coppices and seedlings was performed by the same person within 3 d.

Growth parameters and fruit production of scions (coppices and seedlings) were evaluated 2 years after grafting. Survival rate was assessed by counting. Height growth was measured from the grafting point to the apex with a measuring tape. The diameter growth was measured at the grafting point with a caliper square. The number of branches and the number of fruit were counted.

Analysis of variance was performed on the data using General Linear Model of Minitab (version 15; Minitab, State College, PA) to test the effect of type of rootstock and agro-climatic zone on the performance of the three improved cultivars of ber in terms of height and diameter growth, number of branches, and fruit produced. Because of the difference in size between coppices and nursery seedling rootstocks, collar diameter of the rootstocks was used as a covariate in the analysis of variance. Because generalized linear model also makes an assumption that there are linear relationships between variables, all data were checked for linearity before the analysis. Where there is no linearity, the data were log transformed to do the analysis of variance. Pearson correlation analysis was applied to the data to test relationships between various parameters of trees.

Results

SURVIVAL OF GRAFTS. With seedling rootstock in Massala, cultivars Seb and Sotubata had the higher survival rate (Table 1). In Siramana, with seedlings rootstock 'Seb' had the higher survival rate followed by 'Sotubata'. In both sites with seedlings rootstock, 'Umran' had the lower survival rate. With coppice rootstock in Massala, 'Seb' had higher survival than other cultivars. In Siramana with coppice rootstocks, 'Sotubata' had highest survival and 'Umran' the lowest. Although the survival rate was higher with seedling and coppice rootstocks in Siramana than Massala, the differences were not significant (Table 1).

Table 2. Growth performance of three cultivars of ber trees grown on two rootstocks in Aug. 2006 at two sites (South Sudanian and North Sudanian zones) in Mali, West Africa, assessed 2 years after grafting.

Rootstock	Site	Cultivar	Tree ht [mean $\pm$ SE (cm)] ^z	Scion diam [mean $\pm$ SE (cm)]	Branches [mean $\pm$ SE] (no.)
Grafted coppice	Massala	Seb	88 $\pm$ 12	2.8 $\pm$ 0.3	27 $\pm$ 4b ^y
		Sotubata	91 $\pm$ 13	2.9 $\pm$ 0.2	49 $\pm$ 8a
		Umran	108.8 $\pm$ 16	3.3 $\pm$ 0.3	61 $\pm$ 9a
		Mean	96 $\pm$ 14	3 $\pm$ 0.3	45.6 $\pm$ 7
		Significance-cultivar ^x	NS	NS	**
	Siramana	Seb	290 $\pm$ 11.8	6.9 $\pm$ 0.5	97 $\pm$ 9a
		Sotubata	239 $\pm$ 19	5.9 $\pm$ 0.5	69 $\pm$ 5b
		Umran	303 $\pm$ 28	7 $\pm$ 0.8	100 $\pm$ 7a
		Mean	277 $\pm$ 20	6.7 $\pm$ 0.6	88.6 $\pm$ 7
		Significance-cultivar	NS	NS	**
Grafted seedling	Massala	Seb	62 $\pm$ 3	1 $\pm$ 0.05	15 $\pm$ 1
		Sotubata	56 $\pm$ 4	1 $\pm$ 0.1	14 $\pm$ 2
		Umran	66.4 $\pm$ 3.7	1.3 $\pm$ 0.1	13 $\pm$ 1
		Mean	62 $\pm$ 3	1 $\pm$ 0	14 $\pm$ 1
		Significance-cultivar	NS	NS	NS
	Siramana	Seb	54 $\pm$ 4	1 $\pm$ 0.1	14 $\pm$ 2
		Sotubata	63 $\pm$ 4	1 $\pm$ 0	12 $\pm$ 0.4
		Umran	68 $\pm$ 5	1.1 $\pm$ 0.1	17 $\pm$ 2
		Mean	62 $\pm$ 4	1 $\pm$ 0.0	14 $\pm$ 1
		Significance-cultivar	NS	NS	NS
Significance-rootstock			***	***	***
Interaction site-rootstock			***	***	***
Interaction cultivar-rootstock			NS	NS	NS

^z1 cm = 0.3937 inch.

^yMeans in the same column followed by different letters indicate significant differences ($P < 0.05$) according to Tukey's pairwise comparisons.

^xNS, **, ***Not significantly different ($P < 0.05$), significantly different at $P < 0.01$, and significantly different at $P < 0.001$ according to Tukey's pairwise comparisons.

GROWTH PARAMETERS. The type of rootstock had significant effects on diameter and height growth of grafts (Table 2) with the probabilities ($P < 0.001$ and $P < 0.001$, respectively). The average height growth of grafts on coppices (Fig. 1) was about 1.5 and 4 times larger than grafted seedlings (Fig. 2) in Massala and Siramana, respectively (Table 2). The average diameter growth of grafts on coppices was three to six times larger than grafted seedlings in Massala and Siramana, respectively (Table 2). The differences were much more pronounced in Siramana than in Massala. Overall, site had no effect on diameter or height of trees on seedlings rootstock (Table 2). Site, had significant effect on diameter ($P < 0.001$), height growth ($P < 0.001$) of trees on coppice rootstocks (Table 2). The greatest diameter [$\pm$ SE (7.00 $\pm$ 0.8 cm)] and the best height (303 $\pm$ 28 cm) were achieved in Siramana with 'Umran' (Table 2).

There was no difference for the growth in diameter and height of

trees on seedling rootstocks (Table 2). The number of branches on coppices was about three to six times higher than grafted seedlings in Massala and Siramana, respectively (Table 2). There was also significant difference in the number of branches on grafted coppices between cultivars and sites ($P < 0.01$). The highest number of branches on grafted coppices is found with 'Umran' in both sites [$\pm$ SE (100 $\pm$ 7 branches)] and (61 $\pm$ 9 branches) in Siramana and Massala, respectively (Table 2). The number of branches with coppiced rootstock was significantly higher than seedlings rootstock in Siramana and Massala, respectively (Table 2). The number of branches with coppiced rootstock in Siramana was also significantly higher than that of Massala ($P < 0.001$). However, there is no difference between cultivars and sites concerning the number of branches of grafted seedlings (Table 2).

An interaction was found between site and rootstocks concerning the height and diameter growth ($P < 0.001$ and $P < 0.001$, respectively)

and the number of branches ($P < 0.001$). However, there was no interaction between cultivars and rootstocks.

FRUITING. Type of rootstock had significant effect ($P < 0.001$) on the number of fruit per plant and weight per fruit of trees (Table 3). The weight of fruit on coppices was about two times heavier than that on seedlings. There was also significant effect of site on the number of fruit produced and the weight per fruit on grafted coppices ($P < 0.001$). With coppice rootstock in Siramana, 'Sotubata' and 'Umran' had higher numbers of fruit than 'Seb' ($P < 0.001$). The mean number of fruit produced on coppices in Siramana (1408 fruit per tree) was almost seven times higher than that in Massala (193 fruit per tree). There were no significant differences between cultivars on grafted seedlings concerning the number of fruit produced. In Siramana, on coppice trees, the fruit of 'Sotubata' was heavier than that of 'Seb' and 'Umran'. Concerning the grafted seedlings,

Fig. 1. Ber scion grafted on coppice rootstock in Aug. 2006 and assessed after 16 months of growth in Siramana village (South Sudanian zone) in Mali, West Africa.

Fig. 2. Ber scion grafted on seedling rootstock in Aug. 2006 and assessed after 16 months of growth in Siramana village (South Sudanian zone) in Mali, West Africa.

there was no significant difference between cultivars in both sites. Site has no significant effect on the number of fruit produced and the weight of fruit on grafted seedlings. The interaction between site and rootstock is significant concerning the weight per fruit ($P < 0.01$) and the number of fruit produced per plant ($P < 0.001$). However, there was no interaction between cultivars and rootstocks (Table 3).

ALLOMETRIC RELATIONSHIPS BETWEEN PARAMETERS. There were significant and positive correlations between rootstock collar diameter and all the growth parameters (height, diameter, and number of branches) of grafts on both coppice and seedling rootstocks (Table 4). Very strong correlations were found between

rootstock collar diameter and graft diameter on both coppices and seedlings ($R = 0.88$ and $R = 0.87$, respectively). There were also positive and significant correlations between graft diameter and graft height and number of branches of grafts as well as between graft height and number of branches of grafts on both coppices and seedlings. Concerning fruiting, the correlations between number of fruit and vegetative growth parameters were positive and significant on coppices rootstock indicating that larger trees had more fruit. However, there were no correlations between number of fruit and all growth parameters on seedling rootstocks. No correlation was also found between weight of fruit and all growth parameters on coppices. But there were very

weak and negative correlations between fruit weight and rootstock collar diameter and graft height on seedlings ($P < 0.05$).

Discussion

The results of this study showed that the use of coppice shoots as a rootstock for in situ grafting of improved cultivars of ber was better than nursery-grown seedling rootstock, which is commonly used in most previous grafting studies. A previous study by Sanou et al. (2004) reported that wildings (uncultivated seedlings growing wild) were successfully used for in situ grafting of shea butter tree (*Vitellaria paradoxa*), another very important indigenous fruit tree in the Sahel. This means that adoption of improved cultivars of ber on farms may be less expensive if coppices of local ber are used due to the reduction of the cost of raising seedling rootstocks in the nursery. Also grafted seedlings prepared in the nursery are transported with large volume of soil in polythene bags after grafting for transplanting to the field. A number of these plants could be lost due to damage while packaging, transporting, and transplanting. These operations are cumbersome and could be avoided by using coppices.

The survival rate of grafts 2 years after grafting, although low (about 53%), was satisfactory under farm conditions. This low survival rate may well be the result of differences in managing trees. But, it may be improved by keeping well the trees, by watering (irrigated with 30 L/plant per week) and application of fertilizers (150 g of phosphate per plant) as done by previous workers (Ouédraogo et al., 2006). In fact, soils of arid areas are known to be deficient in phosphorus and moisture and the supply of these two resources was reported to be the most important factor determining survival, productivity, and quality of improved cultivars of ber in dry areas (Lal, 2001; Ouédraogo et al., 2006; Pareek, 2001).

The growth performance of grafts and fruit production was significantly affected by the type of rootstock. In Massala, the height and diameter growth for coppice rootstock were 1.5 and 3 times, respectively, higher than seedling rootstock (Table 2). The number of branches on coppice rootstock was also three

Table 3. Fruit production of three cultivars of ber tree grown on two rootstocks in Aug. 2006 at two sites (South Sudanian and North Sudanian zones) in Mali, West Africa, assessed 2 years after grafting.

Rootstock	Site	Cultivar	Wt per fruit [mean ± SE (g)] ^z	Fruit per plant [mean ± SE (no.)]
Grafted coppice	Massala	Seb	28.9 ± 0.8	140 ± 38
		Sotubata	28.5 ± 0.4	267 ± 50
		Umrans	28 ± 0.2	171 ± 42
	Significance-cultivar ^y		NS	NS
	Siramana	Seb	30 ± 0.6	769 ± 193b ^x
		Sotubata	31 ± 0.5	1829 ± 693a
		Umrans	28.7 ± 0.4	1626 ± 633a
	Significance-cultivar		NS	**
	Significance-site		***	***
	Grafted seedling	Massala	Seb	13.6 ± 0.1
Sotubata			13.7 ± 0.1	16 ± 1
Umrans			11.4 ± 0.1	17 ± 1
Significance-cultivar		NS	NS	
Siramana		Seb	13.6 ± 0.3	12 ± 1
		Sotubata	13.4 ± 0.3	14 ± 2
		Umrans	11.3 ± 0.2	14 ± 1
Significance-cultivar		NS	NS	
Significance-site		NS	NS	
Significance-rootstock		***	***	
Interaction site-rootstock		**	***	
Interaction cultivars-rootstock		NS	NS	

^z1 g = 0.0353 oz.

^yNS, **, ***Not significantly different ($P < 0.05$), significantly different at $P < 0.01$, and significantly different at $P < 0.001$ according to Tukey's pairwise comparisons.

^zMeans in the same column followed by different letters indicate significant differences ($P < 0.05$) according to Tukey's pairwise comparisons.

Table 4. Pearson correlations between parameters of rootstocks and scions of three cultivars of ber trees grown on two rootstocks in Aug. 2006 at two sites (South Sudanian and North Sudanian zones) in Mali, West Africa, assessed 2 years after grafting.

Rootstock	Parameter	Fruit per plant [mean ± SE (no.)]	Wt per fruit [mean ± SE (g)] ^z	Rootstock collar diam [mean ± SE (cm)] ^z	Scion diam [mean ± SE (cm)]	Tree ht [mean ± SE (cm)]
Grafted coppice	Weight per fruit	NS ^y				
	Rootstock collar diameter	0.53***	NS			
	Scion diameter	0.35**	NS	0.88***		
	Tree height	0.38***	NS	0.87***	0.84***	
	Branches	0.25*	NS	0.65***	0.68***	0.61***
Grafted seedling	Weight per fruit	NS				
	Rootstock collar diameter	NS	-0.30*			
	Scion diameter	NS	NS	0.87***		
	Tree height	NS	-0.29*	0.56***	0.52***	
	Branches	NS	NS	0.46***	0.43**	0.67***

^z1 g = 0.0353 oz, 1 cm = 0.3937 inch.

^yNS, *, **, ***Not significantly different ($P < 0.05$), significantly different at $P < 0.05$, significantly different at $P < 0.01$, and significantly different at $P < 0.001$.

times higher than that of seedling rootstock. In Siramana, the height and diameter growth for coppice rootstock were four and six times, respectively, higher than that of seedling rootstock. The number of branches was also six times higher on coppice than seedling rootstock.

The number of fruit per tree was about 12 times higher in Massala and

about 108 times higher in Siramana on coppice than seedling rootstock (Table 3). This could have been because in more favorable condition (more soil moisture) the trees could take more advantage of their larger sized root systems. Size or age of rootstocks has been reported to promote scion growth better than young and small sized rootstocks in

horticulture and forestry. For example, Copes (1987) found that growth was positively related with rootstock age or size in douglas fir (*Pseudotsuga menziesii*). This may have resulted perhaps from older rootstock being more vigorous. Coppice trees not only have a larger root system, but their root system is also well established (Copes, 1987).

The strong correlation between fruit yield and all growth parameters on coppice rootstocks observed in this study is in accordance with the findings of Ouédraogo et al. (2006), who reported that fruit yield was significantly and positively correlated to total height, stem diameter, and crown diameter. Although *R* is statistically significant, they explained less than 10% of the variation. The negative correlations between fruit weight and rootstock collar diameter and graft height on seedling rootstocks may be a correlation artifact more than treatment effect.

Although ber is known to be a dry zone species, it performed much better in South Sudanian zone which is moister than the North Sudanian zone. The highest diameter growth [$\pm$ SE (7 ± 0.08 cm)] and growth in height (303 ± 28 cm) were achieved with grafted coppice, 'Umran' in the South Sudanian zone. The mean number of fruit produced on coppices in the South Sudanian zone (1408 fruit per tree) was about seven times higher than that in the North Sudanian zone (193 fruit per tree). This is further evidence of the need of water supply for enhanced productivity of improved cultivars of ber. The mean annual rainfall of the North Sudanian zone was much less than that of the South Sudanian zone where better performance of the cultivars was achieved (775 and 1000 mm, respectively).

The mean weight per fruit recorded on coppice and seedling rootstocks in this study (29.2 and 13.0 g, respectively) are within the range of values reported by Chovatia (1993), Lal (2001), Mukherjee (2004), Ouédraogo et al. (2006), and Vashistha (2001) (4.6–33 g per fruit). Overall, the values recorded for all the three improved cultivars in this study are several times higher than that of the local variety (1–2 g per fruit) as reported by several workers (Ouédraogo et al., 2006; Pareek, 2001; Williams et al., 2006).

Taking into account the average weight per fruit of 30.11 g, the yield of fruit on coppice rootstock in the South Sudanian zone was estimated at 38 kg per tree. This is within the range of values reported by Chovatia (1993), Lal (2001), and Ouédraogo

et al. (2006) (10.72–67.07 kg per tree), but much lower than the values reported in the literature for adult trees (Bakhshi and Singh, 1974; Pareek, 2001). Peak production of 80–200 kg per tree is achieved at 10 years of age under irrigation and fertilization conditions (Bakhshi and Singh, 1974; Pareek, 2001).

Interactions occurred between sites and rootstocks concerning the growth parameters and fruit production of trees. These interactions allowed us to develop a site-specific recommendation. Grafted coppices in Siramana showed better growth (height, diameter, number of branches) and higher fruit production. This fact may be due to the high rainfall and better soil fertility observed in Siramana. Therefore, the use of grafted coppice as rootstock offers a great opportunity for adoption of the improved cultivars of ber in South Sudanian zone of the Sahel region of West Africa.

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