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RAIN-FED PLANTATIONS OF THE DOMESTICATED *ZIZIPHUS MAURITIANA* IN THE SAHEL: EFFECTS OF VARIETIES AND ROOTSTOCKS ON YIELDS AND FRUIT QUALITY

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ABSTRACT

A long-term study was conducted to explore the possibility of using traditional rain-fed systems for growing domesticated *Ziziphus mauritiana* (so-called Pomme du Sahel) in the Sahel. Five varieties, Gola, Ben Gurion, Seb, Umran and Kaithli, were grafted on six rootstocks of *Z. mauritiana* from various agroecological zones of Niger. Trees were planted inside microcatchments at 8 × 8 m spacing. Over a period of six years, the variety Umran gave the highest fruit yield (3600 kg·ha^{-1}) and the lowest fruit yield was documented for variety Seb (1970 kg·ha^{-1}). Individual fruit weight ranged from 25.8 g for 'Umran' to 9.5 g for 'Seb'. The rootstocks had no effect on average fruits yields and fruit size. There was a significant linear correlation between fruit yield and annual rainfall. In a rainy year (680 mm), the average yield of the five varieties was 7580 kg·ha^{-1}. The results of the current study indicate that dry land plantations of Pomme du Sahel can guarantee food security during dry years in the Sahel. However, further studies are required to evaluate the economic feasibility of this system.

Key words: Pomme du Sahel, domestication, varieties, rootstocks

INTRODUCTION

The Sudano-Sahelian agro-pastoral system is characterized by a very low level of productivity of growing plants that results from an inherent poor soil and severe human induced land degradation. Fruit trees play an important role in the Sudano-Sahelian production system. The introduction of hardy, indigenous, high value fruit trees into the rain-fed production system of the Sudano-Sahel might help to break the poverty trap caused by current production systems (Leakey et al. 2005).

In the Sudano-Sahel, yields of annual crops are affected more by long dry spells between rains than by a total seasonal rainfall. At the same time yields of trees are more affected by the total amount of rainfall and less by the length of the dry spells. Sudano-Sahelian parkland trees are more drought tolerant than the annual crops due to their deeper and prolific root system and their xeromorphic anatomy. Many trees such as baobab (*Adansonia digitata*) or *Ziziphus mauritiana* are less affected by the long dry spell period because they shed their leaves and go dormant during this period. Growing trees in rain-fed conditions ensures income and food in drought years when annual crops fail. Introduction of domesticated fruit trees to the tropics as a means for income generation has been advocated in many studies (Leakey 2001; Leakey & Simons 1998; Leakey et al. 2005).

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Ziziphus mauritiana is a small tree commonly grown in the dry regions of Africa and South Asia (Pasternak et al. 2009). The tree is tolerant to drought, flooding, salinity and withering (Grice 1997; Hooda et al. 1990). In Africa, fruits of the wild *Z. mauritiana* are edible but they are small and hence their economic value is low. *Z. mauritiana* was domesticated in India and many varieties were developed (Vashishtha & Pareek 1989). In India the tree is grafted on vigorous rootstocks such as *Ziziphus rotundifolia* (Lal & Dhaka, 2007). Recently, study made in Mali aimed at adapting three improved cultivars of *Ziziphus mauritiana* from India to the Sudano-Sahelian farming conditions showed that improved cultivars grafted on suckers of local *Ziziphus mauritiana* resulted in a significantly better growth and higher fruit production compared with nursery seedling rootstocks (Sanou et al. 2014).

The current paper describes study carried out in Niger over a period of six years that aimed at creating a profitable rainfed fruit trees plantation. The objective of this study was to assess fruit yield and quality of five improved *Ziziphus mauritiana* varieties grafted on six rootstock genotypes of wild *Z. mauritiana* provenances.

MATERIALS AND METHODS

The study was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sadoré research station in Niger (13°15’ N and 2°18’ E). The climate is characterized by a rainy season that occurs between June and September, and a dry season that prevails during the rest of the year. The mean annual rainfall at Sadoré is 560 mm and the average temperature is 29 °C (West et al. 1984).

In the period 2005-2009 annual rainfall varied from 450 to 550 mm$\cdot$year^{-1} (Fig. 1). The year with exceptionally high rainfall was 2010 when total annual rainfall climbed to 680 mm. Average annual rainfall for the six study years was 525 mm.

The soil of the experimental site is classified as a sandy silicious isohyperthermic Psammentic Paleustalf (Soil Survey Staff 1999). The main characteristics of this soil are a high sand content, low native fertility with low organic matter and low cation exchange capacity. This soil is generally very strongly acid to strongly acid (pH 4.5-5.0). Soil water content at field capacity is 0.09 to 0.10 m$^3\cdot$m^{-3} (Klaij & Vachaud 1992).

Experimental details

The rootstocks of *Z. mauritiana* from Ayerou, Birni N’Gaouré, Dosso, Gaya, Sadoré and Tillaberi were randomly planted in a field. The names of the rootstocks were based on the regions where they were collected (Table 1). A total of ninety rootstocks seedlings were planted at 8 × 8 m spacing between trees. The rootstocks were three years old when grafted. Five varieties of Pomme du Sahel (Gola, Ben Gurion, Seb, Umran and Kaithli) introduced in Niger by the International Program for Arid Land Crops (IPALAC) were grafted in August 2001 on six rootstocks arranged in randomized complete block design and each grafted tree was replicated three times. The combination of rootstock and variety were considered as treatment giving therefore a total of 6 × 5 = 30 treatments.

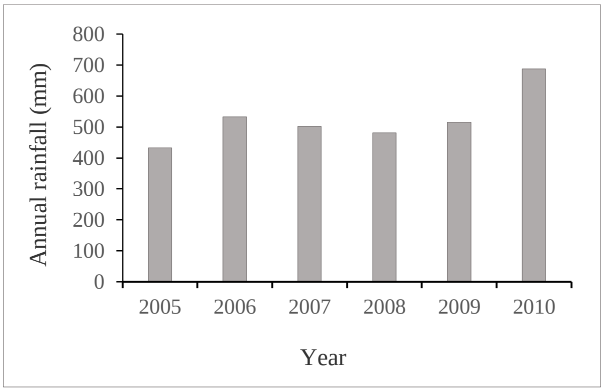

Fig. 1. Annual rainfall (mm) during the six experimental years

Table 1. Rootstocks provenances

Location	Rounded mean annual rainfall (mm)	Coordinates
Ayerou	300	14º44’ N and 0º55’ E
Tillabéry	400	14º13’ N and 1º27’ E
Birni N’Gaouré	600	13º5’16’’ N and 2º55’1’’ E
Sadoré	550	13º15’ N and 2º18’ E
Dosso	650	13’03’ N and 03º12’ E
Gaya	800	11º53’16’’ N and 03º26’48’’ E

A micro-catchment (half-moon shape) for collecting rainwater of 3 meters wide and 3 meters long was dug around each individual tree. The micro-catchments were connected to each other by earth ridges that diverted run-off water into the micro-catchments guaranteeing maximum water harvesting from the field.

Trees were pruned each year during the month of May just before the rainy season. In each pruning about 50% of the canopy was removed. At the same time each tree received 5 kg of composted cow manure and 200 g of NPK 15-15-15. Both the manure and the fertilizer were buried at a depth of 20 cm on two sides of the tree.

Fruits were sprayed each year with Decis (deltamethrin) against fruit flies (*Carpomya incompleta*), which are the dominant pests of *Ziziphus* fruit at Sadoré (Zakari-Moussa et al. 2012). A total of three sprays were done. First spray was applied when the fruits reached the size of a pea.

Data collection

Fruit yield was recorded for six consecutive years (2005-2010). Fruits were harvested when their color changed from green to yellow-green. The weight of individual fruit was taken and yield per tree was calculated. Shelf-life of the Pomme du Sahel fruit was determined in the last year of the study. Ten fruits from each variety were selected at the yellow green stage. The fruits were placed in an air conditioned room at 25 °C for a maximum of four days depending on the variety to determine the color change. The fruits were considered of low quality (but still edible) when the color changed from yellow-green to brown. Total soluble solids (TSS) content of yellow-green fruits was determined in the last year of the study using a refractometer (ERMA Hand Refractometer, Tokyo, Japan, Brix 0-32%). The percent TSS was obtained from direct reading of the instrument.

Statistical analysis

The data collected were subjected to analysis of variance with GENSTAT v.9 (Lawes Agricultural Trust 2007) using a General Treatment Structure (in Randomized Blocks). It is worthy to note that because of some missing data throughout the experimental years, the analysis was carried out on a year by year basis. Since no significant interaction was obtained between the varieties and rootstocks, only the specific effects of variety and rootstock were presented in the current study. Wherever these specific effects were significant, the means were separated using the least significant difference (LSD) at 5% probability level. Regression analysis was performed to establish the relationship between fruit yield and annual mean rainfall.

RESULTS AND DISCUSSION

Effect of rootstocks and varieties on fruit yield

The average fruit yield per variety (Table 2) was significantly different ($P < 0.05$) over the six-year period. Fruit yields ranged from 3603 $kg \cdot ha^{-1}$ for 'Umran' to 1974 $kg \cdot ha^{-1}$ for the 'Seb'. In 2007, 2008 and 2009 there was a significant difference ($P < 0.05$) in fruit yield among varieties. Even though the effect of year was not captured in the current study, the fruit yields were markedly different between the years. The highest fruit yield (7584 $kg \cdot ha^{-1}$) was obtained in 2010 and lowest (1094 $kg \cdot ha^{-1}$) in 2006, which can be attributed to the highest rainfall recorded in 2010 (Fig. 1). In arid or semi-arid areas, mature *Ziziphus* trees require at least 600 mm of water for optimal production (Arora et al. 2002). In the current study this requirement was satisfied only in 2010. This result is consistent with an earlier study which demonstrated that supply of adequate amount of water increased the fruit weight and total fruit yield of *Ziziphus jujube*, a relative of *Ziziphus mauritiana* (Ismail & Almarshadi 2013).

There was a significant positive correlation ($P < 0.05$) between fruit yield and rainfall (Fig. 2). It is apparent from this figure that the relationship between rain and fruit yield was linear. For every increase in 100 mm of annual rain above 400 mm per year there was an increase of approximately 2500 $kg \cdot ha^{-1}$ in fruit yield.

Fruit yields were significantly different among the rootstocks in all the experimental years, except for 2010 (Table 3). From 2005 to 2009, Sadoré and Tillabéry rootstocks gave the highest fruit yields. There was no significant difference in yields among the rootstocks when yields were averaged over a six-year period. There were marked annual variations in fresh fruit yield between the different rootstocks. The lowest yield was recorded in 2005 and highest in 2010 year.

Table 2. Effect of five varieties of *Ziziphus mauritiana* on fruit yield (kg·ha^{-1} ± SE) over a six-year period

Varieties	2005	2006	2007	2008	2009	2010	Average yield/variety
Ben Gurion	2231 ± 555	1181 ± 309	4964a ± 1123	1398b ± 577	1816b ± 764	6770b ± 1201	3060ab
Gola	1223 ± 388	888 ± 137	4348ab ± 483	2022a ± 359	3373a ± 421	8596a ± 1404	3408a
Kaithli	969 ± 452	1150 ± 192	2792bc ± 608	1533b ± 483	1934b ± 483	6848b ± 2090	2538b
Seb	1173 ± 613	1290 ± 243	1839c ± 748	674c ± 483	1022b ± 624	5846b ± 2059	1974b
Umran	924 ± 376	964 ± 154	3716b ± 468	2703a ± 406	3452a ± 452	9859a ± 1872	3603a
Average yield/year	1304	1094	3532	1666	2319	7584	
p	0.071	0.559	0.033	0.029	0.004	0.235	<.001

± Standard error. Means within the same column and row followed with the same letters are not significantly different according to LSD test at $P < 0.05$.

Effect of varieties and rootstocks on one fruit weight

There were significant differences in the weight of one fruit among varieties. 'Seb' had the lowest fruit weight, whereas 'Umran' recorded the highest fruit weight (Table 4). A number of studies assessing the performance of improved *Ziziphus mauritiana* varieties also found that Umran variety had the greatest fruit weight as compared to other improved varieties (Aulakh et al. 2005; Ghosh & Mathew 2002). Rootstocks had no significant effect on the weight of individual fruit.

Shelf-life and total soluble solids (TSS) of Pomme du Sahel (PDS) varieties

A shelf-life of five Pomme du Sahel varieties is presented on Fig. 3. The color started changing from the first day of storage. 'Kaithli' was the only variety that did not start changing color after two days. In all the varieties the color changed fully within 4 days of storage at 25 °C. Short shelf-life is a major problem for Pomme du Sahel fruits. Cooling is a good way for extending shelf-life of this fruit. Earlier study by Jawanda et al. (1980) showed that fruits dipped for 30 sec in waxes and stored in perforated polyethylene bags extends the shelf-life to 10-12 days. Fruits cooling at 3 to 5 °C can extend shelf-life beyond 14 or 21 days depending on the variety (Pareek et al. 2009). However, cooling conditions are not available in most places in dry Africa. Storage in polyethylene bags also improves shelf-life (Jawanda et al. 1980) and this technology can be implemented in Africa.

The TSS of 'Seb' was the lowest out of the five tested varieties and 'Gola' and 'Umran' had the highest TSS (Fig. 4). 'Gola' had relatively high yield, big fruits and a high TSS (Baloda et al. 2012), which is confirmed in this research also, but it was found to be particularly sensitive to the *Ziziphus* fruit fly and for this reason it was discarded.

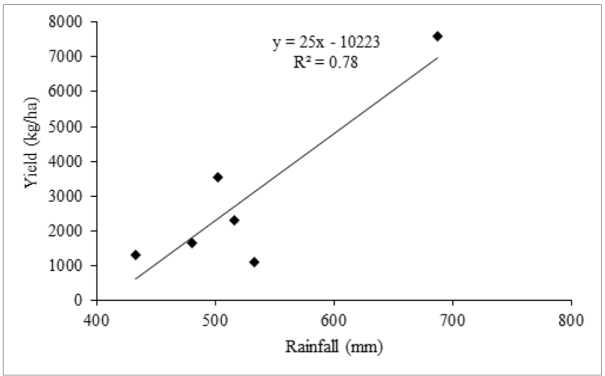

Fig. 2. Relationship between annual rainfall and yield of *Ziziphus mauritiana* varieties

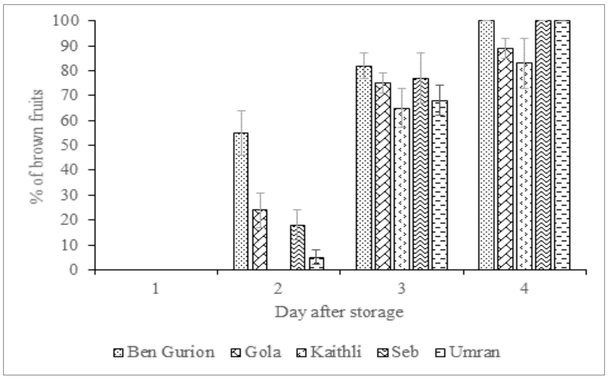

Fig. 3. Effect of variety of *Ziziphus mauritiana* on fruits shelf-life (bar denoted the standard error)

Table 3. Effect of six rootstocks on fruit yield (kg·ha^{-1} ± SE) of *Ziziphus mauritiana* over a six-year period

Rootstocks	2005	2006	2007	2008	2009	2010	Average yield/root stock
Ayerou	1438a ± 384	671c ± 187	3997b ± 608	1794c ± 530	2851c ± 624	9407a ± 1794	3360
Birni N'Gaouré	541c ± 308	950bc ± 163	3432bc ± 530	1654c ± 468	2761c ± 546	7117b ± 1606	2742
Dosso	482c ± 348	1087b ± 178	4649b ± 577	2012bc ± 499	3073c ± 593	8502a ± 1529	3301
Gaya	1005b ± 470	856c ± 240	3058c ± 780	2215bc ± 686	2917c ± 795	6209b ± 2293	2700
Sadoré	635c ± 347	1159ab ± 178	4477b ± 733	3229a ± 499	4493a ± 593	9329a ± 1685	3886
Tillabéry	1465 ± 332	1426 ± 170	5725 ± 936	2465 ± 484	3806 ± 561	9563 ± 1685	4075
Average yield/year	928	1025	4223	2228	3316	8355	
p	0.005	<.001	<.001	<.001	<.001	0.746	0.583

± Standard error. Means within the same row followed with the same letters are not significantly different according to LSD test at P < 0.05.

CONCLUSION

The dry land plantation of Pomme du Sahel gives an alternative for diversifying rain-fed crop production in the Sahel. Fruit yield is highly variable between varieties. The Umran variety produced the highest yield whereas 'Seb' had the lowest. The rootstocks did not significantly affect fruit yield and fruit weight when averaged over the six years period. The identification of rootstocks for improving fruit yields of domesticated *Z. mauritiana* in the Sahel should be therefore continued. The evidence from the current study indicates that the introduction of rainfed fruit trees plantations based on the improved varieties of *Ziziphus mauritiana* to the traditional rainfed production system of the Sahel can improve people nutrition and secure food in drought years. However, the economic feasibility of this system still needs verification.

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Table 4. Effect of variety and rootstock of *Ziziphus mauritiana* on average fruit weight

Varieties	Fruit weight (g)	Rootstocks	Fruit weight (g)
Ben Gurion	13.2 b ± 1.6	Ayerou	15.8 ± 1.7
Gola	13.5 b ± 1.4	Birni N'Gaouré	15.3 ± 3.0
Kaithli	22.2 a ± 4.1	Dosso	16.2 ± 2.4
Seb	9.5 c ± 1.7	Gaya	17.8 ± 3.9
Umran	25.8 a ± 3.6	Sadoré	14.3 ± 1.9
		Tillabéry	17.6 ± 2,9
F. prob.	<.001	F. prob.	0.936

± Standard error. Means within the same column followed with the same letters are not significantly different at P < 0.05.

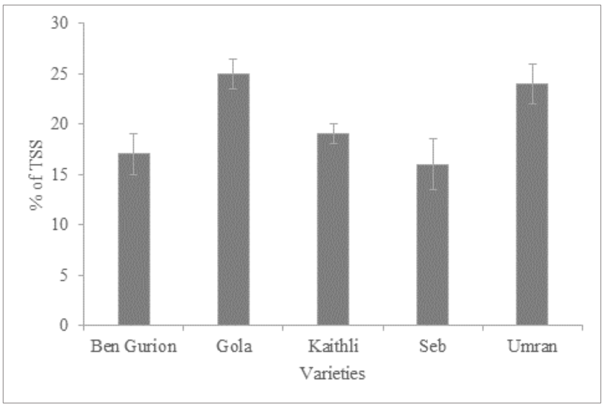

Fig. 4. Effect of variety of *Ziziphus mauritiana* on content of total soluble solids (bars represent ± standard errors)

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