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NEW SUBTROPICAL FRUIT AND NUT CROPS FOR ARID LANDS

Final Report
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Y. Mizrahi,* A. Nerd,* I. Martin and B. Monaghan****

*The Institutes for Applied Research
**Thusano Lefatsheng, Gaborone, Botswana

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ABSTRACT

This report summarizes the activity in the introduction of new orchard crops to arid areas in Israel (four sites) and Botswana (one site) between Sept 1985 to Sept. 1988. Ten species collected in arid regions throughout the world were examined. Among them marula (*Sclerocarya birrea* subsp. caffra), Ber (*Ziziphus mauritiana*), Guava (*Psidium guava*) Cactus apple (*Cereus peruvianus*) and Mongongo (*Ricinodendron rautanenii*) proved to be successful either in all or in some locations. Further R&D and evaluation of the economic potential of the species are discussed.

Key words: wild fruit trees, local fruit trees, propagation, experimental plots, environment, salinity, frost, growth, fruiting, Israel, Botswana

INTRODUCTION

The aim of this study was to expand the number of fruit and nut trees that can be cultivated in warm arid regions. The study was based on the idea that unexploited germplasm available in arid areas all over the world is a potential source of new crop trees with high adaptability to arid environments.

The present report documents methodology and data obtained in Israel and Botswana during the years of the AID-CDR funding, 1985-1988, and also some important recent data. Since this is a long-term study, ongoing observations are still being made.

METHODOLOGY

Plant candidates

Suitable plant species, usually wild fruit trees appreciated by local people or crop trees cultivated in particular areas, were selected against a background of information supplied by economic botanists and growers of rare fruits (Table 1). Most species were propagated by seeds except for ber and prickly pear which were propagated by graftings and cuttings, respectively. Propagation by seed was preferred to vegetative propagation since it provides high genetic variability which is important for testing primitive plant material. The plants were propagated under quarantine conditions and then transferred to a nursery until planting.

Table 1. Plant candidates—source of plant material and fruit characteristics

Name	Source of germplasm	Fruit characteristics
African plum *Harpephyllum caffrum* (Anacardiaceae)	South Africa (East)	Oblong, thinly fleshy, red when mature, small
Marula *Sclerocarya birrea* subsp. *caffra* (Anacardiaceae)	Northern Transvaal central and northern Botswana, Namibia and Zimbabwe	Plum-sized drupe Edible parts: flesh (juicy, aromatic) and nut
Mongongo (Manketi) *Ricinodendron rautanenii* (Euphorbiaceae)	Northern Botswana and Zimbabwe	Plum-sized fruit Edible parts: thin pericarp, chiefly nut
Ciruelo *Cyrtocarpa edulis* (Anacardiaceae)	Baja California	Small berry, yellow skin and juicy pulp
Guava *Psidium guava* (Myrtaceae)	Sri Lanka	Medium-sized berry
Ber (*Ziziphus mauritiana*) (Rhamnaceae)	India	Small to medium berry, apple-like pulp
Prickly pear *Opuntia ficus-indica* (Cactaceae)	Israel and Texas	Medium-sized fruits with hard nonedible seeds
<u>Columnar cacti</u>		
Apple cactus *Cereus peruvianus*	Gardens in California	Medium to large fruit with small edible nutritious seeds
Pitaya agria *Stenocereus gummosus*	Sonora, Mexico	"
Pitaya de mayo *S. griseus*	Oaxaca, Mexico	"

Table 1. Cont.

Name	Source of germplasm	Fruit characteristics
Pitaya dulce *S. thurberi*	Sonora, Mexico	"
Cardon pelon *Pachycereus pringlei*	Sonora, Mexico	"
Cardon burbon *P. pecten-aboriginum*	Sonora, Mexico	"

Introduction orchards

Orchards were established at four sites in the Negev desert of Israel—Qetura and Neot Hakikar (Arava valley), Ramat Negev (Negev heights) and Besor (Western Negev)—and at one site in Botswana—Thusego, which is 45 km west of the capital city Gaborone on the edge of the Kalahari desert.

Each introduction orchard had its particular climate, soil, and water properties (Tables 2 and 3). Qetura and Neot Hakikar are characterized by high summer temperatures and brackish irrigation water. At the other sites the conditions are more moderate, but winter temperatures may fall below zero at Ramat Negev (Israel) and Thusego (Botswana). Soils in Israel have a basic pH, while the soil at Thusego has an acidic pH.

Plants of each species were planted at each site in three blocks, 5-10 plants per block (number limited by availability). The block design was used in order to eliminate the effects of random local conditions on plant establishment. Irrigation was supplied via drippers every 3-4 days in the winter (except during rainy weeks) and every 1-3 days in the summer. The quantity of water supplied was adjusted in accordance with evaporation rate (class A pan) and the area of plant cover (increasing from 10% in the first year to 40% in the fouth year). Fertilizer was

applied through the irrigation system at concentrations of 2.9-4.3 mol/m^3 N, 0.2-0.3 mol/m^3 P, and 1.0-1.5 mol/m^3 K.

Table 2. Climate and soil data for the four sites in Israel and for the site at Thusego (Botswana)

	Qetura	Neot Hakikar	Ramat Negev	Besor	Thusego
Climate					
Max/Min mean daily temperature (°C)					
Hottest month (August in Israel and March in Botswana)	37/23	38/28	33/15	30/18	31/19
(Coldest month (January in Israel and July in Botswana)	18/7	20/12	15/5	17/8	22/6
Annual pan evaporation (mm)	3000	3600	2200	1800	2700
Annual rainfall (mm)	<50	<50	200	90	340
Soil					
Texture	Sandy loam	Sandy loam	Loam	Sandy loam	Sandy loam
pH	7.6	7.7	7.8	7.5	4.0

Table 3. Irrigation water quality for the four sites in Israel and for the site at Thusego (Botswana)

	Qetura	Neot Hakikar	Ramat Negev and Besor	Thusego
EC (dS/m)	3.5-4.5	3.7-4.5	0.9-1.1	0.6-0.8
Osmotic pressure (MPa)	1.3-1.7	1.4-1.7	0.3-0.4	0.2-0.3
pH	7.7	7.6	7.5	~4
Ion content (mg/L)				
Na	240-304	520-1080	100-130	
Ca	260-272	200-265	48-111	
Mg	100-138	131-148	26-52	
Cl	520-650	865-1003	265-278	
SO_4	818-840	360-630	50-102	

Values in the Table are ranges of values obtained over the period of the experiment.

Research activities

Plant height was measured periodically, and phenological events were recorded throughout the year. Yields were determined on fruiting trees, and fruit were sampled for quality analysis. In prickly pear the research was extended to farmer plots, where practical problems were investigated.

Reports

The current research has been described in annual and progress reports (Mizrahi et al. 1986; Nerd et al. 1986; Nerd et al. 1987a,b; Nerd et al. 1988). In addition some subjects which were covered by the research were published in scientific journals and proceedings (Nerd et al. 1989, 1990, 1991, 1993; Nerd and Mizrahi 1993; Weiss et al. 1993; Nerd et al. 1993), see Appendix.

RESULTS AND DISCUSSION

Performance. The growth of the plants, expressed as height or total stem length in 1990, is presented in Table 4 (Israel) and Table 5 (Botswana). For most of the species growth at Neot Hakikar was inferior to that at the other sites. Only marula and ciruelo showed vigorous growth at Neot Hakikar. Mongongo had the lowest adaptivity (Table 4) of all the species; it thrived only at Besor. The sensitivity of most of the species to the conditions of Neot Hakikar is possibly a result of high concentrations of Na^+ and Cl^- in the brackish irrigation water which damage the plant. This assumption is based on the fact that Neot Hakikar is similar to Qetura in climatic and soil conditions and in the EC and osmotic pressure of the irrigation water, but concentrations of Na^+ and Cl^- at Neot Hakikar are much greater than those at Qetura (Table 3). The low growth at Ramat Negev (mongongo, pitaya de mayo and prickly pear) is related to winter subfreezing temperatures that occurred at this site every year and damaged the plants. Ciruelo was also sensitive to low temperatures and suffered even under the more moderate conditions of Besor. In general, the data indicate different adaptivities of the various species to specific sites in the Negev, which may be related to species tolerance to salinity and to extreme temperatures.

Botswana. Since the orchard in Botswana is younger than the orchards in Israel it is too early to evaluate the adaptivity of the species to the conditions of the experimental site. However, it is already very clear that some species, such as African plum, marula, and ciruelo, are sensitive to the low winter temperatures occurring at this site. Since the large native marula population that surrounded the plot did not suffer from cold damage, it can be assumed that sensitivity of plants grown in the orchard to cold was due to cultivation agrotechniques, probably irrigation, which prevented hardening of the plants.

SUMMARY FOR INDIVIDUAL SPECIES.

In this section, plant establishment and evaluation of the economic potential of the plants are discussed.

African plum

This evergreen tree established well in all the orchards. However, at Neot Hakikar it died as a result of salinity. At Ramat Negev it suffered considerably from

Table 4. Plant performance at four sites in the Negev in the Autumn of 1990 for 10 species. Years of planting were 1985-86

Common name	Qetura		Neot Hakikar		Ramat Negev		Besor	
	Height or TSL[z] (m)	Adap.[y]	Height or TSL (m)	Adap.	Height or TSL (m)	Adap.	Height or TSL (m)	Adap.
African plum	3.5±0.4[w]	4	Died		2.8±0.2	4	4.7±0.4	4
Marula	>5.5	4	3.5±0.4	4	2.9 ±0.2	4	5.3 ±0.2	4
Mongongo	1225±0.2	1		1	1.4±0.1	1	3.2±0.2	4
Ciruelo	3.3±0.2	4	3.0±0.4	4	NP[x]		2.4±0.3	3
Apple cactus	7	3	3	2	11	3	18	4
Pitaya agria	1.5	4	1	2	6	4	7	4
Pitaya do mayo	0.5	4	0.5	2	1	4	1	4
Pitaya dulce	0.3	4	0.2	2	0.4	4	0.3	4
Cardon pelon	3	4	0.1	2	0.2	4	0.3	4
Prickly pear (yellow cultivar)	~3	4	0.8±0.2	2	2.5± 0.2	2	~3	4

[z]TSL = total stem length. TSL was measured for the columnar cacti and height was measured for the other species.
[y] Adap. = adaptiv ity. Scale for ranking adaptivity was: 1 = high mortality, 2 = poor growth, 3 = fair growth, 4 = good to excellent growth.
[x]Not planted
[w]Mean + SE.

subfreezing temperatures, and some of the survivors are in the process of recovering. At Thusego after a spell of subfreezing temperatures all the trees died. At Besor the trees reached a height of 4.7 meters while at Qetura the height was less than 4 meters (Table 5). In both orchards three-year-old plants have started to bear fruits. The fruits are small and the flesh is very juicy and tasty but insubstantial (there is not much to eat). The expectation that the fruit of this species would serve as a food source has thus not materialized.

Table 5. Plant performance at Thusego (Botswana) in the summer of 1989-90 for five species planted in 1987

Common name	Height ±SE (m)	Mortality (% of total)
African plum		100
Marula	0.7±0.1	67
Mongongo	2.1±0.5	0
Ciruelo		100
Prickly pear (yellow cultivar)	~3	0
Ber	~3	0

We have made widespread enquiries among colleagues to ascertain whether any selection for larger fruits or higher percent of flesh has been carried out. It appears that, contrary to our previous information, no such studies have been undertaken. At this stage we are assigning a low priority to further research on this candidate. However, it is highly recommended as an ornamental or backyard tree which can bear beautiful, tasty but small fruits.

Phenology: Flowering occurred in Israel in May and fruits ripened in August.

Propagation: The plant is easily propagated by seeds as well as by cuttings.

Marula

This plant is doing well in all locations, with the exception of its native area, Botswana, where subfreezing temperatures in the winters of 1988 and 1989 caused heavy damage to the plants. Branches were frozen and killed almost to the base. The trees were also badly affected by an as yet unidentified wood-boring grub. It was

recommended that in Botswana irrigation be withheld before the winter in order to harden the plants.

Table 6. Yields, average fruit weight and ripening time of the various marula trees at the Qetura orchard

Year and tree no.	No. of fruits per tree	Fruit fw (kg/tree)	Average fruit weight (g)	Ripening time
1988				
1	19	0.418	22.0	7/7-26/7
2	58	1.320	22.8	30/6-26/7
3	48	1.160	24.2	2/7-26/7
1989				
1	55	2.19	39.8	18/7-14/8
2	104	4.05	38.9	15/7-14/8
3	46	1.8	39.1	18/7-14/8
7	10	0.4	40.0	22/7-14/8
1990				
1	1020	25.5	25.0	2/8-26/8
2	2510	50.2	20.0	25/7-26/8
3	1515	50.5	33.3	12/8-38/8
6	123	4.1	33.3	18/8-30/8
7	117	3.5	29.9	18/8-30/8
17	14	0.344	24.6	30/10
20	5	0.148	29.6	30/10

Plants no. 1, 2, 3, 4, 5, 6 & 7 were planted in 1985. All other trees were planted in 1987.

In Israel all the marula plants are doing well at all the locations. During the winter of 1988-89 after a spell of -7°C at Ramat Negev (one night only), all branches were killed almost to the base. The trees were pruned during the spring up to the live portion of the stem. The trees have resumed growth and regained their height. Although the trees reached a significant size at all the sites in the Negev, flowering and fruiting occurred only at Qetura. Flowering and fruiting started in the third year, and yields are increasing from year to year (Table 6). It might be that the combination of warm summer and brackish water at Qetura promote precocious

fruiting in marula. It should be noted that marula was tolerant not only to the salinity of Qetura but also to that at Neot Hakikar, where the toxic ions Na^+ and Cl^- are present in higher concentrations than at Qetura.

Phenology: At Qetura about 50% of the trees retained their leaves throughout the winter. At Neot Hakikar all the plants retained their leaves throughout the winter in the block that was not affected by accumulation of salt. At the other locations leaf abscission occurred at the end of December-beginning of January. In Botswana (southern hemisphere) leaves fell in June and July. At Qetura, flowering occurred in April, fruit set in May, and ripening in July-August. Some seedlings planted in 1987 bore fruit from October to December. Bud break began in April at Neot Hakikar and Qetura, and in May at Besor and Ramat Negev. It thus may be that marula does not require low temperatures for bud-break. In conclusion, marula seems a promising species which deserves more attention during the next stage of our research. We recommend that a search be conducted in Botswana among wild populations to select heavy yielders with large fruit and good color and taste characteristics.

Propagation: Seeds germinate within several weeks when the opercula (the shell which covers the openings of the stone endocarp) is removed. This species can easily be propagated by bud grafting as well as by cuttings; we had 95 and ~50% success, respectively. Root cuttings are also a very promising way of propagation, giving a high success rate.

The results of the marula study presented here and summarized in our paper (Nerd and Mizrahi, 1993) indicate that marula cultivation has a future in the Negev of Israel, and possibly also in Botswana provided appropriate agrotechniques are adopted. We are now in the process of propagating improved clones selected by us in Botswana or by the University of Pretoria. These will be tested for potential commercial cultivation in both Israel and Botswana.

Mongongo

In Botswana, after excellent initial growth, the plants were exposed to -5°C and died back to the thick part of the stem. During the summer they recovered to their original height. After recovery the growth rate was excellent. The natural growth habit is an upright tree with a straight trunk.

In Israel we obtained diverse results with this species, the best location for growth and development being the Besor area. The growth habit in Israel is quite different from that at Thusego, the tree being wide and well developed. There is large variability in growth and development: some of the trees are very well developed while others hardly grow. This phenomenon may be related to the expected genetic variability. At Ramat Negev all 30 plants died due to the subfreezing temperature event (-7°C) which has already been described for marula. Unlike marula, not a single mongongo plant survived. At Qetura, three-year-old plants showed symptoms of yellowing, perhaps due to salinity damage, and later degenerated. Early results showed accumulation of Na^+ and Cl^- in the leaves to have been greater at Qetura than at Ramat Negev and Besor. At Neot Hakikar mongongo plants did not survive more than one year and showed severe leaf burn before death.

Phenology: Mongongo plants shed their leaves in January (July in Botswana) and remain dormant until end of May - early June. Apical dominance is evident even though the side buds develop later. In Botswana, an individual plant (2 years old; recovering from die back from frost!) flowered in November 1989, but the flowers were destroyed by a hail storm. With the exception of *Opuntia*, mongongo was the only species to start reproduction in Botswana (planted one year after Israel).

Propagation: Treating the seeds with Etherel enhanced germination. Vegetative propagation should be considered for the future.

Ciruelo

This species from Baja California established well at all locations. It is currently growing satisfactorily at all the sites with the exception of Thusego (Botswana), where it was eradicated by subfreezing temperatures. It also shed some of its leaves in the winter in the Besor orchard. At Neot Hakikar and Qetura three-year-old plants yielded a plentiful crop of small yellow fruits, more than 2 kg per tree. The fruit is sour and can only be stored for a few days at 20°C (up to 6 days). It then becomes too soft and has a strong "off"-flavor. A few people enjoy the taste of this fruit, while many others are repelled by it. All tasters claim that the fruit leaves a pistachio-like flavor in the mouth. Because of the dispute about its taste, its very short shelf-life and its small fruit size, we will give this species low priority. It

should be mentioned that this plant is a good producer under both salinity types: that prevailing at Qetura and that at Neot Hakikar.

Guava

Seedlings grew vigorously and yielded precociously at Thusego and in the Negev, except at Neot Hakikar where they suffered from salinity. Guava is a crop that is already known in Israel and may also be promoted in Botswana.

Ber

Plants exhibited high adaptivity to the conditions of Thusego as well to the various sites in the Negev. They showed tolerance to the low temperatures of Ramat Negev and to the high summer temperatures and the salinity of Qetura and Neot Hakikar. Ber's tolerance to salinity can be compared to that of the date palm, which is considered to be the fruit tree most adaptive to saline conditions.

Since ber is a well-known crop in India and improved cultivars are available, we are propagating known cultivars by vegetative propagation for planting in the plots. Grafting is very successful, and grafted plants are ready for planting half a year after grafting. We also tried propagation by cuttings, but only <10% of the shoots developed roots under usual nursery conditions. The cultivars in our stock are seb, gola, umran and kaitly. The rootstocks that we examined are *Z. mauritiana*, *Z. spina christi* and *Z. abyssinica*. Farmers in both Israel and Botswana have expressed interest in growing ber, and plant material was recently propagated for commercial cultivation.

Columnar cacti

Most of the research on columnar cacti was conducted in Israel. The apple cactus preferred moderate conditions and grew best at Besor. The other species —Pitaya agria, Pitaya de mayo, Pitaya dulce, cardon pelor and cardon burbon—also did well under more extreme conditions of high temperatures and brackish water (Qetura). The growth of all the species was significantly retarded at Neot Hakikar, probably because of the high Na^+ and Cl^- content of the irrigation brackish water. Two species were sensitive to subfreezing temperatures: apple cactus and pitaya de mayo. Cardon burbon was excluded from the program in the fourth year because of its low quality, despite the fact that it yielded precociously.

At this stage the apple cactus is the most promising candidate for domestication. It has a high growth rate, precocious fruiting and delicious fruits. More data on the columnar cacti are presented in two papers, Weiss et al. (1993) and Nerd et al. (1993) (See Appendix).

Prickly pear

In terms of cultivation prickly pear is the most advanced species. In addition, as was the case for ber, we started with vegetatively propagated, selected plant material. All the plant material that we have in Israel is already growing at Thusego (Botswana). Growth is excellent at Thusego, and a good harvest is expected in early 1992. It is interesting to note that despite the spell of subzero temperatures (-5 and -4°C) at Thusego during July and August 1989 the plants are still doing very well, without any noticeable damage. Prickly pear is already fruiting in Botswana, and in our opinion the recommended cultivars are ready to be tested on a commercial scale and/or given to farmers to be grown in their back yards.

In Israel the species is doing well at Qetura and Besor. At Ramat Negev many genotypes showed cladode "burning" after a spell of subfreezing temperatures of -3 and -7°C. (We note that these are the temperatures registered at the height of the plants, whereas the temperature measurements at the official climatological station are taken at a height of ~2 m and are therefore higher.) Some genotypes also showed severe damage in December 1989 and tey are recovering slowly. At Neot Hakikar development is very slow, probably due to salinity; prickly pear is a salt sensitive plant (Nerd et al. 1990).

SUMMARY OF RESEARCH RESULTS AND STATE OF THE ART

1. A lot of valuable information has accumulated concerning various aspects of the cultivation of lesser known fruit and nut trees. Not all the plant candidates have proved to be successful. The plant candidates can be divided into three groups, as follows:

A. Low-potential candidates that were removed from the R&D program
1. Ciruelo - *Cyrtocarpa edulis*
2. African plum - *Harpephyllum caffra*
3. Cardon burbon - *P. pecten-aboriginum*

B. Species that need more time and R&D before a final conclusion can be drawn:
1. Cardon pelon - *P. pringlei*
2. Pitaya agria - *S. gummosus*
3. Pitaya dulce - *S. thurberi*

C. High-potential candidates that have proved to be successful, either in all or in some of the locations
1. Marula - (*Sclerocarya birrea* subsp. *caffra*) - Thrived in all locations, including highly saline areas; can recover from subfreezing stress; excellent producer
2. Ber - (*Ziziphus mauritiana*) - Excellent producer in all locations, including those with highly saline water
3. Guava - (*Psidium guava*)
4. Cactus apple - (*Cereus peruvianus*) - Very good precocious producer in areas with moderate salinity and not too cold weather - survived -7°C; recovery after subfreezing temperatures should be followed
5. Mongongo (*Ricinodendron rautanenii*) - Has started to produce in Besor (Israel) and Thusego, (Botswana)

It is highly recommended that commercial production be started of selected genotypes of the high-potential candidates, marula, ber, and apple cactus. In addition prickly pear is ready to be distributed among farmers in Botswana.

For the high-potential candidates we are in a position to serve as gene bank—i.e., as a source of plant material (mainly seeds) for interested people around the world. We have already distributed seeds of these species to several countries.

APPENDIX

List of reports

Mizrahi, Y., Aronson, J.A. and Nerd, A. 1985. New subtropical fruit and nut crop for arid lands; progress report Sept. 1985-Feb. 1986; Report No. BGUN-ARI-20-86.

Nerd, A., Aronson, J.A., Horenburg, F. and Mizrahi, Y. 1986. New subtropical fruit and nut crops for arid lands; annual report September 1985-August 1986. Report No. BGUN-ARI-72-86.

Nerd, A., Aronson, J.A., Martin, J., Mizrahi, Y. 1987. New subtropical fruit and nut crops for arid lands; annual report September 1986-August 1987. Report No. BGUN-ARI-51-87.

Nerd, A., Nkhumane, A. and Mizrahi, Y. 1987. New subtropical fruit and nut crops for arid lands; semiannual report July-December 1987. Report No. BGUN-ARI-1-88.

Nerd, A., Aronson, J.A., Martin, J. and Mizrahi, Y. New subtropical fruit and nut crops for arid lands; progress report September 1987-February 1988. Report No. BGUN-ARI-19-88.

List of scientific papers based on the project

Nerd, A., A. Karadi and Y. Mizrahi, 1989. Irrigation, fertilization and polyethylene cover in prickly pear influence bud development. HortScience 24:773-775.

Nerd, A., J.A. Aronson and Y. Mizrahi 1990. Introduction and domestication of rare and wild fruit and nut trees for desert areas. Pages 355-365 *In* J. Janick and J.E. Simon, eds., Advances *In* New crops. Timber Press, Portland, Oregon.

Nerd, A., and Y. Mizrahi 1993. Domestication and introduction of marula (*Sclerocarya birrea* subsp. *caffra*) as a new crop for the Negev Desert of Israel. *In* J. Janick and J.E. Simon, eds. in Proceeding of the Second National Symposium, New Crops, October 6-9, 1992, Indianapolis, IN, USA.

Weiss, J., A. Nerd, and Y. Mizrahi. 1993. Development of *Cereus peruvianus* (apple cactus) as a new crop for the Negev Desert of Israel. *In* J. Janick and J.E. Simon, eds. in Proceeding of the Second National Symposium, New Crops, October 6-9, 1992, Indianapolis, IN, USA.

Nerd, A., E. Raveh and Y. Mizrahi 1993. Adaptation of five columnar cactus species to various condition in the Negev Desert of Israel. Submitted for publication in Economic Bot. (October 1992).