Ziziphus – a Multipurpose Fruit Tree for Arid Regions

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Keywords. Biogeography, physiology, drought stress, fodder, traditional medicines

Abstract. The progressive desertification in many semiarid regions of the world increases the need for plants that can cope with arid environments and meet peoples' requirements for food, fodder and fuel. Species of fruit trees in the genus *Ziziphus* represent examples of such multipurpose plants with great potential for selection and use in drought-prone regions.

Ziziphus trees and shrubs inhabit arid environments on every continent due to their versatility in being able to adapt to drought stress. They play an important role in the conservation of soil, with their strong root system which stabilizes the soil and protects it from erosion. The leaves provide fodder for livestock, the hard wood is used for turning, making agricultural implements, fuel and high quality charcoal. In many regions, *Ziziphus* is grown as a hedge, with its spines creating effective live-fencing, and with its highly nutritious fruits providing a valuable source of energy, vitamins and also income when sold on local markets. In addition, extracts from fruits, seeds, leaves, roots and bark of *Ziziphus* trees are used in many traditional medicines to alleviate the effects of insomnia, skin diseases, inflammatory conditions and fever. For these reasons, *Ziziphus* trees have an important role to play in the integrated economy of the arid lands.

Introduction

Nearly one third of the Earth's surface or ca. 49 million km^2, excluding polar regions, has been classified as arid land according to soil type, vegetation and climate (Kozlowski et al. 1991). The dynamics of arid land ecosystems is controlled by the limiting availability of renewable resources such as water, soil, nutrients, flora and fauna, which result in their low primary productivity. For centuries mankind has tried to confront the problems of arid lands and to revegetate the deserts. Historically, the main focus has been on the development of new irrigation techniques and to select fruit varieties that could cope with poor water quality, with great effort invested in changing the desert to suit the crops, rather than the other way round (Cherfas 1989). However, a lot of promising drought-tolerant plants are growing naturally in drought-prone areas around the

S.-W. Breckle et al. (eds.), *Sustainable Land Use in Deserts*

world and these may be readily exploited to address the problems in those regions. These natural resources provide a good basis for the selection and development of new perennial plants for arid areas that can meet the escalating demands of ever -growing human and livestock populations with regard to food, fuel, fertilizer, fibre, shelter and medicare. A good example of naturally occurring multipurpose plant species with potential for arid regions are the shrubs and trees of the genus *Ziziphus*.

Description and Distribution

The genus *Ziziphus* (ber, jujube) belongs to the buckthorn familiy (Rhamnaceae). It is a genus of about 100 species of deciduous or evergreen trees and shrubs distributed in the tropical and subtropical regions of the world (Johnston 1963). Some species, like *Z. mauritiana* and *Z. jujuba,* occur on nearly every continent, whereas other species, like *Z. nummularia*, *Z. spina-christi and Z. mucronata,* are restricted in their distribution to distinct areas (Table 1). *Ziziphus* species can grow either as trees and shrubs (*Z. mauritiana, Z. rotundifolia, Z. jujuba, Z. mucronata*) or exclusively as small shrubs or bushes (*Z. nummularia, Z. lotus, Z. spina-christi, Z. obtusifolia*).

The fleshy drupes of several species are rich in sugars and vitamins, and this fact has made *Ziziphus* species important fruit trees for many centuries. In both China and India, *Ziziphus* trees have a long tradition of selection and cultivation, with the result that the species occurring in these countries (*Z. mauritiana*, *Z. jujuba*) are better known and more widely researched than those in other regions. *Z. mauritiana* is an example of an extremely drought-hardy species, and is a dominant component of the natural vegetation of the Indian desert (Cherry 1985). These trees are well adapted to seasonal drought and hot conditions. In India during the summer months of May and June, *Z. mauritiana* enters into dormancy by shedding its leaves. These trees perform well even on marginal and inferior lands where most other fruit tree species either fail to grow or give poor performance (Jawanda and Bal 1978). In India, the scions of varieties which have been selected to improve the yield and fruit quality are routinely grafted on to the vigorous rootstocks of wild species to provide a reasonable cash crop on land which is unsuitable for other forms of cultivation (Cherry 1985). Improved Indian cultivars like Gola and Seb have been imported to Israel and Africa, where they have been grafted onto native rootstocks of *Z. spina-christi* and *Z. abyssinica,* respectively (Cherfas 1989). The same technique was successfully used in Zimbabwe to produce high-quality Indian selections on the native *Z. nummularia* rootstock species (Kadzere and Jackson 1997).

Jujubes (*Z. jujuba*) were eaten by the ancients of the chalcolitic age (1500–1000 b.c.), and the fruits have been in cultivation for the past 400 years in both India and China (Anonymous 1976). At about the beginning of the Christian era, the Chinese jujube was imported into Europe and is now widely distributed throughout Persia, Armenia, Syria and the Mediterranean regions in Spain and

France. Reports of early writers and explorers emphasized the heat and drought tolerance of jujubes, and probably because of this, jujubes were thought most likely to succeed in the dry regions of the southwestern US (Locke 1947).

Table 1. Some important *Ziziphus* species and their occurrence

Continent	Species	Region
Africa	*Z. abyssinica* Hochst.	Tropical Africa
	Z. lotus Lamk.	Northern Africa
	Z. mauritiana Lamk.	Tropical Africa, Sahel Zone, Zimbabwe
	Z. mucronata Willd.	Southern Africa
	Z. spina-christi Willd.	Middle east
Asia	*Z. jujuba* Mill.	China, India, Korea, Malaysia
	Z. mauritiana Lamk.	China, India, Pakistan, Malaysia
	Z. nummularia W.i.A.	India
	Z. oenoplia Mill.	Tropical Asia
	Z. rotundifolia Lam.	India
	Z. rugosa Lam.	India
	Z. sativa Gaertn.	Pakistan
	Z. spina-christi Willd.	Middle east
	Z. xylopyra Willd.	India
Australia	*Z. mauritiana* Lamk.	
Europe	*Z. jujuba* Mill.	Mediterranean
	Z. lotus Lamk.	Mediterranean
	Z. mauritiana Lamk.	Mediterranean
	Z. sativa Gaertn.	Mediterranean
North America	*Z. amole* M.C.Johnst.	Mexico
	Z. celata J.i.H.	USA
	Z. jujuba Mill.	USA
	Z. mexicana Rose	Mexico
	Z. obtusifolia Gray	Mexico, USA
South America	*Z. cinnamomeum* Tr.&Pl.	Venezuela
	Z. mistol Griseb.	Argentinia, Paraguay
	Z. joazeiro Mart.	Brazil, Paraguay
	Z. oblongifolia S.Moore	Brazil

Physiological Characteristics

Currently, most cash crop fruit production in semiarid regions relies on species such as peach, which require relatively intensive management and high irrigation inputs for successful establishment and fruit development. Compared to other more commonly cultivated fruit tree species like peach, *Ziziphus* species have several physiological and morphological characteristics that may contribute to their ability to adapt to arid environments (Table 2).

Table 2. Physiological parameters of well watered *Z. mauritiana* and *Prunus persica* (peach) trees measured in the field[a] or in the glasshouse[b], respectively.

Parameter		*Z. mauritiana*		*P. persica*	
[a] A	(μmol m^{-2} s^{-1})	20.4	*c*	9.4	*c*
[a] g_s	(mol m^{-2} s^{-1})	0.5	*c*	0.1	*c*
[b] NRA_{leaf}	(μmol g^{-1} FM)	3.8	*f*	0.8	*d*
[a] Nitrogen	(% leaf DM)	3.7	*f*	3.5	*f*
[a] Starch	(% root DM)	29.7	*e*	15.0	*e*
[a] Root:shoot ratio (DM basis) (1 year old trees)		1.9	*e*	0.5	*e*

A, net carbon assimilation; *g,* stomatal conductance; *NRA,* nitrate reductase activity; *c,* Clifford et al. (1997); *d,* Bussi et al. (1997); *e,* Jones et al. (1998); *f,* unpublished

Ziziphus plants typically develop a deep and extensive root system that ensures its ability to exploit deep water sources, thereby maintaining a sufficient water and nutrient supply for prolonged periods when the upper soil layers are drying out. An indication of the importance of the root is the high root-to-shoot ratio of *Z. mauritiana* and deep rooting which has been reported as a characteristic of both *Z. nummularia* (Anonymous 1976) and *Z. mauritiana* (Depommier 1988). Under ideal environmental conditions, *Z. mauritiana* exhibits very high rates of net photosynthesis and stomatal conductance. Any surplus of assimilated carbohydrates that is not invested in growth is stored as starch in the roots, leading to very high reserves of carbohydrate in the below-ground structures. Compared to other species for which data are available, the nitrate reductase activity (NRA) in leaves of *Z. mauritiana* is very high, with nitrate reductase activity of 1 μmol NO_2^- g FM^{-1} h^{-1} measured in leaves of drought-stressed plants (pre-dawn Ψ_{leaf} 2.0 MPa, unpubl. data from our lab). Nitrate reductase activity is usually very sensitive to drought stress, and high NRA levels are a prerequisite for rapid growth during favourable conditions to meet the plant's high demand for nitrogen for production of amino acids, proteins and nucleic acids. Consequently, total nitrogen content of the leaves is very high, which is a mesic character of *Ziziphus* leaves, that lack xeromorphic adaptations such as heavy cuticularization, or deep folds in their surfaces with sunken stomata. The combination of high levels of NRA and net photosynthesis results in a high relative growth rate, essential if these plants are to compete effectively during brief periods of active growth. The large carbohydrate reserves in the roots contribute to the strong regeneration potential of *Ziziphus* plants. *Z. mauritiana* is reported as having a great power to recover from injury of any kind, including fire, and thrives on burnt grassy tracts (Anonymous 1976; Grice 1996). After such events, most plants of *Z. mauritiana* resprouted vigorously within 3 months and by the 4th month after fire, burnt and unburnt plants were similar with respect to the distribution of individuals and their physiological characteristics (Grice 1997). Because of its ability to resprout from both crown and roots, along with its resistance to herbicides, *Z. obtusifolia* has demonstrated its ability to increase its cover on Texas rangeland after the release of competition from other woody vegetation by bush control treatments (Speer and Wright 1981). There are reports that wild jujube plants (*Z. lotus*) also have the ability to resprout vigorously even after being cut to groundlevel in the previous fall in Morocco (Regehr and El Brahli 1995).

Ziziphus plants are cross-pollinated and are highly outbreeding, and as a result of this, the natural population, which largely regenerates through seeds, exhibits a vast range of genetic heterogeneity. The potential of this variability has been severely underutilized. In contrast, the commercial cultivars which are clonally propagated via budding on a suitable rootstock, have retained their genetic fidelity. In evolutionary terms, this genetic variability may well benefit *Ziziphus* in harsh environments by allowing rapid adaptation to changing environmental conditions at a population level.

Mechanisms of Drought Resistance

A wide range of physiological studies conducted on *Ziziphus* have demonstrated that *Ziziphus* species are tolerant of high temperatures and drought conditions encountered in arid regions (Clifford et al. 1997, 1998; Arndt et al. 2000). This research revealed that *Ziziphus* species are very flexible in response to drought and that they exihibit a range of reaction mechanisms (Fig. 1).

The first mechanism is one of drought avoidance through production of an extensive root system maintaining contact with deep water sources. In times of moderate water limitation, stomatal control of water loss maintains plant water status as the soil dries. Results from glasshouse experiments confirmed the high sensitivity of stomatal closure in *Ziziphus* during drought, with significant reductions in conductance occurring before any change in leaf water potential could be detected (Clifford et al. 1998). When water stress became more severe, osmotic adjustment occurred. Active accumulation of solutes in the cell sap contributed to turgor maintenance, this being a prerequisite for continued growth during drought (Hsiao et al. 1976). As a consequence of osmotic adjustment in *Ziziphus*, many metabolic functions can continue even under severe drought stress. When water is severely limiting, *Ziziphus* trees are able to selectively shed their mesophytic leaves. Leaf loss in water-stressed plants can be regarded as a beneficial adaptation that reduces water loss and in the short-term prolongs survival. *Ziziphus* trees are able to survive long periods without leaves, with high levels of mucilagenous substances in the twigs and stems which may act as a water capacitor (unpubl. data from our lab). This, together with the high carbohydrate reserves in the root, supports the maintenance of metabolism during drought periods and may enable quick, vigorous resprouting, as soon as water is available again.

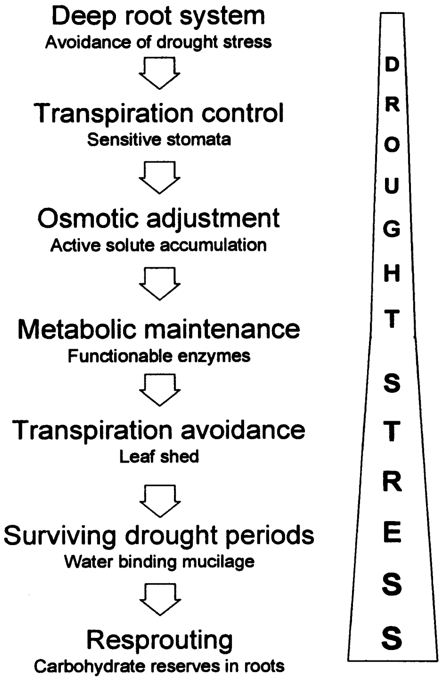

Fig. 1. Mechanism of drought resistance in *Ziziphus rotundifolia*

Consequently, Ziziphus trees exhibit a flexible combination of mechanisms of drought avoidance and drought tolerance. They can respond in various ways to drought stress and this makes them well adapted to changing environmental conditions typical in semiarid and arid regions, where the patterns and amounts of rainfall are extremely erratic.

Use as Multipurpose Trees

A great majority of the rural population in arid regions meet their daily household requirements through biomass or biomass-based products such as food, fuel (firewood, cowdung, crop wastes), fodder, fertilizer (organic manure, forest litter, leaf mulch), building materials (poles, thatch) and medical herbs. *Ziziphus* species meet many of these needs and they can be used for a variety of purposes in arid regions.

Shelter Vegetation

Ziziphus species can contribute to control the rate of desertification. Soil erosion in desert areas is largely due to the removal of structureless topsoil by the wind and rain. This can largely be checked by planting wind breaks, creating shelter belts and stabilizing sandy tracts and dunes with adapted grasses and shrubs like *Ziziphus* (Khoshoo and Subrahmanyam 1985). *Z. nummularia* shrubs have been shown to effectively check wind erosion, help in deposition of soil, and bring about a change in the microhabitat, causing favourable conditions for the appearance of successional species such as perennial grasses (Anonymous 1976). In the Sahelian climate, *Z. mauritiana* plays an important part in the conservation of soil because of its abundance and vigorous root systems (Depommier 1988).

Fruits

The fruits of all *Ziziphus* species are edible and can be prepared for consumption in many ways. The drupes are eaten either fresh, pickled, dried or made into confectionery, and the juice can be made into a refreshing drink (Khoshoo and Subrahmanyam 1985). In Zimbabwe, *Ziziphus* fruits are used to produce jam and kachaso, a crudely distilled spirit of consirable potency (Coates Palgrave 1990).

Though the fruit does not find much favour with the upper classes (poor man's fruit, Khoshoo and Subrahmanyam 1985), it has a high nutritional value and a great commercial potential. Consequently, in many regions of the world, *Ziziphus* fruits are sold on local markets, generating cash income for people of rural areas and improving family nutrition. In Oman, the most widespread indigenous fruit tree that grows in wadis throughout the country is *Z. spina-christi*, and the small brown fruits are sold in the suk (Lawton 1985). In Zimbabwe, the people from the rural areas pick the fruits of the wild-growing *Z. mauritiana* for sale in the urban markets.

Fruits of *Z. mauritiana* have higher contents of protein and vitamins A and C than apples (Anonymous 1976). The fruits contain between 70 and 165 mg ascorbic acid per 100 g of pulp, which is two to four times higher than the vitamin C content of citrus fruits. The mineral content of calcium, phosphorus and iron in *Z. mauritiana* fruits is also reported as being higher than in apples and even oranges (Jawanda and Bal 1978).

For farmers, *Z. mauritiana* is an interesting crop because it is so fast-growing and bears fruits within 2–3 years (Jawanda and Bal 1978). The yield varies according to precocity and bearing potential of different types, but it increases progressively with the age of the trees. In India, Umran is the highest yielding cultivar of *Z. mauritiana* in Punjab, giving an average yield of 80–200 kg ha^{-1}. (Anonymous 1976). In Australia, some large specimens of *Z. mauritiana* were reported as producing more than 5000 seeds per plant in 1 year, but with great variation between individual shrubs and between seasons (Grice 1996). In China, *Z. jujuba* plays an important role as fruit tree. It produces very large, tasty fruits, the so-called Chinese dates, which have an importance similar to that of dried plums in Europe (Warburg 1916). In the late 1950s, *Z. jujuba* was ranked as the most important fruit tree crop in China (Pieniazek 1959).

Fodder, Fuel and Fencing

Besides the fruits, nearly every organ of *Ziziphus* plants can be utilized. The leaves and twigs of most *Ziziphus* species can be used as high nutritional fodder for livestock. Due to their high protein content per dry weight, they are an important nitrogen source for the animals. *Z. nummularia* is prized for its leaves, which provide fodder for livestock in the summer months, particularly in the fodder-deficient areas of Punjab, Haryana and Rajasthan in India, where the average total yield of forage was ca. 1000 kg ha^{-1} (Anonymous 1976). In the Sahelian climate, the young leaves of *Z. mauritiana* are commonly eaten as vegetables, with the older foliage used as fodder (Depommier 1988). Sena et al. (1998) pointed out that leaves of *Z. mauritiana* are an important famine food in Niger because they are an excellent source of the essential fatty acid linoleic acid and several metals including iron, calcium, magnesium and zinc.

The wood of the *Ziziphus* tree species is dense and compact. It is used for various purposes in the everyday life of the people including the production of tools, poles, toys, and for turning. *Z. mauritiana* is an excellent fuel–wood tree and makes a good charcoal, with a heat content of 4900 kcal kg^{-1} (Khoshoo and Subrahmanyam 1985). In the Sahel Zone, it is considered good both as firewood and charcoal (Depommier 1988). *Z. nummularia* has also been reported to produce high-quality hardwood with high calorific value, making it an ideal source of fuel and charcoal (Anonymous 1976).

The spiny branches are widely used as living fences. The twigs of *Z. nummularia* are also used as fencing material and for making cool-airscreens for use on the windows (Jones et al. 1998). In an agroforestry project, *Z. mauritiana* was successfully introduced as a living fence in Burkina Faso.

Medicinal Properties

Most of the drugs from higher plants which have become important in modern medicine had a folklore origin and are traditional in systems of medicine such as the Ayurvedic Pharmacopoeia (Khoshoo and Subrahmanyam 1985). *Ziziphus* species are used for many medicinal purposes in folk medicines all over the world (Table 3). In India and China, *Ziziphus* species in particular have been used to treat different diseases and ailments. *Ziziphus* extracts have also featured in homeopathic folk medicines in other regions such as the Middle East, Southern Africa and South America. Almost every part of a *Ziziphus* plant has been used for medicinal purposes, as listed for *Z. jujuba* in Table 4. The wide variety of medicinal properties of *Ziziphus* plants is suprising, with uses against skin diseases, diarrhea, fever and insomnia. A general characteristic of *Ziziphus* extracts used for medicines is their antiinflammatory and antibacterial properties.

Table 3. Medicinal properties of different *Ziziphus* species and their use in traditional medicines

Species	Traditional Medicine	Medicinal use	Reference
Z. spina-christi	Egypt	Treatment of different diseases	Glombitza et al. 1994
Z. abyssinica	Zimbabwe	Treatment of tonsilitis, pneumonia, gonorrhoea, infectious diseases	Gundidza and Sibanda 1991, Coates Palgrave 1990
Z. joazeiro	Northeastern Brazil	Lessening of inflamation, relief of pain, reducing secondary infections, remedy against fever	Fabiyi et al. 1993, Nunes et al. 1987
Z. jujuba	Turkey	Hypoglycaemic agent at diabetics	Erenmemisolglu et al. 1995
Z. jujuba	China	Treatment of bronchitis, insomnia, diarrhea, ulcers, wounds and fever, sedative activity	Kustrak and Males 1987, Tanaka and Sanada 1991
Z. mucronata	Southern Africa	Treatment of diarrhea, dysentery, lumbago and skin infections, remedy agains pain	Auvin et al. 1996, Coates Palgrave 1990
Z. nummularia	India	Treatment of skin diseases, colds and coughs	Dwivedi et al. 1987
Z. rugosa	India	Treatment of diarrhea, menorrhhagia and infection of teeth	Acharya et al. 1988
Z. sativa		Treatment of ulcers, wounds, eye diseases and bronchitis	Shah et al. 1985
Z. spina-christi	Saudi Arabia	Treatment of wounds, skin diseases, inflammatory conditions, fever; diuretic agent	Tanira et al. 1988
Z. spina-christi	Bedouines	Birth control	Shappira et al. 1990
Z. spinosa	China	Treatment of insomnia, neurasthenia	Zeng et al. 1987

Data from our lab demonstrated the biological antibiotic and fungicidal activity of extracts of Z. jujuba, Z. mauritiana and Z. nummularia leaves, stems and roots (unpubl. data). The work suggested that some of the Ziziphus extracts had a higher antimicrobial activity than Penicillin G and Nystatin, and they were also effective against multiresistant strains of Aspergillus and Candida species, but further work is required to identify the active constituents of the extracts. It has also been reported that some Ziziphus species may contain the potential anticancer agent betulinic acid. In seeds of Z. spinosos (Zeng et al. 1987), stem bark of Z. joazeiro (Barbosa–Filho et al. 1985), Z. nummularia (Maurya et al. 1989) and Z. vulgaris

(Li and Zhang 1986), betulin or betulinic acid has been detected. These data indicate that Ziziphus might have commercial potential as a source of much -needed new antibiotic and antitumour agents as well as other medically effective substances.

Table 4. Medicinal use of the different plant organs of *Z. jujuba*

Plant organ	Medicinal uses or properties
Leaves	Astringent, febrifuge, promote growth of hair, used in form of plaster in the treatment of strangury
Fruits	Anodyne, anticancer, pectoral, refrigerant, sedative, stomachic, styptic, tonic, considered to purify blood and aid digestion, used internally in the treatment of chronic fatigua, loss of appetite, diarroea, anaemia, irritability and hysteria
Seed	Hypnotic, narcotic, sedative, stomachic and tonic, used internally in the treatment of palpitations, insomnia, nervous exhaustion, night sweats and excessive perspiration
Root	Used in the treatment of dyspepsia, treatment of fevers, powdered roots are applyed to old wounds and ulcers

according to: Grieve (1971), Duke and Ayensu (1985), Bown (1995), Chopra et al. (1986)

Conclusion

Due to their characteristics as a drought-adapted fruit tree with multipurpose uses, *Ziziphus* species are promising plants for arid regions, and especially in developing countries. Local varieties can be used as shelter vegetation, fuel, fodder and for fencing, with improved varieties imported and used as stock for valuable fruit crops. The successful introduction of *Ziziphus* trees to Israel and Zimbabwe has provided a good model for the development of this species as a successful perennial crop for other drought-prone regions of the world.

Acknowledgements. The authors would like to thank the European Commission/BBSRC for funding the research (contract TS3*-CT93-0222)

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