16

NTFP based Agroforestry to Sustain Income and Employment Generation Activities of Arid Regions of Rajasthan

Subbulakshmi V[1], Sheetal KR[1], Renjith PS[1], Birbal[1], Keerthika A[2] and Dipak Kumar Gupta[2]

[1]*ICAR-Central Arid Zone Research Institute*
Regional Research Station
Bikaner - 342003 (Raj)
[2]*ICAR-Central Arid Zone Research Institute*
Regional Research Station
Pali Marwar - 342003 (Raj)

Introduction

The hot arid zone of India is located between 24° and 29° N latitude and 70° and 76°E longitude, and occupies an area of 31.70 million hectares. Arid western Rajasthan, Gujarat, Punjab and Haryana constitute 89.6% of the total hot arid zone of India better known as the Thar Desert (Table 1). Arid western Rajasthan is considered as principal hot arid region,has an average width of 300 km and stretches out for 640 km from northwest to southeast. Little more than 10% of the arid regions are located in Andhra Pradesh Karnataka and Maharashtra states and is called as the peninsular hot arid zone. Even though the climatic and edaphic conditions are inhospitable the population density is more (101 persons/km^2) compared to world average for arid zones (6-8 persons/km^2) (Sharma and Tewari, 2005).

Frequent droughts and extremes of aridity are characteristics of the arid western Rajasthan. The rainfall distribution is erratic with the annual average of 200-400 mm occurring mostly during the July to September which is the main cropping season. During the summer mean maximum daily temperature is around 40˚C (maximum 52˚C) and during winter it is 22-28˚C. The minimum daily temperature varies from 4-10˚C during winter and 24-26˚C during summer. The mean evaporation rate during summer exceeds 10mm/day (Gupta, 2000). The soils in Rajasthan are mostly sandy, alkaline, saline and chalky (Mala, 2012). Poor fertility, high infiltration rate (10-12 mm/hr), low water holding capacity, high salinity and alkalinity hazards, surface crusting, soil erosion and undulating topography pose problem to soil management in this region. On irrigated lands the availability of ground water is meager and problematic owing to deep water table, negligible recharge and high salinity.

The forest vegetation occupies about 9.36 per cent of the total geographical region of Rajasthan which is mostly seasonal and includes a few dwarf trees and shrubs, grasses and bushes. Forest resources have diverse endemic plant species which plays a major role in the household food security mostly of the rural inhabitants who depend on them to meet their additional food requirements and livelihood improvement of the local communities (Tiwari *et al.*,2010).

Table 1.Distribution of arid regions in different states of India.

State (s)	Area (millionhectares)	Percent of total
Rajasthan	19.61	61.0
Gujarat	06.22	19.6
Punjab and Haryana	02.73	09.0
Andhra Pradesh	02.15	07.0
Karnataka	00.86	03.0
Maharastra	00.13	0.4
Total	**31.70**	**100**

Source: Roy *et al.* (2011)

Importance of Agroforestry in Arid Region

In arid regions agricultural crop production is very in secure because of harsh climatic condition. So it is not economical to depend completely upon sole arable crop production, which is uncertain. Instead, it is sensible to adopt alternative land use systems which prove more sustainable, meet the timber and non-timber needs and alsoprotects the environment (Singh *et al*., 1998). Agroforestry is the best option and insurance against sole crop failure in such condition. The people of western Rajasthan, since ages, have developed a variety of agroforestry systems. The farmers allowed growing scattered trees and shrubs in their agricultural fields or grazing fields mainly for their products and environmental services.

The entire system has been customarily developed to spread the danger of drought in diversified segments and for effective usage of hardly accessible natural resources. Evaluating the value of forestry in monetary terms is difficult in arid zone. Arid zone agroforestry in this manner should be seen extensively as management of trees and shrubs to enhance the livelihood and employment opportunities of rural people in arid region. Even the conventional cropping system has multiple agricultural crops with trees. The commonness of this system uncovers potential advantage in production, stability, resilience and ecological stability. Farmers are frequently observed blending different arable crop seeds together to sow in their fields as mixed cropping, with an optimism to gain at least some produce even when the conditions are not amicable for one or another crop.

Prosopis cineraria based agroforestry system is the most dominant agroforestry system in western Rajasthan which occupy 47% of the total area followed by *Ziziphus nummularia* based agroforestry system (28%). *Acacia nilotica, Tecomella undulata* and *Acacia tortilis* based agroforestry system occupy about 26% (Tewari *et al*., 2007). Harsh *et al*., (1992) described the structural components and distribution of traditional agroforestry systems of Thar Desert based on the investigation of administrative districts of western Rajasthan. The scheme of the classification is given in Table 2. The major woody, crop and grass species prominently used in agroforestry systems being practiced in different districts of Thar Desert region have been described in simple qualitative terms.

Table 2. Components of traditional agroforestry practices in various districts of arid Rajasthan (Thar Desert region)

District	Main tree/shrub species	Main crops	Prominent grass
Ganganagar & Hanuman	*Prosopis cineraria, Acacia nilotica sub sp indica, Acacia tortilis*	Pearl millet, moongbean and clusterbean (rainfed). Wheat, cooton, rice and moongbean (irrigated)	*Lasiurus sindicus*
Bikaner	*Prosopis cineraria, Ziziphus nummularia, Calligonum polygonoides, Acacia jacquemontii*	Moongbean, mothbean, clusterbean and pearl millet	*Lasiurus sindicus*
Jaisalmer	*Calligonum polygonoides, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Capparis decidua*	Moongbean, pearl millet, clusterbean	*Lasiurus sindicus*
Barmer	*Prosopis cineraria, Tecomella undulata Ziziphus nummularia, Capparis decidua*	Pearl millet, moong bean and cluster bean	*Lasiurus indicus Cenchrus ciliaris*
Jodhpur	*Prosopis cineraria, Ziziphus nummularia, Capparis decidua, Acacia senegal*	Pearl millet, moong bean and Cluster bean (rainfed). Wheat, chilli, mustard and moongbean (irrigated)	*Cenchrus ciliaris*
Churu, Jhunjhunu & Sikar	*Prosopis cineraria, Gymnosporia montana, Ziziphus nummularia*	Pearl millet, moong bean and clusterbean	*Lasiurus indicus, Cenchrus ciliaris*

District	Main tree/shrub species	Main crops	Prominent grass
Nagaur	*Prosopis cineraria, Acacia nilotica*	Pearl millet and moongbean (rainfed). Wheat, moongbean and mustard (irrigated)	*Cenchrus ciliaris*
Jalore	*Prosopis cineraria; Salvadora persica, Salvadora oleoides, Acacia nilotica*	Pearl millet, moongbean, isabgol, sorghum and cumin	*Cenchrus ciliaris*
Pali	*Acacia nilotica subsp. Indica, Acacia nilotica var. cupressiformis, Acacia leucopholea, Acacia catechu, Salvadora spp.*	Sorghum, pearl millet, moongbean and clusterbean	*Cenchrus ciliaris Cenchrus setigerus*

Source: Harsh *et al.* (1992)

Role of Agroforestry in Sustaining Farmer's Income in Arid Region

Livelihood improvement isn't just about the positive change towards better quality of life and human prosperity but it also considers the local and global change which decides livelihoods (Pandey, 1996). The antagonistic effect of environmental change may be more extremely felt by poor people who are more vulnerable to climate change than rich. Suitable policy arrangements combining the agro ecosystems as key resources can strengthen the adaptation and help build the resilience of communities and households to local and global change (AFD *et al.*, 2003). Ventures to promote the mainstreaming of adaptation into livelihood improvement may conceivably convey better outcomes when combined with adaptive management of natural resources and agro ecosystem. There is, thus, a need for intensified conservation efforts and resort to in situ and ex situ conservation as well as growing products and generating services in agro ecosystems

Non-Timber Forest Products (NTFPs) are biological resources of plant and animal origin, obtained from natural forests, woodlands, plantations and trees

outside forests. Domestication of NTFP trees grown in agroforestry systems offer significant opportunity for livelihood improvement through the food and economic security of poor people in the dry areas (Uma Shaanker *et al*., 2001; Leakey and Tchoundjeu, 2001; Gupta, 2004). Trees in farm lands have an important role to play in building social capital. Trees in farm boundaries define landholdings and systems of tree tenure determine who benefits from trees. Agroforestry systems will certainly open an opportunity for further employment for rural youth during most of the months compared to agriculture, which is exclusively dependent on rains and confined to a limited period. These systems involve collection of fodder from grass and top feed from trees, raising nurseries, grafting of trees, training, application of silvicultural and tree protection measures, thinning, pruning, irrigation, grading, marketing and managing farm produce for compost preparation, etc. Such multifunctional agroforestry systems protect the social wellbeing of the rural people in addition to providing goods and services. Suitable programmes that design the plantations of NTFP trees can serve dual purpose of conserving the useful species at the same time improving the livelihoods of local people.

Worldwide wood carving industry is emerging as a vital source of income to local artisans (CIFOR, 2002). Promotion of plantations of species used in wood carving industry facilitates long term locking-up of carbon in carved wood and supports local knowledge, therefore, strengthening livelihoods and helping to mitigate climate change. For example, Jodhpur city in Rajasthan exports woodcrafts worth Rs. 60 million annually facilitated by the traditional knowledge, skills and growing tourism has emerged as a major centre of wood carving. Suitable agroforestry systems with improved technologies, with different tree species may enhance the availability of wood and other tree products in agroecosystems thereby increasing the ability of developing countries to participate in the growing global economy.

Agroforestry Systems based on NTFPs in Arid Region

In the last three decades attention to NTFPs has increased globally due to their compatibility with environmental objectives including the conservation of biological diversity, and their contributions to food security, household economies and to

national economies (Neumann and Hirsch, 2000). The Indian arid zone is vegetated with a rich floral diversity of about 682 species, out of which 131 are known for their economic uses (Bhandari, 1990). This region comprises a wide range of NTFP trees viz., *Prosopis cineraria, Ziziphus rotundifolia, Ziziphus numularia, Salvadora oleoides, Carissa carandas, Capparis decidua, Cordia gharaf, Grewia tenax, Balanites roxbhurghii, Calligonum polygonoides, Haloxylon spp., Simmondsia chinensis, Acacia senegal, Commiphora wightii*, etc (Fig.1).

In humid or sub-humid regions, trees are typically grown for timber but in arid region trees are grown mainly for NTFPs. In the arid zones, dense forests are seldom available and agroforestry has been followed since time immemorial in which people conserve and manage whatever native tree species germinate in the agricultural field or on the common land (*Prosopis cineraria* and *Zizyphus nummularia*). These tree branches are lopped annually to get precious fodder during scarcity/drought. *Prosopis cineraria* is found in this region at densities ranging from 40 to 120 trees ha^{-1} which can be called as natural forest in common or private lands, otherwise no dense forest is found as in the high rainfall areas. In the month of December, people lop the branches of this tree and it becomes lush green in the month of May-June and provides fodder when no other fodder is available. Similarly many other tree species in arid region also provide fodder, vegetable pods, fruits, edible flowers, etc. The interesting thing is that, during drought when annual crops fail, there is no drastic change in the yield of NTFPs, thus trees provide food security during drought. Some trees produce other products like gum, resins, edible/non-edible oils, act as a host of silkworms, etc. which supplement the income of the marginal farmers who are in the majority in arid region (Sharma, 2000). The other significant NTFPs in these arid areas are plants with medicinal values. Due to unique climatic condition there are medicinal plants which are either endemic to this region or they exhibit poor quality if they are grown/found in higher rainfall areas.

Edible Products and Fodder Production based Systems

There are around 30 plant species in arid zone known for their edible use and of these around 20 plant species are known for their edible fruits either raw or use as

vegetable. Many of the above play a multiple role in dry zone agroforestry systems viz, wind protection, providing soil cover, biofencing, shelterbelt, fodder and fuel wood as well as food. Most of the fruits of the desert tree species find common use as vegetables when unripe. They are also medicinally important.

a. *Prosopis cineraria*

Prosopis cineraria (L).druce commonly known as khejri is a perennial evergreen, thorny, leguminous multi-purpose tree belonging to the family Mimosaceae (Shukla *et al*.,2004). This tree plays an important role in traditional agroforestry practices of the hot arid zones of Thar Desert (Jatasra and Paroda, 1981). The tree also plays an increasingly important place in the economy of arid deserts and a significant role in sand dune stabilization by soil erosion control, soil fertility improvement, providing source of feed (leaves and pods) for grazing animals, fire wood, timber and vegetables (fruits) (Tewari *et al*., 1998). The dried leaves of khejri called as *loom* or *long* serve as quality fodder for the animals during lean period. Revered by Rajasthani farmers as '*Kalpvriksh*', it is grown in fields mainly due to the age-old belief that crops grow better underneath these trees (Jaimini and Tikka, 1998), which might be due to the addition of nutrients through leaf fall and partial amelioration of the harsh climate.

Better growth and biomass production by forage species under Khejri tree canopy was reported by Aggarwal *et al*. (1976) and Shankar *et al*. (1976) as a result of higher soil fertility under the tree. Traditional agroforestry practices by farmers in this region involve intercropping agricultural crops like bajra, moong, guar, sesame, etc. with khejri, as they have noted the higher yields of crops in this association. The economic analysis of khejri based traditional agroforestry system shown that from bajra alone gross income of Rs. 1600 per ha can be obtained whereas bajra intercropped with khejri (30 trees ha^{-1}) is capable of providing an income of Rs. 4600 per ha. Thus it revealed that khejri + bajra based agroforestry system is much more remunerative (Harsh and Tewari, 2007). Another study conducted at AFRI, Jodhpur indicated, at 12^{th} year (208 tree ha^{-1}) *Prosopis cineraria* provides utilizable biomass of 19.96 tonnes ha^{-1} including leaf fodder of 0.85 tonnes ha^{-1} as the additional output. In addition to the crop harvested farmer may obtain an annual return of Rs. 3000-3500 per hectare as per the present rate of leaf forage and firewood (Singh,

2009). Khejri was also reported to improve soil conditions and increase crop yields by 11.1%. Comparison studies on the effect of tree species on crop yields with the purpose of integration in agricultural land showed that *Prosopis cineraria* was more beneficial over other native species like *Techomella undulata*. In the same study by Singh (2009) the yield of agricultural crops was observed to increase when optimum tree density was maintained over traditional practice of maintaining random number of trees in farmlands, though variations were also noted based on the tree size and resource availability.

This leguminous tree is a very important source of food for the nomads who move with cattle during the dry season. The dried pods of khejri are called as 'sangri'. The sale of the fruits has brought about an improvement in economy of this region. One kilogram of sangri costs around Rs. 300-400 in the market. Green fruits are also used as vegetable. Central Institute of Arid Horticulture (CIAH), Bikaner has developed high yielding variety called 'Thar Shoba'. It has been recommended for uniform tender pod harvesting for vegetable use. This yields a harvest of about 4.25 kg tender pods and 6 kg dry fodder per year (CIAH, 2017). Boiled and dried pods form important constituent of arid Rajasthan's famous dish 'Panchkutta' which includes sangri, seeds of kummat (*Acacia senegal*), fruits of ker (*Capparis decidua*), kachri (*Cucumis supp*) and goonda (*Cordia mixa*). The ingredients are crushed, mixed and fried after adding condiments to taste (Panwar *et al*., 2014).

b. *Ziziphus spp*.

The genus *Ziziphus* belongs to the family Rhamnaceae. This genus includes about 100 species of deciduous or evergreen trees and shrubs distributed in the tropical and subtropical regions of the world. The leaves are good fodder; the hardwood is used for making agricultural implements, fuel and high quality charcoal. Its spines create effective live-fencing hence, grown as a hedge. Its highly nutritious fruits provide additional income when sold in local markets (Arndt *et al*., 2001). *Ziziphus nummularia* (bordi) is a branched thorny shrub with a height of 1 - 2m, it is found in almost all parts of the desert areas except the saline soils and sand dunes. The dark brown round berries relished by children and women, ripen during late November and December and are eaten fresh as well as after drying. The fruits contain considerable

amount of soluble carbohydrates and ripened fruits fetch market prices of Rs.1-2/kg (CAZRI, 1981). Powder prepared by grinding whole fruits can be consumed as such or mixed with jaggery. 'Borakuti', a delicious locally prepared paste is also relished by young and old alike (Mala, 2009). It is often intercropped with millet, legumes and oil seeds. It is planted to make micro windbreaks in arid region. Rainfed crops such as mungbean, cluster bean, mothbean and pearl millet are grown with *Ziziphus nummularia* in areas where mean annual rainfall is less than 400mm. Maximum leaf forage of 169 kg $DMha^{-1}yr^{-1}$ was obtained from this plant in deep alluvial sandy soils (Tewari and Singh, 2006.)

Farmers intercrop *Ziziphus nummularia* and *Ziziphus rotundifolia* with Bajra or legume crops. In the month of October - November, after harvest of bajra crops, *Ziziphus spp* are cut from the ground level and allowed to dry. This dry leaf called 'pala' is stored for lean period to feed livestock. This agroforestry system can give gross return of Rs. 7000 – 8000 ha^{-1} (Harsh and Tewari, 2003). CAZRI, Jodhpur has made some efforts to improve the existing *Ziziphus spp.* based agroforestry system for a higher return. Some of the *Ziziphus* plants were budded with improved cultivars of 'Gola' and 'Seb'. These budded *Ziziphus* plants produce fruits in the first year itself and from 2nd year onward their fruit yield increases to 30 kg $tree^{-1}yr^{-1}$. A farmer can earn gross returns of 12,000-15,000 ha^{-1} if farmers maintain 50 trees ha^{-1} besides natural growing *Ziziphus* (Faroda and Harsh, 1999).

c. *Salvadora oleoides*

Salvadora oleoides is the dominant multipurpose tree growing on dry, saline and sand dune areas in Indian desert,commonly called as jhal, pilu, peel, meetha jhal etc., belonging to the family Salvadoraceae. The tree is known to tolerate a very dry environment with mean rainfall of less than 200 mm in Barmer, Jalore, Jodhpur and Pali districts of Rajasthan (Bhandari, 1978). Its thick and dense foliage and drooping branches make it suitable for rehabilitation of bare and desert tracts. The tree is primarily sourced for its fruits known as desert grapes.

Salvodora oleoides (density 10 trees ha^{-1}) are intercropped with bajra with a production of average 9.5 qha^{-1} (Harsh and Tewari, 2003). The average fruit

production per tree is 30 kg. The fruits are available at the rate of Rs. 10 kg^{-1}. Fruits are sweet, edible and have reportedly saved the lives of inhabitants in famine or crop failure. These are very good source of calcium (Duhan *et al.*,1992; Zodape and Indusekhar, 1997).The fruit is value added and can be used as squash as per the technology developed by Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan. The cost of processing 1 kg Pilu fruits for Pilu squash comes to Rs. 32. One kg fruits on processing provide 1.5 litre squash. Farmers can earn Rs.13000 ha^{-1} yr^{-1} from *Salvodora sp.* based agroforestry system if the fruits are utilized properly for making squash whereas the sole agricultural crop yield will be Rs.10000 ha^{-1} yr^{-1} (Harsh and Tewari, 2007). Leaves are considered as good fodder for goats and camels. Goats, sheep and camels consume foliage round the year but the young tender leaves, which appear in spring season, are more eagerly devoured by the grazing animals. Seeds contain 40-50% of a greenish yellow, non-edible fat. Purified oil is used in soap and candle making as well as in detergent industries as a substitute for coconut oil (Chopra *et al.*, 1968). The seed oil content is about 45 to 50% in Gujarat and Rajasthan.

Roy *et al.* (2011) reported the economics of traditional agroforestry systems of arid western Rajasthan. Net B:C ratio of such agroforestry systems is generally on positive sides (Table 3). Among all the systems *Prosopis cineraria* and *Acacia nilotica* based system shows higher net B:C ratio.

Table 3. Economics of traditional agroforestry systems of arid western Rajasthan

AF system	Expenditure (Rs/ha)	Returns(Rs/ha)			Gross Returns (Rs/ha)	Net returns (Rs/ha)	Net B:C ratio
		Crops	Fuel wood	Leaf fodder			
P. cineraria–A. nilotica based	11850	4103	1230	870	6203	4353	2.3
P. cineraria based	1550	3670	600	420	4690	3140	2.0
Zizyphus spp. - P. cineraria based	1550	1506	620	600	2726	1176	0.7
Zizyphus spp. - P. cineraria - Salvadora spp. based	1500	1400	500	500	2400	900	0.6

Base year: 2000 Source: Roy *et al.* (2011)

d. *Carissa carandas*

Commonly known as karonda in India (Bbengal currant/christ's thorn in South India), this indigenous shrub belongs to the family Apocynaceae (Imran *et al.*, 2012). It is hardy, drought-tolerant, evergreen tree grows in diverse climatic conditions including high temperatures, marginal and poor soils where most of the other crops cannot be grown. Fully developed bushes provide 6-8 kg fruits per year compared to 2-3kg from the plants grown as hedge plants. The fruits are a rich source of minerals such as iron, calcium, magnesium and phosphorus; vitamin C and anthocyanin which provides antioxidant properties to the fruit (Sawant and Godghate, 2013). The stage of harvest depends on purpose: for use as vegetable fruits are generally harvested at immature stage, while for direct consumption or processing, fully ripen fruits are preferred (Malik *et al.*, 2010). Ripe karonda fruits when candied resemble canned cherry and referred to as 'Imitation cherry' (Mandal *et al.* 1992). The latex from fruits and seeds and roots are used to treat several diseases like rheumatoid arthritis, piles, cardiac diseases, intestinal worms, scabies, diabetic, ulcer, nervous disorders etc. (Maheshwari *et al.* 2012). It may be grown as biofence due to presence of auxiliary spines and also as hedge (Sharma and Banyal, 2010).

Studies on the performance of karonda germplasm by Meghwal *et al.* (2014) at CAZRI, Jodhpur over 8 years led to identification of three accessions CZK2011, CZK2022 and CZK2031, giving better fruit yields, bigger sized fruits and other desirable attributes and have been recommended for cultivation in arid zones. In intercropping studies conducted in saline conditions in north-western India over 5 years, barley followed by mustard and cluster bean were found to give good performance, when intercropped with karonda. In addition this agroforestry system also gave 1.6 Mg ha^{-1} fruits (Dagar *et al.* 2015). A fruit tree like Karonda is recommended to grow along with crops like clusterbean and barley in arid areas of Hisar by ICAR-Central Soil Salinity Research Institute, Karnal (CSSRI, 2007).

e. *Capparis decidua*

Capparis decidua is locally referred as kair in Rajasthan. It is distributed over 3540 km^2 piedmont plains in Bikaner and Jodhpur districts of Rajasthan. Its estimated

annual production is 7000 tonnes of fruits (Chandra *et al.*, 1994). Kair will be fully laden with flowers and fruits if there are drought and high temperatures. Farmers of arid Rajasthan use this tree as a climate indicator to predict the drought occurrence based on the quantity of flowers it produce in the respective year. Kair comes to fruit after 4-5 years of age. The fruits are harvested in April - May. The initial yield of green immature fruits is about 2-3 kg per plant; however, a fully grown, wild plant can give as much as 10-15 kg of fruits (Meghwal and Tewari, 2002). The fruits should be harvested when green and tender at the 'small pea' stage for pickling and use as vegetable. To fetch better price in market, fruits should be harvested 7-10 days after fruit set (Meghwal, 2002). Young green fruits are important ingredient of famous 'Panchkutta' mixture of dry vegetables. The flower buds and immature green fruits of kair are pickled, cooked and consumed as vegetables (Pareek, *et al*., 1998). One kg of fresh fruit yields about 200 gm of processed, dried fruit. The fruits are rich in protein (8.6%) and vitamin C (7.8 mg/100 gm of pulp by weight) (Gupta, *et al*., 1989). The dried fruits, with 5-7% moisture, can be preserved for 2-3 years in airtight containers and can be marketed when the prices are high. The fresh fruits are sold at Rs. 20-25 per kg, while dehydrated fruits are sold at Rs. 150-200 per kg (Meghwal and Tewari, 2002). The seeds of kair contain up to 20.3% high quality oil which is edible when processed. The oil consists of 68.6% unsaturated fatty acids and 31.4% saturated fatty acids. Fruit is relished by camels and goats. Green or dried leaves of *Capparis decidua* are used as diet supplement during period of grass scarcity (Anonymous, 1989).

Kair is a very strong candidate to plant in both plantation forestry and agroforestry in the arid tropics. Pandey and Rokad (1992) reported that it is one of the best species for shelter belts to check the movement of sand in the Thar Desert. It can be planted in the boundaries of farmlands as a live fence (Orwa *et al*., 2009).

f. *Cordia gharaf*

Cordia gharaf is a tall, erect, branched shrub or tree grows up to 5-8 m in height belonging to family Borginaceae. It is locally called as goondi/gondni. It can survive well in gravely areas and even under saline and alkaline conditions. It is distributed in Western Rajasthan particularly in Jaisalmer, Barmer and Bikaner districts. Flowers

usually after rains, fruiting about two months later; fruit is a kind of soft red ball. Fruits and gum are edible. The sweet and sticky tasty pulp of the fruit is eaten fresh. The fresh fruits are squeezed in water to dissolve the pulp. The fresh juice may also be drunk or fermented (Khyade *et al.*,2009). The fodder provided by this tree is highly preferred by desert dwelling browsing animals like sheep and goats. This species is planted as windbreak as boundary plantations and shelter belt.

g. *Grewia tenax*

It is locally called as gangeran and gangan belongs to the Family Tiliaceae. It is one of the underutilized shrubs that survive in adverse climatic conditions like drought. The deep rooted system stabilizes soil from water and wind erosion and is promising as a dune fixing shrub in desert reclamation. It can withstand temperature of more than 50°C. Adequate sunlight and warm / hot temperature are required for fruit ripening.

Intercropping with *Grewia tenax* may not affect crop growth adversely. It is suitable for developing silvi pastoral model particularly with *Cenchrus spp*. The shrub can also be used as hedge in boundary/barrier. Periodic pruning towards the end of the dry season stimulates new growth on older shrubs, as they are expected to produce fruits in the next year (Gebauer *et al.*, 2007). The top feed of *Grewia tenax* yield varied from 33.0 to 111.5 kg ha^{-1}. The fruit is nutritionally balanced and are rich in iron and calcium and also can be made in to refreshing drink. *Grewia tenax* has potential to yield 4-5 kg fruits/plant per year (El Tahir, 2002). The fruit pulp represents 40-50% of the whole fruit. A thin porridge called 'nesha' is prepared by boiling millet flour and fruit pulp of *Grewia tenax* for lactating mothers (Geubauer *et al.*, 2007). Young leaves are consumed by livestock, they are slightly palatable at the end of dry seasons, and have fairly good feed value. It is recommended for boundary plantations and intercropping with *Grewia tenax* may not affect crop growth adversely (Orwa *et al.*, 2009)

h. *Balanites roxbhurghii*

Balanites roxburghii Planch belonging to the family Zygophyllaceae/ Balanitaceae, also known as hingota, soap berry tree/ thorn tree/ desert date, is an important genus

of thorny shrubs or trees distributed in dry regions of India. It is found in open sandy plains of Osian, Jodhpur and whole of north-western part. It is mainly valued as a wild food plant. The plant starts to produce fruit after 5-7 years (Gour and Kant, 2012). Finest of the trees can yield date fruits up to 52 kg/trees (Chapagain *et al.*, 2009). The fleshy pulp of the fruit is eaten fresh or dried which contains a large amount of carbohydrates (64 -72%), plus crude protein, steroidal saponins, vitamin C, ethanol and other minerals (Abu Al-Futuh, 1983). Ripe fruits can be eaten raw or sun-dried and stored like dates, made into sweetmeats or fruit juice (when macerated with water) and mixed with cereals, or fermented to alcoholic beverages (Storrs, 1982; Burkill, 1985).

The fruits were found to contain saponin and it is locally used to wash silk. The Indian tribes use the pulp of the fruit as a detergent and substitute for soap. The seeds are bitter in taste and therefore debittered seeds are possibly marketed as salted or roasted nuts. Leaves of this plant serve the purpose of fodder for livestock especially for goat. The leaves contain 26.3% protein (Rathore and Meena, 2004). Oil cake is also used as an animal feed. Kernel oil content may reach up to 46.7% (based on dry weight) and successfully tested for biodiesel production (Chapagain *et al.*, 2009). Linoleic acid was found to be the most prevalent fatty acid, ranging from 31% to 51% of the fatty acids profile necessary for biodiesel production. Oil is edible and can be used for cooking purpose. The thorny and evergreen nature of the species potentially makes it as an attractive tree to introduce into shelterbelts and boundary plantations.

It is clear from Table 4. that the natural fruits from arid zone are nutritionally much better than the commercially available market fruits. They are rich in carbohydrates and proteins which are present in negligible quantity in commercially available fruits. Additionally they have higher mineral substance. In many arid zone fruits, the total energy gained is significantly higher than that gained from commercial fruits. Therefore, wild natural products from dry zone can give much better nutrient supplements when eaten and can be utilized parallel to the commercial fruits.

Table 4.Nutrient content of some important forest fruits from arid zone

Species	Protein (%)	Carbohydrate (%)	Fat (%)	Fibre (%)	Vitamin A (mg/100g)	Vit. B2 (mg/100g)	Vit. C (mg/100g)	Ca (mg/100g)	P (mg/100g)	Fe (mg/100g)	Energy (Kcal/gm)	References
Balanites spp.	4.9	69.9	0.1	3.5	-	0.07	46	147	58	4	300.1	Nour *et al.*, 1985; Tayeau *et al.*, 1955
Capparis decidua	8.6	1.8	-	12.3	-	-	7.81	55	57	-	41.6	Duhan *et al.*, 1992
Cordia spp.	2.0	92.	2.0	2.0	-	-	-	55.0	275.0	6.0	394.0	Duhan *et al.*, 1992; Chandra *et al.*, 1994
Prosopis cineraria	23.2	56.0	2.0	20	-	-	523.0	414.0	400.0	19.0	334.8	Rathore and Meena, 2004
Salvadora oleoides	6.0	76.0	2.0	2.0	-	-	-	6.0	76.0	8.0	346.0	Duhan *et al.*, 1992
Ziziphus spp.	0.8	17.0	0.3	-	0.02	0.02	76.0	4.0	9.0	1.8	73.9	Chandra *et al.*, 1994
Aegle marmelos	1.8	31.8	0.3	2.9	0.055	1.2	-	85.0	31.8	0.6	137	Parichha, 2004
Feronia limonia	7.3	15.5	0.6	5.2	-	0.170	2.0	0.13	0.11	0.6	96.6	Anon, 2008

In addition to fruits, fodder produced by trees also forms an important component of animal feed security in arid zones. Table.5 shows the list of fodder producing trees/shrubs, optimum spacing for agroforestry and their production capacity in arid Rajasthan.

Table 5. Important fodder trees/shrubs and their fodder production in arid Rajasthan

Tree/shrub	Optimum spacing (m)	Green fodder yield and availability after plantation
Prosopis cineraria	10 x 10	About 100 kg 8-10 years
Colophospermum mopane	8 x 8	5-7 kg 3-4 years
Zizyphus nummularia	5 x 5	3-5 kg leaves 3-4 years
Salvadora oleoides	12 x 12	80-100 kg leaves 8-10 years
Cordia gharaf	8 x 8	5-8 kg 3-4 years
Acacia senegal	8 x 8	8-10 kg leaves 7-8 years

Source: Sharma (2013)

i. *Calligonum polygonoides*

Calligonum polygonoides Linn. locally known as phog, is a shrub belonging to the family Polygonaceae. It is found throughout the Southern Europe, North Africa, Western and Central Asia (Brandbyge, 1993) and is bestowed with the status of key-stone species of the Thar desert (Bhandari, 1995). It is highly drought and frost resistant and commonly grows on dry sandy soils and on sand dunes where it is the most common shrub component of Psammophytic scrub desert (Saxena and Singh, 1976). It is usually seen as a small glabrous, winter shedding, perennial shrub attaining the height of 2-3 m. Flowering occurs from February to March. Flower buds locally called phogla are used in preparing traditional dish called 'Rayata' by

mixing these buds with curd during summer after light boiling or frying of buds. A dose of 50 gm flower buds in 100 gm curd is effective in sun stroke (Suresh Kumar *et al*., 2008).Young branches are also chewed to quench the thirst during summer. It is also used as fodder for sheep, goat and cattle particularly during lean period. Moreover, it is an excellent species to plant as strips in agroforestry systems as it is a good soil binder, arrests wind erosion, stabilizes sand dunes and is reported to improve water regime, improve soil biological activity and crop yield.

j. *Haloxylon spp.*

Haloxylon salicornicum is a desert shrub known as lana belonging to the family Amaranthaceae. It is a much branched almost leafless shrub, growing up to 60 to 90 cm in height with a woody base. In India, it is found particularly in the western part of Thar Desert and Punjab and grows well even in regions with 100 mm rainfall. It is a well-known feed resource for camel and small ruminants in north western Rajasthan. Generally its green twigs and flowering tops are harvested and stored for using in lean period and is fed to animals after mixing with straw and other left overs. The different plant parts of *Haloxylon salicornicum* have been used in traditional medicine for cure of number of diseases like internal ulcers, insect stings, diabetes, cold and hepatobiliary disorders and contains a wide range of bioactive phytochemicals (Singh *et al*., 2015). Rathore *et al* (2014) demonstrated that establishment of *Haloxylon salicornicum* improved soil physical properties, water holding capacity, organic carbon, available nitrogen, available phosphorus, and electrical conductivity; and decreased pH, and bulk density. Furthermore, density and biomass of herbaceous plants in alleys of *Haloxylon salicornicum* was found 1.2 and 1.6 fold greater than open area.

Another species *Haloxylon stocksii* (syn. *H. recurvum*) known as khara-lana has been traditionally used as camel fodder and for making 'Saji'. They serve as important reserve feed particularly under drought conditions for livestock. The main economic use of the plant is 'saji' production, which is the soda ash obtained by burning the air-dried foliage of the plant. The purified form of saji is known as choa. Studies by Rathore *et al*. (2012) indicate that a farmer may earn upto Rs. 11700 ha^{-1} returns by saji and choa production from the species. As *Haloxylon spp*. are economically viable and are tolerant to multiple abiotic stresses (drought, high temperature and salinity)

can be grown as strips in agroforestry systems in arid Rajasthan to get additional income and also to protect the soil.

Edible/Non-Edible Oilseed Production based System

a. *Simmondsia chinensis*

Simmondsia chinensis commonly known as jojoba is a potential tree borne oilseed that has attracted much attention in recent years. Much of the interest is due to the survivability of the plant in harsh desert-like environments with low rainfall and extremes of cold and hot temperature. Jojoba can be grown on marginal lands, which may not be under use currently. Fully mature shrubs/trees can reach a height of 15 feet with a potential natural life span of around 200 years. Its oil is used in several industries as a lubricant such as automotive manufacturing, as well as in cosmetic, pharmaceutical and food products. Each jojoba seed contains an average of 45-50% oil by volume, irrespective of the variability in size or where grown.

Association of Rajasthan jojoba plantation and research project (AJORP) was set up in Jaipur in 1995, to produce and supply jojoba seeds to registered farmers, to provide technical assistance and trainings to farmers, undertake related research, promote processing and marketing of jojoba products, etc. In Rajasthan few farmers who planted jojoba in 1992, earned gross income of Rs.125000-200000 per hectare per year after 10^{th} year of plantation (Sandhu, 2001). In a case study of a farmer from District Sriganganagar of Rajasthan, his views are that jojoba crop is very successful in marginal land where there is scarcity of water and more returns per unit with adequate irrigation facilities. It is better in those areas where plants prepared by cuttings are made available to farmers, along with complete technical know-how for its cultivation (Saini 2008). Khan (2005) concluded that cultivation of jojoba in one hectare of land gives revenue of Rs. 50000 per year to the farmers. He also reported that one kg oil extracted from the jojoba seeds costs about Rs. 5200 in the world market.

Gum Production based Systems

a. *Acacia senegal*

Acacia senegal (L) Willd (*Kummat)*is a low branching shrub or small tree that grows upto 7 m high (maximum 15 m) and belongs to the family Leguminosae. It is an edible gum producing tree, found prominently in the arid western Rajasthan, occupying rocky hills, sandy plains and sand dunes, where it is an important component of traditional agroforestry system (Tewari and Pareek, 2016). The gum commonly known as 'Gum Arabic' refers to the dried exudates obtained from the stems and branches of the tree (FAO, 1999).

Traditional methods of gum tapping were more laborious, and resulted in more injury to plant while providing lower gum yields; and thus required a more improved gum tapping technique; which was provided by researchers at CAZRI, Jodhpur, Rajasthan. The technique involves use of a synthetic plant growth regulator compound of ethylene, phosphate and chloride ions called Ethephon. The assumption behind this was that gum exudation is a stress response of the tree, and that application of ethephon could accelerate the developmental response to stress and in turn lead to more gum exudates (Pareek *et al*., 2017).

The optimum dose of CAZRI Gum Inducer is 4 ml per tree, which may vary from 4-5 ml according to tree structural traits. The average sale rate of gum Arabic in local markets of India has been found to be Rs. 500 per kg. Adoption of this technique provided a gum yield of 23.6t and a gross income of 235.9 thousand US$ by gum tappers of hot arid region of western Rajasthan over 3 years. CAZRI gum tapping technique has provided employment and an income source in drought prone hot arid and semi-arid farming systems (Moola Ram *et al*., 2013).

b. *Commiphora wightii*

Commiphora wightii known as guggal or Indian myrrh is a 2-3m tall, slow growing spiny shrub or tree, native to India, Arabia and Pakistan. In India it is found in Rajasthan, Gujarat, Madhya Pradesh and Karnataka. Guggal prefers semi-arid and

arid conditions and can be grown in sandy to silt loam soils, with poor organic matter content. It is also drought and salinity resistant. Yellowish gum-resin is produced by the stem of the guggul tree. Gum guggul is used to make lacquers, varnishes, in perfumes and medicine and as incense. Currently, availability of guggal gum in India has plummeted because the shrub population is declining due to its unregulated exploitation. Subsequently, the prices have increased in the last 10 years from Rs 25 to Rs 300-Rs 500 per kg (Paliwal, 2010). But the slow growing nature and time required for maturation deter farmers from its cultivation. In Rajasthan, it has been planted as boundary plantations in cultivated fields, as its spiny nature deters other grazing animals from entering the field. At KVK Jhabua, farmer's wastelands where normal agriculture is not possible due to severe drought and poor soils, were used for developing guggal based agroforestry models (Upadhyaya and Sharma 2007). Guggal can also be intercropped with millets and legumes like pearl millet and cluster bean. Experiments indicated a synergistic relationship resulting in better yield of agricultural crops, while the quality and yield of guggal plantation remain unaffected (NMPB 2008).

Animal Products based Systems

a. *Colophospermum mopane*

It is a desert plant species that was introduced in India for sand dune stabilization from South Africa. It is commonly called as mopane. The tree is hardy and has been used for reclamation of ecologically poor areas. The tree can be used for economic purposes by utilizing it for rearing wild silkworm, *Gonometa rufobrunnea* which produces a silk. It is hoped that the collection and processing of the wild silk moth cocoons will do much in providing people in these resource poor conditions with a source of income. Moharana *et al.* (2016) successfully used mopane and other arid species to rehabilitate the lignite mine spoil area in Barmer, Rajasthan.

Colophospermum mopane were intercropped with *Vigna radiata* at Jodhpur a view to study the tree crop interaction. It was found that mopane enhanced the land productivity through increased system production and agriculture yield in the

initial 4 - 5 years (Singh and Rathod, 2007). In another study, mopane was grown in agri-horti-silvi system with citrus and shisham and with intercrops viz., mungbean and clusterbean under sprinkler irrigation. Though the tree showed better growth (height, diameter, canopy) with intercrops, over sole plantations (Yadava *et al.*, 2013; Singh and Singh, 2015); the intercrop yield was affected due to more competition for moisture as observed in studies at CAZRI - Regional Research Station, Bikaner (Yadava *et al.*, 2013). Singh and Singh (2015) also observed that the roots of the tree were more confined to top 80 cm soil layer and almost parallel to soil surface, which might be responsible for higher competition in agroforestry system at Jodhpur, Rajasthan. Proper root pruning of mopane by making trenches near mopane tree line and canopy restructuring may reduce the competition. Further studies on mopane based agroforestry systems are needed as mopane is one of the best evergreen trees introduced in Rajasthan to stabilize the sand tunes and also the fallen dried leaves are good fodder source at the time of grass shortage.

Silvipastoral System

Silvipastoral systems refer to growing of grasses, legumes and trees in optimal combinations to produce more wholesome fodder and forage, simultaneously increasing land productivity by collection of fuel wood and timber on the same unit of land. In arid regions, several people depend on livestock rearing to maintain their economy. But, the availability of pasture lands has declined over the years to around 0.11 ha and 0.31 ha in semi-arid and arid areas respectively (Gaur *et al.*, 2016). This activity requires the development of pasture lands and fodder trees as in silvipastoral systems of agroforestry. Nutritive value of pastures may be increased by growing legumes with grasses which will increase productivity of livestock and ultimately increase the income of farmers. Trees in silvipastoral system also provide fruits, fodder, gum which will provide additional income to the farmers.

Studies by Harsh *et al.* (1992) at CAZRI, Jodhpur for nine years report that average carrying capacity of pastures can be increased by adopting silvipastoral models growing *Cenchrus ciliaris* (*dhaman*) with mopane (*Colopospermum mopane*) and anjan (*Hardwickia binata*) trees, compared to sole grass. These systems were also reported

more remunerative than sole tree or sole pasture blocks. The forage production from arid areas can be increased from 0.50 to 3.6 t ha^{-1} by growing grasses (*Lasiurus sindicus, Cenchrus ciliaris, Cenchrus setigerus*), legumes (*Clitoria ternatea, Lablab purpureus, Atylosia scarabaeoides*), and trees (*Prosopis cineraria, Prosopisjuliflora, Azadirachta indica,* (*Ziziphus nummularia* and *Acacia tortilis*) in suitable combinations with improved management practices (Ramana 2013). Studies at CSWRI, Avikanagar, Rajasthan showed that three tier silvi pastoral system (*Cenchrus* + *Ailanthus excelsa* + *Dichrostachys cinerea*) provided maximum average forage production (2.78 t ha^{-1} dry forage from pasture + 0.95 green tree leaves) over other systems. In another study conducted at Jodhour it was found that the carrying capacity of silvi pastoral system is (8.5 sheep ha^{-1} after 7 years of establishment) more than a pure pasture (3.9sheep ha^{-1} after 9 years). *Zizyphus nummularia* with grass strips in 1:2 ratio gave higher economic returns due to higher wool production and increase in weight gain of the goat (Tanwar *et al*., 2015).

Carbon Sequestration Potential of NTFPs based Agroforestry Systems

Kyoto protocol allows developed countries to invest in climate change mitigation projects in developing countries under CDM. This provides an economic opportunity to the marginal farmers of developing countries, the major practitioners of agroforestry to sell the carbon sequestered in agroforestry systems to the developed countries. The carbon sequestration potential of the arid region is more, as there is large area currently with low carbon contents. Root production of trees strongly affects the carbon sequestration in soil. Roots contribute 25% to the total living biomass of trees which continuously add organic matter to soil by death and decay. Large volume of carbon gets sequestered in lower layers as arid zone trees put forth a large volume of below ground biomass in the form of roots. It is more important in arid zone where climax tree species like *Prosopis cineraria* have very deep root system which can reach upto 70 m depth. The soil carbon stock can be increased from 24.3 Pg to 34.9 Pg by planting trees and grasses in the degraded lands of arid zone.

A study was conducted in a six year old agri-silvi-horti system grown on a farmer field in arid region of Rajasthan to compare carbon accumulation in both

tree biomass and soil (0-30 cm in depth). Silvicultural species viz., *Prosopis cineraria*, *Ailanthus excelsa* and *Colophospermum mopane* along with horticultural species viz., *Ziziphus mauritiana*, *Cordia myxa* and *Emblica officinalis* were planted alternate plant to each other. Wheat (*Triticum aestivum*) was intercropped with these trees. The *Colophospermum mopane* recorded the highest carbon content of 45.84% and the lowest by *Ailanthus excelsa* (43.61%). *Prosopis cineraria* based agroforestry recorded the highest average carbon stock compared to other two silvicultural species. Average carbon stock was more in agroforestry than in sole agriculture plots, horti and silvispecies (Singh and Singh, 2015).

Summary and Conclusion

Trees in traditional agroforestry systems of arid Rajasthan are grown only for NTFPs, not for timber. Because in arid regions establishment of trees are very difficult, hence felling of trees for timber is not practiced. NTFPs based agroforestry systems have the potential to improve livelihoods of poor farmers in arid region, but efforts are needed to provide knowledge on the on-farm value addition innovation, development of supply chain for the products, minimum support price, etc. Degraded pastures and other underutilized farming lands can be brought under vegetation through NTFPs based agroforestry systems which help control wind erosion, conserve moisture, provide nutritive fodder, edible products, medicinal and other economic products, and increase the crop productivity which in turn increase the income of farmers in arid region. Agroforestry based industries are lacking in this region which should be promoted for proper marketing of NTFPs. Support from financial institutions is also needed for farmers of this region to start commercial agroforestry and to provide insurance against failure of plantations because of drought and other unforeseen climatic changes. There is also a potential to utilize agroforestry in arid regions to mitigate global warming by preserving the carbon in the wood of trees which also provide economic benefits to the farmers.

Fig.1. NTFP trees and their products in agroforestry systems of arid Rajasthan

Prosopis cineraria

Prosopis cineraria pods

Capparis decidua

Salvadora oleoides

Grewia tenax

Balanites roxbhurghii

References

- Abu-Al-Futuh I.M. 1983. Balanites aegyptiaca: An Unutilized raw material potential ready for agroindustrial exploitation. UNIDO Document no. 12419 project TF/INT/77/021. UNIDO of the United Nations.
- AFD, ADB and DFID 2003. Poverty and Climate Change: Reducing the Vulnerability of the Poor Through Adaptation, DFID, London.
- Aggarwal, R.K., J.P. Gupta, S.K. Saxena and K.D. Muthana. 1976. Studies on soil physico chemical and ecological changes under twelve years old five desert species of Western Rajasthan. Ind For. 192: 863-872.
- Anonymous, 1989. IBPGR- Kew, Forage and browse plants for arid and semi arid Africa (Rome, IPBGR)
- Arndt S.K., S.C.Clifford , M.Popp 2001. Ziziphus - a Multipurpose Fruit Tree for Arid Regions. In: Breckle SW., Veste M., Wucherer W. (Eds.) Sustainable Land Use in Deserts. Springer, Berlin, Heidelberg.
- Bhandari, M.M. 1978. Flora of Indian Desert, Scientific Publisher, Jodhpur, pp 471.
- Bhandari, M.M. 1990. The flora of the Indian Desert. Scientific Publisher, Jodhpur. 522 p.
- Bhandari, M.M. 1995. Biodiversity of Indian desert. In: Taxonomy and Biodiversity (CBS Publishers) Delhi 29-43.
- Brandbyge, J. 1993. Polygonaceae. In: The Families and Genera of Vascular Plants. (Eds.) Kubitzki, K.K., J.C.Rohwer, and Bittrich (springer-Verlag) Berlin.
- Burkill, H.M. 1985. The useful plants of west tropical Africa.Vol.1 Families A-D.Kew Royal Botanic Garden.
- CAZRI, 1981. Bordi-Ziziphus nummularia, A Shrub of Indian Arid Zone. (Eds.) H.S. Mann and S.K. Saxena, CAZRI Monograph, 13.
- Chandra, A., Chandra Anju and I.C.Gupta. 1994, In: Arid fruit research, (Scientific Publisher, New Pali Road, Jodhpur).

- Chapagain B.P., Y.Yehoshua and Z.Wiesman . 2009.Desert date (Balanites aegyptiaca) as an arid land sustainable bioresource for biodiesel.Bioresour. Technol. 100(3): 1221- 6.
- CIAH, 2017. Varieties Released by CIAH, Biknaer. ICAR-Central Institute of Arid Horticulture, Bikaner, Rajasthan-334006.
- CIFOR, 2002.Planning for woodcarving in the 21st century.Center for International Forestry Research, Bogor, Jakarta, Indonesia, 2002, 4 Pp.
- CSSRI, 2007.Annual Report 2006-07, ICAR- Central Soil Salinity Research Institute, Karnal-132 001, Haryana, India. Pp.154.
- Dagar, J.C., R.K.Yadav, S.R.Dar and Ahmad Sharif. 2015 Liquorice (Glycyrrhiza glabra): A potential salt-tolerant highly remunerative medicinal crop which also helps in remediation of alkali soils. Curr Sci. 108(9):1683-1688
- Duhan, A., B.M.Chauhan and D.Punia. 1992. Nutritional value of some non conventional plant foods of India.Plant Foods Hum Nutr. 42: 193-200.
- El Tahir, B.A. 2002. Grewia tenax: a valuable fruit producing shrub in Western Sudan. Unpublished report, Agricultural Research Station, El Obeid, Sudan.
- FAO. 1999. Compendium of food additives specifications. Rome: FAO. Food and nutrition paper 52, addendum 7, Gum Arabic.
- Faroda, A.S and L.N.Harsh. 1999. From empty bowl to sell-reliance: Success of farmers of Desert Villages. Environmental News.June-July Pp.14.
- Gaur, M.K., K.Chand, A.K.Misra, M.M.Roy, M.Louhaichi and D.E.Johnson. 2016.Monitoring of sheep migration in arid region of Rajasthan, India using EO Data. J Ecosys Ecograph.6: 190.
- Gebauer, J., K.El Siddig, B.A.El Tahir, A.A.Salih, G.Ebert and K.Hammer. 2007. Exploiting the potential of indigenous fruit trees: Grewia tenax(Forssk.) Fiori in Sudan. Genet Resour Crop Ev.54:1701 -1708.
- Gour, V.S and T.Kant. 2012. Balanites aegyptiaca (l.) del: a multipurpose and potential biodiesel tree species of the arid regions. Int J Sci Nat. 3 (2): 472- 475.

- Gupta, A. K. 2004.Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. Current Sci. 87:54-59.
- Gupta, I.C., L.N.Harsh, K.A.Sharikarnarayan and B.D.Sharma. 1989. Wealth from Wastelands.Indian Farming. 38 (11): 905-911.
- Gupta, J.P. 2000. Technology approach for greening degraded arid lands. Division of Integrated Land use Management and Farming System, Central Arid Zone Research Institute, Jodhpur, India. Pp.55.
- Harsh, L.N and J.C.Tewari. 2003.Agroforestry systems in hot arid regions with special reference to value addition. In: Agroforestry : Potentials and Opportunities. (Eds.) Pathak P.S and Ram Newaj. 159-165
- Harsh, L.N and J.C.Tewari. 2007.Agroforestry systems in arid regions of India. 2007. In: Agroforestry : Systems and Practices. (Eds.) Puri, S and P.Panwar.175-189
- Harsh, L.N., J.C.Tewari, U.Burman and S.K.Sharma. 1992.Agroforestry in arid regions.Indian Farming (Special Issue on Environmentally Sound Biotechnology) 45: 32-37
- Imran, M.A., G.Begum, K.Sujatha, and B.Mallaiah. 2012 Effect of adenine sulphate (ads) with cytokinins on multiple shoot production in Carissa carandas. Int. J. Pharma Bio Sci. 3(1): 473- 480
- Jaimini, S.N. and Tikka, S.B.S. 1998. Khejri based agroforestry system for dry land areas of north and north western Gujarat. Ind J For. 21 (4): 331-332.
- Jatasra, D.S and R.S.Paroda. 1981. Prosopis cineraria an exploited treasure of Thar desert. Forage Res. 7: 1-12.
- Khan, T.M.M. 2005. "Jojoba: a suitable plant for sand-dunes". Hindusthan Times. Sept. 9 : 22.
- Khyade, M.S., S.R.Kolhe and B.S.Deshmukh. 2009. Wild edible plants used by the tribes of Akole Tahasil of Ahmednagar District (Ms), India. Ethnobotanical Leaflets.13: 1328-1336.

- Leakey, R. R. B and Z.Tchoundjeu. 2001. Diversification of tree crops: Domestication of companion crops for poverty reduction and environmental services. Exp.Agric. 37: 279-296.
- Maheshwari, R., A.Sharma and D.Verma. 2012. Phyto-therapeutic significance of Karonda. Bul. Environ. Pharmacol Life Sci. 1 (12): 34-36.
- Mala Rathore. 2009. Nutrient content of important fruit trees from arid zone of Rajasthan. J Hortic For. 1(7):103-108
- Mala Rathore.2012. Important Lesser Known Wild Edible Plants of Arid And Semi-Arid Zone of Rajasthan Forestry Bulletin. 12(2):56-60
- Malik S.K., R.Chaudhury, O.P.Dhariwal and D.C.Bhandari. 2010 Genetic resources of tropical underutilized fruits in India, NBPGR, New Delhi, 47-54.
- Mandal, U., R.S.Singha and B.C.Mazumdar. 1992. A recently developed agro-industry in the southern suburb of Calcutta city utilizing a bramle fruit. Ind J Landscape Systems and Eco Studies, 15(1):100-102
- Meghwal, P.R and J.C.Tewari. 2002. Kair (Capparis decidua (forsk.) Edgew.)-a multipurpose woody species for arid regions.For trees livelihoods. 12:4, 313-319.
- Meghwal, P.R. 2002. Judging the culinary maturity of ker fruits (Teent) (Capparis decidua Forsk), Curr Agric. 26(1-2): 75-76.
- Meghwal, P.R., S.K.Singh, Akath Singh and Rakesh Pathak. 2014. Characterization of Karonda (Carissa carandas) accessions underarid region. J Appl Hortic.16(2): 157-160,
- Moharana, P.C., P.Santra, D.V.Singh, Suresh Kumar, R.K.Goyal, Deepesh Machiwal and O.P.Yadav. 2016. ICAR-Central Arid Zone Research Institute, Jodhpur: Erosion Processes and Desertification in the Thar Desert of India. Proc. Indian Natn Sci Acad 82 (3) July Spl Issue. pp. 1117-1140. DOI:10.16943/ptinsa/2016/48507
- Moola Ram, J.C.Tewari, L.N.Harsh, H.A.Khan, Prahlad Singh, Poona Ram, Yogendra Singh, Manmohan Singh and Naveen Singh. 2013. Tree Gum Tapping

Technique of CAZRI Proved to be a Boon of Livelihood for Gum Arabic Tappers of Western Rajasthan in India. Popular Kheti 1(1):16-20

- Neumann, R.P and E.Hirsch. 2000 Commercialization of Non-Timber ForestProducts: Review and Analysis of Research. Bogor, Indonesia: Centre forInternational Forestry Research (CIFOR), p176.
- NMPB. 2008. National Medicinal Plants Board, Department of AYUSH, Ministry of Health and Family Welfare, Government of India.
- Orwa, C.A., R.Mutua, Kindt, R.Jamnadass and S.Anthony. 2009. Agroforestree Database: a tree reference and selection guide version 4.0(http://www.worldagroforestry. org/sites/treedbs/treedatabases.asp)
- Paliwal, A. 2010. Guggal faces sticky end. Down to earth. Available at:http://www. downtoearth.org.in/coverage/guggal-faces-sticky-end-1538
- Pandey, A.N and M.V.Rokad. 1992. Sand dune stabilization: an investigation in the Thar desert of India. J Arid Environ. 22(3): 287-292.
- Pandey, D.N. 1996. Beyond Vanishing Woods: Participatory Survival Options for Wildlife, Forests and People, Himanshu/CSD, New Delhi. Pp.222.
- Panwar, D., Kailash Pareek and C.S.Bharti. 2014. Unripe Pods of Prosopis cineraria used as a vegetable(sangri) in Shekhawati region. J. Sci. Eng Res. 5(2):892-895
- Pareek, K., J.C.Tewari, K.Shiran, M.K.Gaur, P.R.Bishnoi, Anil Sharma and Vikash Chaudhary. 2017. Gum Production on Different Land Forms in Arid Western Rajasthan. J Agric Vet Sci. 10(9.II):14-17
- Pareek, O.P., B.D.Sharma and S.Sharma. 1998. Wasteland Horticultura, Malhotra Publishing House, New Delhi, 141-143.
- Parichha, S. 2004. Bael (Aegle marmelos) Nature's Most Natural Medicinal Fruit Orissa Review.
- Ramana, D.B.V. 2013.Silvi-Pastoral and Horti-Pastoral Models for Small Ruminant Production. Central Research Institute for Dryland Agriculture,

Hyderabad. Available at :http://www.crida.in/DRM1-Winter%20School/DBVR. pdf.

- Rathore, M and R.K.Meena. 2004.Nutritional Evaluation of some Famine Foods of Rajasthan Desert.Ind. For. 130 (3): 304-311.
- Rathore, V.S., J.P.Singh and M.M.Roy. 2012. Haloxylon stocksii (Boiss.) Benth. et Hook. f., a promising halophyte: distribution, cultivation and utilization. Genet Resour Crop Evol. 59:1213-1221.
- Rathore, V.S., J.P.Singh, S.Bhardwaj, N.S.Nathawat, M.Kumar and M.M.Roy. 2014. Potential of native shrubs Haloxylon salicornicum and Calligonum polygonoides for restoration of degraded lands in arid western Rajasthan, India. Environ Mang. doi:10.1007/s00267-014-0372-1
- Roy, M.M., J.C.Tewari and Moola Ram. 2011. Agroforestry for climate change adaptations and livelihood improvement in Indian hot arid regions. Intl. J Agri Crop Sci. 3(2): 43-54
- Saini, H. 2008. Impact of jojoba cultivation through AJORP' in Rajasthan - A Process Evaluation.Ph.D thesis.Maharana Pratap University of Agriculture and Technology, Udaipur.
- Sandhu, L.S. 2001. A case study for successful cultivation ofjojoba under resource constraints. In: Proceedings of National Seminar on Production, Marketing and Processing of jojoba (Simmondsia chinensis) AJORP, Jaipur. Pp.25-26.
- Sawant, R.S and A.G.Godghate. 2013. Comparative studies of phytochemical screening of Carissa carandas L. Asian J. Plant Sci. Res. 3(1): 21-25.
- Saxena, S.K and S.Singh. 1976. Some observations of the sand dunes and vegetation of Bikaner district in Western Rajasthan. Ann. Arid Zone. 15: 313-322.
- Shankar, V., N.K.Dadhich and S.K.Saxena. 1976. Effect of Khejri tree (Prosopis cineraria) on the productivity of range grasses growing in its vicinity. Forage Res. 2:91-96.

- Sharma A.K and J.C.Tewari. 2005.Arid zone forestry with special reference to Indian hot arid zone. In: Forests and Forest Plants, Encyclopedia of Life Support Systems (EOLSS), Developed under auspices of the UNESCO, EOLSS publishers, Oxford, UK (http://www.eolss.net).
- Sharma, A.K. 2000. Addition in tradition: agroforestry in the arid zone of India. LEISA-INDIA. 2(3):19-20.
- Sharma, N.K. 2013. Fodder Strategy for Sustainable Animal Production in Arid Rajasthan. Ann. Arid Zone 52(2): 101-108.
- Sharma, S.K and S.K.Banyal. 2010.Rehabilitation of marginal lands through Karonda cultivation.Intensive Agriculture, Oct-Dec 6 - 12.
- Shukla, J., K.Kasera and P.Kumar. 2004.Response of irrigation and spacing levels on growth parameters of Khejri (Prosopis cineraria). Ind. J. For. 27(4): 335-338.
- Singh, G and Bilas Singh. 2015. Rooting pattern and equations for estimating biomasses of Hardwickia binata and Colophospermum mopane trees in agroforestry system in Indian desert. Research and Reviews. J. Bot Sci 4(1):30-40
- Singh, G and T.R.Rathod. 2007. Growth, production and resource use in Colophospermummopane-based agroforestry system in north-western India. Arch Agron Soil Sci. 53(1):75-88
- Singh, G. 2009. Comparative productivity of Prosopis cineraria and Tecomella undulate based agroforestry systems in degraded lands of Indian Desert. J Forest Res. 20(2): 144-150
- Singh, J.P., V.S.Rathore and M.M.Roy. 2015. Notes about Haloxylon salicornicum (Moq.) Bunge ex Boiss., a promising shrub for arid regions. Genet Resour Crop Evol. 62:451-463
- Singh, M., M.L.Arrawatia and V.P.Tewari. 1998.Agroforestry for Sustainable Development in Arid Zones of Rajasthan. Int. Tree Crops J. 9:3:203-212. DO I:10.1080/01435698.1998.9752976.

- Suresh Kumar, Farzana Parveen, Sangeeta Goyal and Aruna Chauhan. 2008. Indigenous herbal coolants for combating heat stress in the hot Indian Arid Zone. Indian J Tradit. Know. 7(4): 679-682
- Tanwar, S.P.S., Suresh Kumar and M.M.Roy.. 2015. Integrated Farming System for Higher Income, Security and Optimum Resource Utilization in Arid Regions. Agri Care. Available at: http://agricare.kisanhelp.in/content/integrated-farming-system-higher-income-security-and optimum-resource-utilization-arid
- Tewari, J.C and K.Pareek. 2016. Annual Progress Report on Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums, CAZRI Centre, ICAR-CAZRI, Jodhpur, 26p.
- Tewari, J.C., N.M.Pasiecznik, L.N.Harsh and P.J.C.Harris. 1998.Prosopis species in the Arid and Semi-Arid Zones of India. The Prosopis society of India and Henry Doubleday Research Association, Jodhpur, India and West Midlands, U.K. 127 p
- Tewari, J.C., A.K.Sharma, Pratap Naraian and Raj Singh. 2007. Restorative forestry and agroforestry in hot region of India: A Review. J Tropical Forestry. 23: 1-16.
- Tewari, V.P and Singh, Mahenda. 2006. Tree-crop interactionin the Thar Desert of Rajasthan (India).Secheresse. 17(1-2):326-32
- Tiwari, J.K., R.Ballabha and P.Tiwari. 2010. Some promising wild edible plants of Srinagar and its adjacent area in Alaknanda Valley of Garhwal Himalaya, India. J Am Sci. 6(4): 167-174.
- Uma Shaanker, R., S.D.Lama and K.S.Bawa. 2001. Ecology and economics of domestication of non-timber forest products: An illustration of broom grass in Darjeeling Himalaya. J Trop For Sci.13: 171-191.
- Upadhyaya, S.D and A.Sharma. 2007.Agroforestry systems in Madhya Pradesh-Potentilities, Possibilities and Opportunities. In: Agroforestry: Systems and Practices by Sunil Puri and Pankaj Panwar (Eds.). New India publishing Agency, New Delhi.

- Yadava, N.D., M.L.Soni, N.S.Nathawat, and Birbal. 2013. Productivity and growth indices of intercrops in Agri-Horti-Silvi system in arid Rajasthan. Ann Arid Zone. 52(1):61-65
- Zodape, S.T and V.K.Indushekhar..1997. uSalvadora persica: a boon to wasteland development". J. Scient. Indus. Res. 56:657-661.