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Review Article

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Khejri (*Prosopis cineraria*) research for horticultural harnessing and environmental services: an appraisal

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Abstract

Dry-land agriculture has enormous potential in ensuring nutritious food to the inhabitants and eco-restoration. Khejri (*Prosopis cineraria*) is a life-line tree of the Thar Desert. It is the most important component of the traditional farming systems of arid and semi-arid region of the north-western part of India. It tolerates extreme edapho-climatic conditions with lush-green foliage and bears fruits that too during the driest period. Its nutritious leaf-fodder (*loong*) and tender pods (*sangri*) used extensively. Sangri is sold fresh and dehydrated at high price, and it is the main constituent of *Panchkutta* vegetable cooking. Prior to CIAH - Khejri Technology, the rural people used to collect tender pods from the natural seedling trees and there was no quality standard for it. For horticultural exploitation, a series of technological advancements have been made at ICAR-CIAH and first-time recommended are patch-budding for vegetative propagation for conservation of the elite genotypes and mass-multiplication of true-to-type plants in the nursery, *in-situ* orchard establishment by bud-grafting, induction of thornlessness in plants, variety-Thar Shobha, crop-regulation to harvest both *sangri* and *loong* annually, on-farm value-addition and diversified crop-combination models adopting HBCPSMA concept such as Organic *Panchkuta*, native, multi-purpose and intensive production. Based on crop-commodity potentialities, khejri planting models *viz.*, KM-1, KM-3, KM-7, KM-9 and KM-11 exhibited tremendous scope for desert horticultural promotion and agro-ecological prosperity.

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Introduction

The 20th century advancement in Indian horticulture is production technology for favorable climatic regions of the country. The diverse land-scape of hot arid, semi-arid

and tribal areas of the north-western part of India is yet not getting logical thought for resource based exploitation. Here, native crop-plants both annual and perennials are drought tolerant and playing vital role in food and fodder especially in the state of Rajasthan where animal husbandry is an integral part of farming. Based on the research findings, SWOT analysis and experiences gained over the 25 years at ICAR-CIAH, Bikaner it is accomplished that the hot arid region has an excellent production opportunities with the unique and varied crop-plants, and them, khejri is most prospective tree for the desert horticulture (Samadia 2016; Samadia & Haldhar 2017; More et al. 2018). This multiple-function tree is the chief perennial component compatible to the almost any companion crop in the traditional farming systems. It grows luxuriantly under the extremes adverse temperature, hot and dry climate and that too without much cultural care (Pareek 2002). The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) has also identified 64 priority crop-complexes for conservation and where *Prosopis* is kept in forage-legume and thus, khejri is versatile tree for sustainable use and ecological prosperity.

The path-breaking technology of khejri (bud-grafting as vegetative method of propagation for establishing varietal orchards) at ICAR-CIAH, Bikaner resulted into its wide-spread popularity for the systematic plantations. This newer techniques led to the availability of standard planting material of named genotypes, and recommended for uniform *sangri* production orchards and planting models for diversified cropping.

Thus, the organized production of standard product from the developed plantations would add value to the already existing lucrative trade in dehydrated pods and provide assured income to farmers and quality sangri to consumers (Samadia 2014; Samadia 2016; Samadia et al. 2009). For horticultural harnessing, a series of technological advancement have been made in khejri at CIAH, and recommended are bud-grafting or patch-budding for vegetative propagation and mass-multiplication of plants in the nursery, *in-situ* orchard establishment by bud-grafting, induction of thornlessness in plants, first variety Thar Shobha, crop-regulation to harvest both *sangri* and *loong* annually, on-farm value-addition, and diversified combination models adopting HBCPSMA concept viz., organic *Panchkuta*, native, multi-purpose and intensive crop-plant production (Samadia 2018).

The khejri

Khejri is very useful plant of dry-land farming systems of the north-western part of India. Botanically, khejri is *Prosopis cineraria* (L.) Druce and also known as *shami* (Sanskrit), *janti* and *jand* (Delhi, Haryana, Punjab), *sumi* / *sumari* (Gujarat), *banni* (Karnataka), *vanni* (Tamil Nadu), *kandi* (Sindh), *ghaf* (United Arab) and is a leguminous tree. It is sacrosanct arbor of *Bishnoi*'s, worship (*Shami*) tree of Hindus and the life-line for inhabitants of desert ecosystem. The prevailed situations verifying the glorification of khejri tree as *Kalp-taru* of the Thar Desert. It not only tolerates the extreme edapho-climatic conditions of hot arid region with the lush-green foliage but also bears

fruits and that too during the driest period (Pareek 2002; Samadia et al. 2012).

Uses, nutrition and benefits

Khejri is a multi-function tree and ensuring nutrition rich leaf-fodder, pods and seeds and also fuel-wood. Its favorable impact on the soil fertility build-up and ecology is well recognized. Tree has mono-layered canopy, deep tap root system and fixes nitrogen in the soil. It is natural and perennial component in most of land-use systems and obliging environmental services. Because of deep roots, it does not compete for moisture or nutrients with crops grown close to it. In winters, it casts lesser shade. Farmers have long belief that it improves the field productivity and it is also proven too that soil content high organic matter, nitrogen, phosphorus, calcium and lower pH level. The tree recorded abundant flowers and valued for honey production (Pareek 2002; Samadia et al. 2002; Kaushik & Kumar 2003; Pasiecznik et al. 2004; Samadia 2007; Kumar et al. 2017). During the Vedic era, khejri wood was used to kindle sacred fire for performing Yajana. The Ramayana and Mahabharata epics described spirituality of this tree (*Shami-puja*). The Bishnoi community is well known for conservation of tree-plants as a religion. Government of India has instituted 'Amruta Devi Bishnoi' national award for wild-life conservation in the memory of Amruta Devi Bishnoi, who in year 1731 sacrificed her life along with 363 local members for the protection of khejri trees in the Khejarali village of Jodhpur.

There is a common saying that death will not visit a man even at the famine time if he has a khejri, goat and camel, since, these three

together sustained the life of inhabitants. Green and dry leaves, twigs and pods feed to animals. All these are used as famine food and even known to the pre-historic man too. In severe famine of year 1899 and 1939, even the bark having an astringent taste was eaten. The rural communities encourage the growth of khejri in their farm, pastures and common lands. This is because of its extensive root system that stabilizes shifting of sand-dunes, and the tree foliage is lush-green in summer months and thus useful as wind-break, shelter-belt and afforestation component. This is widely protected tree species, since it provides much needed shade and shelter to farmers working in the fields as well as to cattle and wild-life during summer months.

Khejri is much valued for its leaf-fodder (*loong* or *loom*) and is a major source of nutritious animal feed. Both green and dry *loong* is highly palatable and feeding in winters is much beneficial. Trees heavily lopped with the on-set of winter months when no other green fodder is available in the *Thar* Desert. Un-lopped trees produce tender pods (*sangri*) and used for vegetable culinary and pickles. Tender pods used extensively and *sangri* is the main constituent of *Panchkutta* vegetable. Traditionally, the rural people collect pods on large-scale for fresh or dehydration purpose. So far, what-ever produce of *sangri* is available on wide-spread natural trees and it is being harvested and used by the desert dwellers. Whereas ripen pods (*khokha*) used for fresh consumption (*Marwadi-mewa*) and flour making, and it mixed with wheat or bajra flour to make chapati (*roti*). Dry ripen pods has sweet-pulp and full of seeds is protein rich and good

source for animal feed and preparation of bakery items.

In general, leaf-fodder and pods are rich in dietary fibre, protein, carbohydrate and minerals. Leaves contain 12-18% crude protein, 13-22% crude fibre, 43-45% carbohydrate, 2.9% fat, 0.4% phosphorus, 2.1% calcium and 6-7% trace elements and have 5000 kcal calorific value. Pods also contain 18% crude protein, 26% crude fibre, 56% carbohydrate, 2% fat, 0.4% phosphorus, 0.4% calcium, 0.2% iron and other minerals. The pulp of khokha is sweet and rich in sugars (6-16%).

Khejri tree yields yellowish-brown colour gum similar to the gum of kumat. Bark of the tree is dry, acrid taste and used in preparation of formulation for tonic, blood purifier and treatment of diseases. Bark used as remedy for cough, cold, anathematic, leprosy, dysentery, bronchitis, asthma, leucoderma, piles and tremors of muscles. Smoke of leaves is good for curing eye troubles. Mature and dry pods of some trees found astringent and considered hot and have a flavour, indigestible and causes biliousness and damages nails and hairs. Khejri make product recommended for treatments of snake-bite and scorpion-sting. Flowers mixed with sugar and used during pregnancy as safe-guard against miscarriage. Water-soluble extract of stem-bark exhibits anti-inflammatory properties.

Khejri provide quality wood and used in house-building as rafters, posts, doors, boxes, tool-handles and agricultural implements. In desert, container manufacturing is wood-based industry and depends largely on native trees. It wood contains high calorific value fuel (5000 kcal/kg) and good for charcoal making. The

lopped branches are used as fencing material or fire-wood. In all, the tree provides fodder, vegetable, fruits, gum, medicine, fuel-wood, timber, fencing material and shade besides enrich soil and ecology, and therefore, khejri exhibited tremendous scope for horticultural harnessing and environmental services.

Origin and distribution

The genus *Prosopis* have 44 species and are trees or shrubs of leguminous and prioritized crop-complex commodity for sustainable use and conservation. The *Prosopis juliflora*, *P. nigra*, *P. alba*, *P. pallida*, *P. chilensis*, *P. spicigera* and *P. cineraria* are the most common. The widespread *Prosopis juliflora* is the South and Central American species and promoted for re-forestation world-wide. Now, this species is becoming a weed (*vilayati babool*) and damaging indigenous crop-plant genetic diversity in the dry-lands of India. The *Prosopis cineraria* is old world species but lesser attention is given, however, it is the most useful and economical tree of arid and semi-arid region of the north-western parts of India. The Central Arid Zone Research Institute (CAZRI) and Arid Forest Research Institute (AFRI), Jodhpur (Rajasthan) and Henry Doubledy Research Association (HDRA), England (UK) has long research programme and conducted investigations on this species. ICAR–Central Institute for Arid Horticulture, Bikaner is pioneer in developing clonal multiplication (bud-grafting) techniques for conservation of its elite, trait-specific and true-to-type germplasm and varietal promotion for horticultural orcharding (Dwivedi et al. 1997; Pareek 2002).

Prosopis cineraria (L) Druce / Mac Bride, is indigenous to the India, Pakistan, Iran, Arabian Peninsula and Afghanistan. Naturally, it is most widely distributed component of arboreal flora of the *Thar* Desert in India and extends to western Pakistan, Afghanistan and Iran. In India, it is found abundant in arid and semi-arid areas mainly Rajasthan, Haryana, Punjab and Gujarat. It is common in Delhi, Agra, Western Uttar Pradesh and Bundelkhand area of the central India. It is also found in the driest parts of Maharashtra (Nasik), Andhra Pradesh, Karnataka (south Godavari) and Tamil Nadu (Tuticorin) of the southern India. In dry-land, it is suitable for close or hedge-row planting but in the sub-humid areas this tree spreads freely by root-suckers and forming dense thickets. Self-sown seedlings initially dense-thorny shrub and becomes tree reaching to 10-12 meters height and roots penetrates 30-35 m below surface. It grows luxurious with 75-450 mm rains/annum and dry seasons of eight months or more. It tolerates severe drought, high temperature and frost conditions. Naturally, it spreads in sandy plains, slightly undulating ground and ravine, and at low altitudes of <600 metre. It is also found growing on heavy soil, dry-stony and saline-alkaline lands where pH is high (9.8).

In general, the greenery climax of *Thar* Desert is depicted by trees of *Prosopis cineraria* and it is spread on the agri-fields, cultivable-fallow, grazing, barren and reserved forest lands. It is found in association with the native plants such as *Salvadora oleoides*, *Tecomella undulate*, *Capparis decidua*, *Maytenus emarginata*, *Ziziphus* and other perennial flora of desert and sand-dune landscape. In sandy area of Arabia and Oman,

ancient *P. cineraria* trees found isolated and recorded with *Acacia tortilis* and it form dry wood-lands in the desert eco-system. There is a considerable phenotypic variation between the *Prosopis cineraria* individuals for crown shape, growth behaviour and branching patterns and also growing conditions of trees from desert sand-dues to highly saline coastal areas. In Rajasthan state, density of khejri trees is increases from the western to eastern region. It varies with rainfall, range management, farming systems and utilization patterns of non-culturable, barren and waste-lands. In general, khejri seedlings range is 15-165 trees/hectare from arid to semi-arid region of Rajasthan, and it is scattered in nature (Pareek & Nath 1997; Samadia et al. 2002).

Botany and Taxonomy

Prosopis cineraria (L) Druce, $2n=28$, belongs to the family Leguminosae and sub-family Mimosaceae. Khejri is small to medium sized and thorny tree. As with other *Prosopis*, rooting is very long and deep and the tap root of khejri may penetrate vertically up to 35 m or more. It has armed shape, irregular, glabrous and slender branches. It is ever-green or nearly so and has 2-3 growth flush/annum. It forms open-crown and big trunk or stem is mostly straight with thick, rough, gray bark exfoliated in numerous thin flakes and deep fissures. Branch-lets have conical thorns and light bluish-green foliage. Leaf-lets are dark green with thin casting of light shade. Trees coppices or lopped profusely in winter and produces new flush leaves before summer. The leaves are alternate, bi-pinnately compound and 1-3 pairs of pinnae. Each pinnae has 7-14 pairs of leaf-lets, and are 4-15 mm long and 2-4 mm width.

Thorns become visible when the seedlings are 6-8 weeks old. The thorns are straight with a conical base and distributed sparsely along the length of stem. In this way, the *P. cineraria* differ from the thorny new world species *P. juliflora* which have thorns in pairs at the nodes but thornless inter-nodes.

Flowers are small (0.6 cm) and yellow-green or creamy-white in colour. Flowering appears from March to May along-with new flush of leaves on un-lopped trees. Flowers borne on 5-23 cm long spike like racemes and axillary spikes solitary or terminal panicles. Pods develop in a sequence and thereafter, grow rapidly and attaining full-size in about two months. Khejri is considered to be a perennial vegetable and fruiting occurs during the driest period and pods are used both tender and mature stages. The light yellow ripened pods are cylindrical, long (8-21 cm), narrow (0.4-0.9 cm) and contains 5-25 seeds which are dull brown and 0.3-0.8 cm length. Dry pods are rigid, glabrous having thin exocarp, pulpy mesocarp and papery endocarp. The pods has two kinds of taste i. e. sweet (without any acid) and acid. The sweet pods are preferred for sangri. Therefore, trees yielding sweet pods are suitable for horticultural exploitation and this is an important attribute for selection of elite types. Due to cross pollination, high degree of variation is observed in the agro-morphology of this species which gives excellent opportunities to identify elite-types from the wide-spread natural population. Various surveys have been conducted by CIAH, Bikaner and RS of NBPGR, Jodhpur from 1994 to 2002 in the areas of regional diversity and also identified some of the potential types suitable for

vegetable pod quality (Pareek & Nath 1997; Dwivedi et al. 1997; Samadia et al. 2002)

The phenology of khejri was studied from 2000-2006 involving ten selected seedling trees alongwith variety Thar Shobha and this information is found useful in improvement programme. The study revealed that lopped and un-lopped khejri trees depicted two distinct vegetative growth flushes in a year but flowering behaviour is in response to the pruning practices. The first growth flush is in the spring season from February-March and it is alongwith flowering on the un-lopped plants. The second growth is starts at the pods maturity in the June month and is continuing with the on-set of monsoon and rainy season. The duration of appearance of floral buds is from 2nd week of February to 1st week of April. These buds develop as raceme which bears tiny flowers. The racemes appear in cluster and number of racemes per cluster ranges from 2.0-12.5, and the length of each raceme can be 3.4-20.3 cm. Number of flower buds/raceme varies from 27.3-193.5. Initiation of raceme to anthesis took 28.4-31.2 days and duration of anthesis in raceme was 1.3-3.5 days which occurs between 4.00 AM to 2.00 PM. The number of flowers opened per raceme was 19.4-84.3 out of which 1.2-37.5 flowers set pods. Only 1.2-15.4 tender pods developed on a raceme of vegetable-use, and it weighing fresh 1.3-3.8 g, 4.8-32.3 cm long and having 5.2-24.6 seeds that can not separated. Tender pods harvested during April-May from the racemes after 15.4 to 30.2 days of setting and are variable sizes. Only 0.4-4.2 pods attain full maturity in 53-60 days after anthesis and weighing 1.75-2.68 g. The colour of seeds varies from brown to dark

brown and weight of 100 seeds is 4.88 g (Purohit et al. 2004).

Genetic resource

Prosopis cineraria, a multiple-use, nitrogen fixing and king of trees of Indian Thar desert. In the western Rajasthan, where the maximum population of khejri do exists, wealth of the farmer's is judged by presence of its trees in their fields. During extremes drought, live-stock depends entirely for feed on leaves and pods of this species, and farmers sell its produce to earn money too. Within its natural population, seedlings of *P. cineraria* represent significant diversity and the variable trees density playing key role in the in-hostile environment. In Pakistan, Oman, Arab and Middle-East countries, *P. cineraria* appears to be a highly variable species and the individuals ranging from tall, straight trees to low height, branching shrubs. In addition, the population exhibits considerable differences in their tolerance to the drought and salt. Historically, *P. cineraria* trees are vital to the inhabitants and used in sustainable manner. However, increased pressure on land and mechanization has halted regeneration and threatened its survival. Therefore, there is need to conserve the diversity and there is great opportunity to utilize the variability for commercial exploitation (Dwivedi et al. 1997; Pareek 2002; Samadia et al. 2002; Shivlingum et al. 2011 and Shivlingum et al. 2016).

For conserving the khejri diversity, systematic surveys were conducted in May-June months of the year 1989, 1990, 1992 and 1995 by the Regional Station of NBPGR, Jodhpur and 430 seed accessions were collected. The germplasm were collected from different production and range sites of

Bhiwani (10), Hisar (11), Jind (4), Mahendragarh (9), Rohtak (4), Sirsa (1) in Haryana and Ajmer (9), Barmer (56), Bikaner (26), Churu (22), Dausa (14), Hanumangarh (16), Jaipur (9), Jaisalmer (37), Jalore (21), Jhunjhunu (22), Jodhpur (63), Nagour (39), Pali (15), Shriganganagar (15) and Sikar (27) in Rajasthan. A wide range of areas was explored and variations were recorded in its distribution, tree-age, height, stem, branching, leaf-lets, pods and seed attributes. From the surveys, elite germplasm were identified and can be used for developing varieties of fast growing with larger canopy and sweet pods with palatable quality.

In view to exploit khejri as horticultural crop-plant, intensive survey studies were conducted in rural areas of Bikaner, Nagour and Churu district of Rajasthan during 1994 to 2002 by CIAH. Natural population of khejri trees is abundant in this part and good number of plants kept un-lopped to harvest tender pod. In Bikaner area, khejri population density varies from 10-55 trees/hectare and much variability was recorded in plant growth, pruning and harvesting of loong and sangri. With a view to identify the elite types having desirable attributes for their uses as perennial vegetable, 625 naturally occurring 10 to 50 years age-old seedling trees were marked and observed over a period of three years (2000 to 2002). From these seedlings, 18 trees of 20-25 year age that had sweet pods without any acidity were selected for collection of bud-wood and established *ex situ* from 2001-2005 at Bikaner.

The studied seedlings exhibited considerable variations for height (4.5-12.4 m), spread (4.7-10.3 m), pod shape (straight,

curved, round, lobed and flat), pod colour (light green, green and tinged), pod taste (bitter, acrid, less sweet and sweet), immature pod weight (1.21-4.50 g), pod length (4.5-32.3 cm), pod diameter (0.2-0.6 cm), number of seeds/ pod (5.2-24.6), weight of seeds/ pod (20.5-60.9 mg), weight of 100 seeds (4.07-5.15 g), seed length (0.42-0.75 cm), seed width (0.27-0.43 cm), seed thickness (0.17-0.25 cm), and thus depicted enough scope for better selection. The component of genetic variability was studied and the values of PCV and GCV were high for pod diameter and tender pod yield and moderate for pod length and number of seeds/pod. The heritability estimates were high for pod length, number of seeds/pod and tender pod yield. Thus, selection for these characters could be effective directly on phenotypic values.

Crop improvement

Khejri is a life-line tree and vital component of *Thar* Desert flora and traditional farming. It readily perpetuates from dispersed seeds consequently giving rise to a wide spectrum of variability with respect to morphological characters. Natural population of khejri is abundant in the arid and semi-arid farm-lands of north-western parts of India (Pareek & Nath 1997; Dwivedi et al. 1997; Samadia et al. 2002), and thus, there is tremendous scope to identify diversified use genotypes for crop improvement. The research out-come of CAZRI and CIAH with the ending of 20th century established that the native tree-shrubs and *Prosopis cineraria* in particular are better in comparison to the exotic species for survival, adaptability, growth, soil fertility build-up, socio-economic uses and checking desertification in the *Thar*

Desert. Although, massive plantations of khejri was not popularized due to the slow growth of saplings (1-2 m height in 4 years of age), and this was the greatest obstacle in its systematic orcharding. However, millions of self-sown saplings are protected and conserved on large-scale for promotion of this multi-function species.

Genetic improvement work on *Prosopis cineraria* was started initially at CAZRI in 1983 for identifying fast growing genotypes by selection from wide-spread natural population. In addition, detailed studies were also made to understand the extent and pattern of variability present. Based on the survey studies, seeds were also collected from selected types and progeny trials were conducted. A half-sib progeny trial of 142 plus-trees indicated an appreciable amount of genetic variability existence between and within the progenies. Progeny from the accession-264 of Jodhpur showed consistently better performance over the years for plant height. Some of the trees from the progenies attained 7.3 m height in the 6 years as against the average 2.1 m height of progeny, and thus seed orcharding was not found much gainful. Being a cross-pollinated species, considerable genetic variability is present and reported by various workers and a good amount of variations were also recorded for pod attributes. At CIAH, intensive studies were conducted to assess the extent of variability in the seedling population having horticultural attributes, and K-1, K-2, K-4, K-9, K-11, K-16 and K-17 were found promising trees. Therefore, it would be worthy to identify elite trees of khejri yielding high quality pods, loong or multiple valued which could then be

multiplied clonally to develop progeny orchards and plantation for diversified function. From the intensive seedling population studies and showing wide variations for desirable traits, 18 genotypes that produces excellent quality tender pods (sweet, long and many seeded) and multiple-use attributes were collected and established in field repository for *ex situ* conservation and evaluation at CIAH, Bikaner (Samadia 2007). Like-wise, seed progenies of khejri Selection-1 and Selection-2 were studied to understand segregate behavior of seedlings, growth, flowering, pod-set and other morphological characters and documented over 15 years from orcharding under hot arid environment at CIAH, Bikaner. Saplings of progenies exhibited much variation for growth, foliage, thorniness and pod bearing behavior.

Varietal development

Owing to cross pollination, significant variability exists in the widespread seedling population of khejri for plant and pod morphology. Wide range of variations were also recorded in prioritized attributes of immature pods such as taste (bitter, acrid, sweet), tenderness (hard, semi-hard, less tender, tender), shape (round, flat, flat-round or straight, wrinkled), fibre content (fibrous, less fibrous, fibreless), colour (green, light green, dark green) and length (6-39 cm) for horticultural exploitation. From the intensively studied seedlings trees showing variability, 18 genotypes were collected from 2002 for *ex situ* conservation and characterized, and two selections (KS-1 and KS-2) were found most promising at CIAH. Till, the first variety of khejri in 2007 by CIAH, there was no standard variety for uniform sangri production in the

traditional systems and no systematic orchards for commercial cultivation. In the past, due to non-availability of production techniques in particular to vegetative method of khejri multiplication, no much progress was made for varietal development too and it was started first at CIAH and variety Thar Shobha was recommended for orcharding.

Prior to the promotion of CIAH-khejri technology, owing to vegetable culinary of tender pods, the rural people collect sangri on large-scale. There was no pod quality standard and thus, what-ever produce of sangri is available and it is harvested and used it by desert dwellers. At present, sangri is sold at high price both fresh and dehydrated (50-120 and 400–650 Rs/kg, respectively) and it is eye-catching vegetable. Bud-grafted plants of the developed varieties are vigorous in growth, thornless and tolerates extremes of high (50⁰ C) and low temperature (–4⁰C) situations. Bud-grafted plants are extremely drought tolerant and have high production potential under rainfed conditions. Varietal development at CIAH resulted to systematic orcharding, and now, it would ensure good quality harvest of both fodder and pods from khejri plantations even-when there is complete failure of monsoon rains during the current growth year. The indigenous germplasm of khejri having horticultural significance in the form of tender pods for vegetable culinary (*sangri*) were initially spotted during 2000 to 2005 from the traditional farm-lands of Bikaner, Nagour and Churu districts of Rajasthan. First of all, a large number of potential trees were studded *in-situ* and then collected clonally at CIAH for *ex situ* conservation as regional diversity and

evaluated. For horticultural exploitation, 18 selections were studied over the period from 2003–2017 and it is with *in-situ* orchard establishments through bud-grafting technique and two promising varieties are recommended for uniform pod yield and high bio-mass production (Samadia 2016, Shivlingam et al. 2011; Shivlingam et al. 2016).

Thar Shobha

Thar Shobha (KS–1) is the first variety to develop uniform plantations for better quality and high *sangri* production on commercial scale and recommended in 2007 by CAIH. Bud-grafted plants are thronless and have spreading growth, dense-leaf and longer branch-lets. Marketable stages tender pods are light-green, straight, roundish-flat, 13.1–20.2 cm length, 0.17–0.42 cm diameter and 0.97–1.75 g weight. At commercial harvest age-group of 6th year, plants are 3.54 m height and 3.72 x 3.98 m spreading, and recorded 5.25 kg sangri and 6.85 kg loong yield annually. Fresh sangri pods contain 76.41 % moisture and 23.59 % dehydration recovery. Dehydrated sangri rich in nutraceutical value and contains 52.6 % carbohydrate, 18.2 % protein, 1.4 % fat, 22.7 % crude fibre, 3.7 % calcium, 0.3 % phosphorus and 4.8 % trace elements. The variety is vigorous in growth, high loong yielding and the mature fresh leaves contains 57.98 % moisture and have 42.02 % dehydration recovery. Dehydrated loong rich in nutritional values and contains 56.05 % carbohydrate, 13.88 % protein, 1.92 % fat, 19.6 % crude fibre, 2.65 % calcium, 0.47 % potassium, 0.24 % phosphorus and 10.48 % trace elements.

Khejri Selection–2

Khejri Selection–2 was identified in year 2007 from regional diversity and evaluated *in-situ* for horticultural potentials. This established through bud-grafting technique and studied *ex-situ* at CIAH, Bikaner from 2013–2017 and it is high yielding. Bud-grafted plants are thronless and have compact growth, dense-leaf and longer branch-lets. Marketable stages tender pods are light-green, straight, roundish-flat, 15.32–21.81 cm length, 0.28–0.53 cm diameter and 0.852–1.796 g weight. At commercial harvest age-group of 6th year, plants are 3.81 m height and 3.62 x 3.75 m spreading, and recorded 5.62 kg sangri and 5.98 kg loong yield annually. Fresh sangri pods contain 75.04 % moisture and 24.96 % dehydration recovery. Dehydrated sangri rich in nutraceutical value and contains 50.2 % carbohydrate, 17.2 % protein, 1.8 % fat, 23.7 % crude fibre, 3.2 % calcium, 0.4 % phosphorus and 3.9 % trace elements.

Climate and soil

Historically, khejri has played vital role to rural eco-system in the north-western arid region of Indian sub-continent. It is a strong light demander species and dense-shade kills its seedlings. It is drought resistant and tolerates drier conditions to such an extent that it is described as the aridity-loving tree. It is adapted to the desert landscape of Rajasthan and stands well to the adverse vagaries of climate and browsing of animals too. Goat, sheep and camel readily browses it. In areas open to regular goat browsing, young growth of the plants assume cauliflower shaped bushy appearance but it may be a very age-old with strong root system. Khejri is one of the principal tree species on higher and older

alluvium in the Indus river valley and an important constituent of the vegetation system. It is found in the alluvial and coarse, sandy and saline-alkaline soils. It is legume and thus improves soil fertility. Its root system is long and well developed. Growth above the ground is slow but below the ground the roots penetrate deeper and deeper for sub-soil water. Very deep roots help in securing firm footing and obtaining moisture supplies from deep soil layers. In roots, bacterium nodulation with *Rhizobium* is described.

Khejri prefers dry climate and most of its distribution areas is characterized by extremes in temperature. It is extremely abiotic stresses tolerant and easily grown in areas with as little as 75 mm rains/annum. It is frost hardy. The tree is able to tolerate temperature up to 50⁰ C and withstand the hottest winds (*loo* and *aandhi*) of driest season and remain alive and yields green under the worst situations of *Thar* Desert. Because of its economic viability and helping in eco-restoration, a large number of khejri saplings left standing in the arable farmlands and farmers regulate its population adopting suitable agro-forestry management. Mature tree possesses the great vitality and rapid vegetative growth in its natural system and considerable power of reproduction from lopped shoots is found. Khejri has deep tap-root system therefore it does not compete with associated crops, and also many other species plants grow around its trunk. It adds organic matter through leaf-litter and decomposition led to improved soil properties. It fixes atmospheric nitrogen through microbial activities. The better growth of crops under khejri canopy is an indication of higher nutrients availability and good soil-health.

Khejri grows well on a variety of soil and it is best on alluvial soils consisting of wide-range of mixtures of sand and clay. It is common on moderately saline soils but it quickly dries with high salinity. It is capable to tolerate saline water for limited irrigations. It prefers older alluvial plains for its habitations but it is also well on sand-dunes and undulating plains. Because of its capacity to avail perched water and to absorb moisture from the rains through its foliage, it can grow easily in the extremely desert areas receiving less than 100 mm rainfall. The primary objective of soil conservation is to maintain and improve the fertility status for efficient crop production. For this, maintenance of physical properties, addition of organic matter, improvement in nutrient status and control of erosion is necessary at the defined land-scape. In this context, a long-term research study was done for soil fertility build-up adopting khejri based cropping systems with variable land-use pattern for agri-horti-pastoral production under the desert eco-system. The comparative data from different pattern of land-use giving a clear picture for soil fertility status and building-up under variable 47 situations with or without khejri based production system. The status of nitrogen, phosphorus, potassium, sulphur and other soil properties enhanced and recorded as increase with 9th year age-old khejri plantation in comparison to plots without trees or 3rd and 6th year age-old production sites. The results have ample evidences and demonstrated that soil surface with khejri trees were richer in organic matter and nutrients than that soil surface area without trees, and thus signifies the importance of khejri plantations on the sand-

dunes and desertic landscape (Kumar et al. 2017). The analyzed soil data of 47 variable plot situations indicated comparable wide-range for pH (8.27-8.92), TDS (37-130 ppm), EC (0.057-0.203 dSm⁻¹), OC (0.068-0.100 %), N (72.73-107.76 kg/ha), P (8.11-11.56 kg/ha), K (181.84-246.00 kg/ha) and S (3.50-8.27 kg/ha). The mean values from the 47 sites sample is of 8.65 pH, 67 TDS, 0.105 EC, 0.088 % OC and kg/ha of 94.32 N, 9.92 P, 217.75 K and 6.14 S, and thus, the results verified that there is ample scope in improving the fertility status and requisite nutrients in the sandy soils with organized planting of native crop-plants and cluster bean cultivation.

Plant multiplication

Khejri is readily perpetuates it-self from the dispersed seeds and giving rise to a wide-spread seedling population as natural genetic variability. Trees also regenerated it-self by the root suckers. There are enough reports that indicating the need of research for solving the problems of vegetative propagation in *Prosopis cineraria*. It is difficult to propagate by cuttings and treatment with rooting hormones has proved success but the results are not much encouraging in field. Multiplication of plants by root-suckers and air-layering is reported but not feasible in large (Rawat et al. 1983; Solanki et al. 1986; Arya et al. 1994). Attention has also been given to micro-propagation, but it appears that *in-vitro* multiplication is more difficult with *P. cineraria* than other *Prosopis* species. The research work out-put on the vegetative propagation is not visible in the fields and therefore, non-availability of easiest method is yet obstacle for uniform and large-scale plantations in khejri.

The seed-propagated khejri progenies plants are thorny and depicted wide variations for growth and pod characters. Genotypes that produce high quality edible pods have been identified from the natural variability in India. Attempts were made to develop its true-to-type population by propagating them through vegetative means such as air-layering and cuttings but not successful. Propagation by cuttings and tissue culture could be effective for rapid multiplication of khejri but it is not yet materialized. At CIAH, patch-budding gave best results (Pareek & Purohit 2003), and now, bud-grafting is path-breaking technique for uniform and thornless khejri plantations. To raise true-to-type plantations of elite khejri genotypes, suitable techniques of vegetative propagation is required. The vegetative multiplied plants bear in 3-4 years age as against the long juvenile phase of 10-15 years as observed in seedling trees of khejri. Attempts have been made from time to time to propagate khejri by cuttings, grafting and tissue culture but results not encouraging, and thus, this was call for developing appropriate propagation techniques to multiply true-to-type plants. Realizing the facts of khejri, systematic technological interventions for the horticultural harnessing was initiated with the establishment of NRCAH at Bikaner in year 1994. First time, a mission mode R&D work was done by Dr. O. P. Pareek and his team with the main objectives (i) to identify elite types for use as scion material, (ii) to develop simple vegetative propagation technique, (iii) to identify root-stocks and standardize nursery technique for fast, easier and mass multiplication, and (iv) to develop techniques for *in-situ* orchard establishment.

(a) Seed propagation

The wide-spread distribution of khejri is solely by seed propagation. The natural dispersion of seeds resulted into the self-sown seedlings as well as nursery raised seedling plantations has been protected and promoted by the inhabitants as life-line tree of desert eco-system. The ripen pods with full of seeds falling down in June month and eaten by small animals (goat and sheep) and through their litter it is spreads every-where. The seeds do not show any dormancy and germinates quickly. The monsoon rains from June to August helps in easy germination of seeds. The young seedlings grow very fast and develop strong tap-root system within the monsoon period. Plants under the protection grow-up very well and took shape within 4 - 5 years. Where as the unprotected saplings drastically and regularly bruised by the animals and its above ground growth hampered but are with well developed root system for the survival.

Freshly harvested and non-infested khejri seeds should be used for sowing in polyethylene tubes (30×10 cm) filled with a mixture of sheep-manure, vermi-compost and sandy soil in 1:1:1 ratio to raise the nursery. Prior to sowing, seeds should be soaked in water containing 2 % common salt for two hours, and then dry it for few minutes and treated with fungicide. One or two seed/beg sowing is best, and thinning is done at 18-21 DAS keeping single seedling/beg. Seedlings raised under open-conditions were with better height and stem diameter than those from shade-net nursery. Seedlings are ready in 7–9 months either for field planting as root-stocks or budding use in nursery and at this stage

seedling should be shifted in another beds. Irrigation by rose-cane is found better than mini-sprinklers under nursery situations. Seedlings of February and June month sown nursery are ready for the planting during June-July and September-October, respectively and gave very high (80–90 %) success in field establishment. Since, the success in budding and subsequent rate of sprouting of scion-bud depends on vigour of seedlings and desirable thickness of rootstocks. Therefore, proper care is required in the saplings for budding in the nursery, and seedling developed *in-situ* or raised in nursery followed by field planting and *in-situ* budding (Samadia, 2016).

(b) Cuttings

It is simplest and low cost method of vegetative propagation. Propagation by cuttings could be a suitable technique for rapid mass-multiplication of khejri, but it is not so successful.

(c) Air-layering

At CIAH, studies on air-layering (*gootee*) was done on 6 to 12 months old shoots emerged after the lopping of khejri trees and treated with lanolin paste. The success in air-layering was very low (35 %) and rooting obtained in June month practice. This method is difficult and slow, and field survival is very poor and plants are thorny.

(d) Bud-grafting or budding technique

For genetically uniform khejri planting material, now, it is successfully multiplied by patch budding or bud-grafting technique on *P. cineraria* root-stocks. For this, first time systematic studies on vegetative propagation were done at CIAH, Bikaner (Pareek 2001; Pareek 2002; Pareek & Purohit 2002; Samadia 2007)). For budding, selected elite trees

having a record of producing good quality tender pods should be pruned during November-December or June month to induce new growth and bearing juvenile scion-buds. The fully developed scion-buds can be patch budded in March-April, May-June and July-October on nursery raised seedling root-stocks and *in-situ* planted seedlings, and on an average 76 per-cent success was obtained at Bikaner. The extent of scion-bud success, its growth in terms of length, diameter and linear growth is depends on stem diameter of root-stocks, environmental conditions and management practices adopted after the bud-intake on nursery raised or field established saplings.

The patch budding technique as standardized at CIAH is most practicable, simple and results obtained is highly successful on 7–15 month age-olds nursery raised root-stocks, and 12–24 months old *in-situ* established root-stocks for khejri plantation as well top-working the naturally established seedling of 3–4 years age-group. The selected mother trees of variety should be pruned every year during November–December or June to induce juvenile buds suitable for regular budding. For best results, stem diameter of root-stocks should be about one centimeter, and in such case it is possible to achieve cent per cent budding success. The in-take bud may took 18 to 40 days for sprouting and it is weather dependent too and all the sprouted scion-buds were survived (Samadia 2007; Samadia et al. 2009).

(e) Graft-compatibility

Wild seedlings of *P. cineraria* and *P. juliflora* and seedlings raised from the seeds of *P. alba* and *P. nigra* were used in the studies

as root-stock to graft the buds taken from the selected mother tree of *P. cineraria* growing at the research farm of CIAH, Bikaner. The possibility to develop inter-specific graft combinations of *Prosopis cineraria* with the other species such as *P. juliflora*, *P. alba* and *P. nigra* were also explored. The graft combinations of the Asian *P. cineraria* with any of the three species of *Prosopis* section *Algarobia* were incompatible. The species within the section *Algarobia* were compatible with each other. Budding success was poorer when *P. cineraria* scion buds were grafted on the *Prosopis* species of South American origin (*P. alba* and *P. nigra*) than on its own roots. There was no graft success on *P. juliflora* rootstocks. As high as 88.9 % successful grafts in *P. cineraria* and *P. juliflora* and 72.2 % in *P. alba* were obtained by patch budding on their own rootstocks. In *P. nigra*, 83.3 % successful grafts were obtained by budding on *P. juliflora* rootstock. Thus by taking bud-wood from the selected mother tree of these species (considering the attributes such as high yield of good quality edible pods, leaf-fodder, timber, fuel-wood, etc.) and then patch budding on the identified rootstock, their true-to-type plantations can be developed. The quality standard of the existing wild plantations can also be upgraded with respect to these attributes by top-working with the bud-wood from elite mother trees (Pareek et al. 2006).

Production technology

The successful cultivation of bajra, guar, moth, moong, cowpea and groundnut in the kharif and wheat, barley, mustard, gram, cumin, methi in the rabi, and better vegetative growth and yield in the most of vegetables,

fruits (ber, aonla, bael, mandarin, sweet orange, lime), desert trees-shrubs (jharber, ker, lasora, bordi, pilu, rohida, kumat, phog, khimp) and grasses (sewan, dhaman, bharut) beneath the scattered khejri trees exhibited the impact of this versatile species. Therefore, strategic promotion of khejri technology is needed to develop conventional and non-conventional cropping models, and this can be an innovative tool for breaking yield gap over existing production systems.

(i) Field planting and orchard establishment

In general, natural khejri trees perpetuation through seed is confined to the moist-land and not in drier situations. Fresh or stored seeds soaking in water before sowing are used and it gave very good germination both in nursery and open-fields. Seedlings can be raised easily in summer months, and the rainy period is best for planting. In practice, 4-12 month age-old seedlings are planted. In addition, direct seeding on the farm-lands and shifting of self-sown young saplings (1-2 month old) is also practiced on rainy-days, and is found quite successful. The root system of *in-situ* plants is quite longer and well developed. Sapling growth above the ground surface is slow but the roots penetrate deeper in search of sub-soil moisture. To raise the uniform and varietal plantations, vegetative propagation practices are found. The bud-grafted nursery are ready for budding from April–October, and gave 75 % success. The *in-situ* budding is more successful on 12–24 months age-old field-rootstocks for orchard establishment and it is also effective for top-working of self-sown young plants or 3–4 years age-old seedlings as found scattered in the protected farm-lands. For higher pod setting and longer period of tender pod

harvesting, two to four khejri varieties should be accommodated in the orchard. Seedlings of khejri can be planted in lines as close hedge-row of 2-4 m and 4-10 m spacing or scattered tree densities of 50-100/ha for horticulture, agro-forestry and silvi-pastoral systems. Owing to the slow initial growth of plants, 2-3 weeding are necessary in the first year of field establishment. Life-saving irrigations even mixing with 40-50 % saline water during the plant establishment age-group gave very high success. Training-pruning from the early plant-age is found advantageous to encourage straight growth of stem. Protection from animal's browsing is essential for the requisite growth as tree and otherwise very age-old plants become exhibits "cauliflower" shape at ground level. For promotion of khejri trees, there are two approaches of developing systematic or block plantations, and it can be with multiple objectives. First objective is of horticultural uniformity and high bio-mass production, and for that vegetative propagated and varietal plantation is the primary requirement. The second approach plantation is of agro-forestry and eco-restoration, and here, the seedlings should be planted. For developing block plantation, systematic field lay-out is done as per objectives and planting techniques of its establishment such as (i) field planting of nursery raised bud-grafted plants (ii) field planting of nursery raised seedlings and *in-situ* bud grafting on the established rootstocks (iii) *in-situ* seed sowing in field for rootstocks followed by bud grafting and (iv) field planting of nursery raised seedlings.

(ii) Planting models and their management

The pressure on land and water is very high in the north-western part of arid region of India. Here, rain is in the short-spells, erratic, uncertain and together environmental restrictions limiting the scope of crop-genotype choice, produce quality and productivity. Failure of monsoon rains and droughts causes frequent shortage of food and fodder to the inhabitants. Therefore, there is a long-call to develop resource based crop-plant models for the desert land-scape which would ensure the production and employment opportunities through out the year. Now, the answer would lay with innovative concept “Horticulture Based Crop Production Site Management Approach” as technological tool (Samadia, 2016). This would connect agri-horti-silvi-pastoral systems by integrating the agronomic crops, nutritious vegetables, trees, shrubs and grasses for dry-land horticulture, forestry and multiple utility commodities in one micro-production site of 4–10 ha area. Under the resource constraints arid climate, khejri based models would result into better productivity and diversified out-put in comparison to the conventional or mono-cropping. In this, the food crops and grasses fulfill the basic needs, fruits and vegetables provide nutrition rich diet and seasonal revenue whereas the perennial component would ensure regular output from 4–8 years of their establishment and additional income too. In the long-term, this system would create a favourable micro-climate at the production site for intensive farming in an integrated and diversified mode for social prosperity and ecological sustainability.

For studying the khejri models, variable spacing, single or paired rows at wide-distances and scattered tree planting can be selected. The possible conventional crop-combinations under rainfed situations would be (i) khejri + conventional mixed farming (ii) khejri + guar or moth, moong, cowpea, bajra, kachri, kaakdia, mateera, tumba or sewan (sole inter-crop) and (iii) khejri + ker or jharber, phog (sole inter-plantation). The potential and non-conventional crop-combinations with irrigations would be (i) khejri + groundnut or cotton, wheat, barley, mustard, gram, cumin, rainy-winter season vegetables (sole inter-crop) and (ii) khejri + pomegranate or citrus, ber, aonla, perennial vegetables (sole inter-plantation). Based on SWOT analysis on the research work of the desert horticultural technologies, some principles have been recommended under the HBCPSMA concept for developing and management of production sites. The production sites should be developed in accordance to the topography of sand-dune landscape and soil conditions. Fencing of production site is the first order priority. Multi-tier rows of seedling plantation with native trees and shrubs all-around the block has been taken in to consideration for creating favourable micro-climate and protection of production site from the hot, cold and strong winds. Keeping the field-plot fallow during April-June or October-November is a good practice for the soil health build-up and security. For enhancing marketable quality and productivity of resources, innovative techniques under the HBCPSMA includes selection and development of khejri based production models, preparation and

maintenance of production sites for *in-situ* rain-water harvesting and soil moisture conservation, and inter-crop-plant cultivation. Pre-monsoon field ploughing during June prior to the rainy season crop sowing and post-monsoon field ploughing during November after the crop harvest and this resulted in to more *in-situ* rain water harvesting, moisture conservation and weed-free fields at the production site. Besides, seed selection, sowing time and techniques, maintenance of plant population and crop protection measures are the good management practices for inter-crop-plants.

Khejri based crop production site management approach

The traditional farming systems have provided sustenance to the desert dwellers. In the vast spread arid farm-lands, cultivation of pearl millet, cluster bean, moth bean, sesame and native cucurbits is done as a component crops between the natural plantations of khejri. In-addition, some trees, shrubs and grasses (bordi, jharber, ker, phog, kheep, sewan, dhaman, etc) are the part of long-established agri-horti-silvi-pastoral system prevalent under the rainfed situations. This system of crop-commodity harvesting can support the sound farm economy, improves nutrition and health standards of livelihood and stability when the monsoon rains is good during the kharif season. With the changed scenario, now, focus is shifted from sustenance to remunerative farming but mono-cropping is much risky for developing dry-land agri-horticulture models. Therefore, the conventional systems pre-dominantly mixed cropping needs multi-dimensional intervention through the use of native crop-plants and

newer technological advancements, and now it can potentially be exploited under the HBCPSMA concept – Khejri based crop production site management approach as an innovative tool for doubling the farm income (Samadia 2016). For studying khejri based planting and cropping models with the HBCPSMA concept, virgin sandy soil and sand-dunes land-scape area was developed for orchard establishment and crop-plants cultivation as the production site of hot arid environment. For this strategic study, ten hectare khejri based production blocks were developed as per technical work-plan at ICAR-CIAH, Bikaner from 2007 and are being maintained to generate over the years scientific information.

Names were designated to the variable spacing planting models such as KM-1 (4x4m), KM-2 (6x6m), KM-3 (8x8m), KM-4 (8x4m), KM-5 (8x4x4m), KM-6 (16x4m), KM-7 (16x4x4m), KM-8 (24x4m), KM-9 (24x4x4m), KM-10 (44x4m), KM-11 (44x4x4m) and KM-12 (control, scattered plants) and studded in combinations. These khejri model plots were established through seedling root-stocks planting during 2007 and *in-situ* budding of variety Thar Shobha was performed under rainfed situations. As per technological advancement studies in sandy soils at Bikaner, inter-space field-area of above said models were used for inter-cropping of cluster bean and native mix-crops for 3-5 years during the kharif season and it was in establishment period of production sites. Simultaneously, the inter-spaced field-area was also utilized for cultivation of prioritized native crop-plant species to understand their feasibility, bio-mass harvest,

soil fertility build-up and economic analysis. For perennial fruit plant components, ker and jharber (4mx4m) were studied with wide-spacing planting models as test-crop and selected models were also studied with inter-cropping of grasses and native vegetables. For boundary-side plantation studies, seedlings of khejri, kumat, rohida and lasora were taken on all-around block and the desert shrubs (phog, khimp) were incorporated in-between rows as crop-plants for micro-climate development at production site and additional source of income.

In native crop-plant species studies, annual growth rate and development observations were recorded periodically in response to their field establishment and training-pruning techniques. The bud-grafted khejri plants of 5-6 years age-group recorded 3.46-4.62 m height and 3.38-4.34x3.37-5.31 m spread with 5.34-6.88 kg sangri and 6.23-8.34 kg loong yield/tree annually. In khejri plantations, no significant differences is recorded with respect to vegetative growth parameters of the variety Thar Shobha under varying planting models and it was up-to the economic harvest stages of 6th and 7th year's tree age-group during 2015-16 and 2016-17. It is also observed that closer spacing and paired rows (4mx4m) khejri planting systems exhibited requisite maximum canopy at 6-7 years and thus, this age-group plant growth from which normal pruning is recommended for the annual harvest of sangri, loong and fuel-wood, and the highest bio-mass/year can be obtained per unit area economically.

Annual observations were compiled on growth, yield and bio-mass harvest studies in khejri with the varying planting models (12),

and based on three years mean data, variety Thar Shobha recorded tender pod yield of 6.58 kg/plant under model KM-1, KM-9 and KM-11. Similarly, marketable quality fruit yield of kachri var. AHK-119 (56.58 q/ha) and tender pod yield of cluster bean var. Thar Bhadavi (54.34 q/ha) was recorded as the monsoon supported inter-crop harvest with khejri and adopting recommended techniques of HBCPSMA concept during 2014-15 to 2016-17 at Bikaner. Khejri based crop-combinations resulted into higher family employment and returns @ Rs 75,000–2,25,000 ha/year in comparison to the conventional (Rs. 23,000–42,000 ha/year) cropping systems, respectively as rainfed or limited irrigations. The crop yield, bio-mass harvest and income is stabilized at 5–6 years age in khejri and jharber, and double income from the production sites is further in the increasing order with 8–10 years period of establishment of HBCPSMA concept.

The region and crop-specific long-term research studies findings under HBCPSMA concept from the year 2004 to 2016 enables me to conclude it with the recommendations and on that basis some principles are suggested for developing and maintenance of the khejri based production sites under hot arid climate. The production site should be developed in accordance to the topography of sand-dune landscape and soil conditions, and fencing of block is the primary requirement to protect the crop-plants from the animals. In addition, development of multi-tier rows of seedling plantation with the desert trees (khejri, bordi, kumat, rohida, lasora, ker, pilu) and shrubs (jharber, phog) all-around the field block is also prime considerations for creation

of favourable micro-climate and it is must for protection of crop production sites from extremes of hot, cold and high wind conditions.

The four-side field area of the horticultural production site should be develop with multi-tier rows of seedling plantation (single or paired, 4mx4m) and the directions such as khejri and lasora or kumat, pilu (south), khejri and lasora or ker, pilu (west), khejri and kumat or bordi, rohida (north) and khejri and ker or rohida (east). For systematic block orchard or planting model, single or paired rows of khejri (variety Thar Shobha and Selection-2) should be lay-out in the east-west geometry and the wide-spaced area is developed field-plots for fruit, vegetable, seed-spice, agronomic and fodder crop-plant cultivation, and seasonal sequences is followed based on the available resources in particular to irrigation water. Based on crop potentialities and critical analysis over 25 years, so far, two agri-horticultural path-ways are suggested for developing khejri based production sites. First is native crop production technology and it is primarily for low-inputs and rainfed or limited irrigations. Here, organic *Panchkuta* (khejri, ker, lasora, kumat and kachri) and dry-land horticulture (native fruits, vegetables and desert floras) production is most viable and in which khejri planting model KM-1 (4mx4m) or KM-3 (8mx8m) can be practiced, respectively with a hectare block lay-out.

Further, khejri model KM-3 is also feasible for low-inputs and prioritized agri-horti-pastoral native crop-plant production under rainfed situations. In-addition, model KM-7 is unique for animal husbandry based

multiple fodder crop-plants and in which khejri is in paired rows (4mx4m) at 16 m spacing and the wide-spaced area is for jharber or sehjan, phog plantation (4mx4m) and mixed or sequence inter-cropping of sewan, dhaman, guar or cowpea is done for the highest bio-mass harvest. For diversified cropping and irrigated cultivation, wide-spacing planting models KM-9 and KM-11 is the best and here, 4mx4m paired row khejri plantation is done at 24m and 44m distances, respectively with a four hectare block layout and it is intensive crop production technology. The wide-spaced area is developed as field-plots and used intensively for seasonal crop cultivation and tree's orcharding (4mx4m) to obtain the highest income under dry-land climate. For developing desert horticulture with vegetables, khejri planting model KM-1, KM-3 and KM-9 is found successful at the resource constraints production sites and it is highly remunerative with crop-genotype such as kachri (AHK-119), cluster bean (Thar Bhadavi), snap melon (AHS-82), mateera (Thar Manak and AHW-19), tinda (AHRM-1), bottle gourd (Thar Samridhi), sponge gourd (Thar Tapish), ivy gourd (Thar Sundari), Indian bean (Thar Kartiki and Thar Maghi), brinjal (Thar Rachit and CIAH-22) and cowpea (AHCP-1 and AHCP-2). With drip technology, cultivation of winter vegetables such as palak (Thar Hariparna), paan-methi (AHLM-1), cabbage, cauliflower, knol-khol, radish, carrot, onion, garlic, chillies, tomato, peas and perennials (sehjan, guarpatha and curry-leaf) is much beneficial under dry-lands of Rajasthan.

Training and pruning

Training and pruning are the two essential operations for tree structure, canopy management and bio-mass production. The wild scion-bud may become faster. The wild sprouting below the bud-graft should be removed regularly through pruning operations using sharp cutter. For better frame-working in plants, training-pruning operations should be done twice a year *i.e.* November and June months and it should be continued up to four years of field establishment. The regular training and pruning operations should be started after attaining the age-group of 4-5 years for better plant canopy management and harvesting of economic produce and time should define after assessing the objectives of the khejri plantation. Therefore, training-pruning and growth regulation for the annual harvesting of both *sangri* and *loong* was studied and results are most profitable. The bud-grafted plants are vigorous in growth and branching load is heavy, and therefore annual or biennial training-pruning is required otherwise it got damaged due to high wind-storms.

In general, khejri trees are lopped (pruned) annually during November–December month to harvest the leaf-fodder (*loong*). Such pruned trees do not bear flowers as the new shoot sprouting after the pruning is very immature during the flowering period of khejri *i. e.* February–March and thus does not produce pods. When *sangri* is desired to be harvested from a particular tree and then, it is not lopped during the November–December but then the tree would not yield *loong*. With the technological advancements, systematic plantation would developed for *sangri* production and with traditional practice it will

have to be left un-lopped, and consequently trees would not yield *loong*, and thereby it is not beneficial to the farmers. To over-come this situations, studies on plant growth, flowering and fruiting regulation were conducted at CIAH and results revealed that plantations developed primarily for *sangri* production must not followed the traditional practice of lopping during November–December. But here, regular pruning or tree lopping should be done during June month to obtain *loong* and it can be done after harvesting of ripen pods. The pruning of plants at this time-schedule synchronizes with start of the second growth flush of khejri during June–July. This growth flush get sufficient time (6–7 months) to mature it and differentiate floral buds which develop into flowers and produce good crop of pods. The tender pods are ready for harvesting from third week of April to second week of May month (Samadia 2007; Samadia et al. 2006). Thus, June month pruning is recommended to harvest both *loong* and *sangri* annually and in practical, it should be done when the dried pods (*khokha*) starts falling down from the trees. At this time, harvested *loong* dried quickly and excellent in quality so that it can be used as summer-greens or stored in the form of concentrated fodder for prolong period of time. For production of maximum fodder yield only from bud-grafted plantations, lopping of *loong* can be done 2-3 times/year *i. e.* April-May, June-July and November-December month following the 50-60% coppice of current season and it should be done after understanding the growth flush of trees in respect of region and production site management.

Yield and economics

In general, naturally perpetuated, scattered and mature seedling khejri trees of 15-20 years age-group yields 25–30 kg leaf-fodder and 10–15 kg tender pods annually, and the desired harvest is associated with lopping practices followed to produce it. Sangri is eye-catching and high priced vegetable sold both fresh and dehydrated @ 50–120 and 400–650 Rs/kg, respectively. Leaf-fodder is sold @ 10–15 Rs/kg and has excellent market potential. At CIAH, the well protected seedling khejri plants reached 4.65-5.16 m height in 6-7 years and have 4.24-4.58 x 4.88-4.96 m spread and 41-49 cm stem girth. From this age-group, trees can be coppice, lopped or light pruning is done to harvest the desired bio-mass. Seedlings of 8-9 years age-group recorded 2.25-3.54 kg sangri, 5.46-6.18 kg loong and 7.56-9.84 kg fuel-wood, and this bio-mass harvest is variable, and also depends on lopping and orchard management practices. With technological adoptions, the vegetative growth of the budded plants is fast in comparison to the seedling. The bud-grafted plants have dense and thornless foliage and it is most advantageous attribute for easiness in sangri harvesting and higher bio-mass production. Well maintained budded plants took good shape in 3 - 4 years and start to bear economic harvest. Budded plants at stabilized age-group of 7–8 years are 3.92-4.78 m height and 3.82-4.17 x 3.78-5.12 m spread, and yielding 5.88-6.68 kg sangri and 6.72-8.23 kg loong annually. The fuel-wood yield is 9.23-11.25 kg/plant. With variable spacing khejri planting systems, the average yield potential (q/ha) of sangri and loong was obtained in model KM-1 (31.84 & 35.94), KM-3 (5.84 &

6.61), KM-7 (15.16 & 17.11), KM-9 (12.12 & 13.69) and KM-11 (7.58 & 8.55) at 6th year age-group, and this was through the adoption of good management practices under rainfed situations of hot arid environment at Bikaner. For obtaining the maximum pickings and good quality yield, *sangri* should be harvested at 2–3 days intervals and two or more varieties should be accommodated in a plot. Traditionally, khejri trees coppice or lopped in the winter month and sun-dried leaf-fodder is stored. In common method, seedling trees coppice regularly and annual lopping practice resulted to the minimum loong yield and no sangri production. Maximum yield from the seedlings is obtained when trees are lopped in alternate years and in rotation for loong. In bigger and age-old seedlings, loong yield is very high and it is 20, 40, and 60 kg/tree when coppice of branches is done one-third, two-third and up-to central main branches of the crown, respectively.

Value addition and processing

Tender pods of khejri are dehydrated on large-scale and dry-sangri is widely used in making different types of vegetables and pickles. Ripen dry pods (*khokha*) are sweet and eaten by the rural people, animals or wasted. Ripen pods full of seeds are rich in nutrients (crude protein 9-14%, sugars 6-16%, phosphorus 0.3%, calcium 1.6% and iron 0.06%) and energy. Thus, studies were conducted to prepare biscuits from the *khokha* to serve as the nutrition supplements. The biscuits prepared by mixing *khokha* flour at all three proportions (15, 20 and 25 %) were nutritionally richer than those prepared from only wheat-*maida*. The biscuits containing 25% *khokha* flour were significantly richer in

protein, starch, calcium, potassium and sodium irrespective of whether the *khokha* flour was prepared alongwith or without seeds. In these biscuits (25 % *khokha* flour with seed), carbohydrate, reducing sugars and phosphorus contents were also higher. All the treatments, except the one having 25 % *khokha* flour without seeds had overall acceptability score of over 5.0. Thus, studies revealed that biscuits prepared from ripen pods can serve as a nutrient supplement to obviate the rampant nutritional deficiencies in the rural human diet (Purohit et al. 2004).

Insect-pest and diseases

Khejri foliage is badly damaged by the attack of Desert locusts (*Shistocerca gregaria*) and *Melolonthidae* beetles. Termites (*Odontotermes obesus*) and white-grubs (*Halorachia* spp.) also damages and kills the plant through root system. An infestation of *Homoeocerus variabilis* Dallas (Hemiptera: Coreidae) on khejri, *Prosopis cineraria*, was first noticed in 2010 at the Experimental Farm of Central Institute for Arid Horticulture and other fields of Bikaner district, Rajasthan, India. The maximum incidence was observed in December (66.7%) and minimum in June (16.7%). The number of this bug ranged between 27.3 and 222.9 adults per plant. The mean body lengths of the male and female adult vary and were recorded as 12.2 mm and 15.5 mm, respectively (Haldhar, 2012). The gall-fly (*Goccidomulid galli*) is the most devastating insect to foliage and flower panicles, and limiting tender pod yield. The bruchid beetles infested dried seeds severely. The moth, *Anarsia triaenota* (Gelechiidae: Lepidoptera) was recorded on khejri from April to September months. The larvae

damages to new leaves and make the gallery inside the leaves of the khejri plant. Due to attack of this pest, the growth of khejri plant is suppressed and dry of the new leaves. Larval and pupal development took place inside gallery of leaves. The incidence of moth was recorded from 14.67 % to 80.33 %. The incidence was started from the month of April to end of September and highest intensity was recorded in the month of June to July (Haldhar and Karuppaiah). So far, there is little information on any major diseases in khejri.

Future thrust and prospect

To-date, very insufficient research on khejri has been carried out to determine profitability and productiveness when it incorporated into forestry and agro-horticultural production systems out-side the distribution region of the species. However, its high degree of tolerance to adverse soil and climatic situations, presence of requisite genetic variability within *Prosopis cineraria*, significant benefits on soil-health and nutritional vitality suggested that it may have a great role for the diverse programmes of crop-production, green-oxygen, eco-restoration and agro-ecological prosperity where the volume of timber is not the prime concerned. Thus, genetic conservation of the valuable resource and mass-multiplication of khejri varieties through tissue culture may considered a priority research for the sustainable food and environmental services for the mankind. Now, the path-breaking R&D out-puts on khejri at ICAR-CIAH, Bikaner may open the new road-maps to collect and conserve the unique and representative candidates from the natural genetic variations for their systematic

exploitations in respect to the objectives framed. Although, it plays a very important role in some parts of its natural spreads but further in-depth research work is needed to establish the diverse use production sites or range systems under which it might prove usefulness to combat the problems of climate change and water deficit.

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