Seed Purpose Watermelon in Arid Zone

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Central Arid Zone Research Institute
ISO 9001 : 2008
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Foreword

In India, the arid regions of Rajasthan, Gujarat, Punjab, and Haryana account for 90 per cent of the total hot arid region with an area of 31.7 million hectares. This region is characterized by high velocity wind, huge shifting and rolling sand dunes, high diurnal variations in temperature, intense solar radiation, scarce rainfall and high rate of evaporation. Further, the sandy soils of the desert have high infiltration rates, poor fertility, low humus content due to rapid oxidation and high salinity, making cropping difficult and uncertain.

The main rainfed kharif crops in western Rajasthan are moth bean, clusterbean and pearl millet grown over an area of 99.7, 93.7 and 76.4 per cent area of the State, respectively. But the productivity of these rainfed crops varies (< 100 kg to > 500 kg ha^{-1}) over the years depending on the quantum and distribution of rainfall during the growing season. Therefore, sole cropping in western Rajasthan is very risky and not profitable and farmers follow mixed cropping system. Traditionally, the preferred choices are cucurbits, viz., Watermelon (*Citrullus lanatus*), Tinda (*Citrullus fistulosus*) and Kachri (*Cucumis melo*), due to their hardy nature and trailing growth habit.

Watermelon, popularly known as '*Mateera*' has multipurpose uses but grown for its protein and oil rich seeds and supports the livelihood of desert dwellers in a big way. Its seed contains 20-25 per cent crude protein and 30-40 per cent oil and offers good remunerative price in local market (₹ 5000-8000 per quintal). In the recent past, *Mateera Beej* demand is increasing day by day due to people's health concerns and changing food habits. Such crops support livelihood in the hostile situations where commercial crop diversification is not feasible. However, limited attention was paid for its seed yield improvement and other aspects.

Genetic improvement of watermelon for higher seed yield at Central Arid Zone Research Institute (CAZRI) provided a base for better seed yield and other quality aspects. The present research work on seed purpose watermelon carried out under rainfed conditions of Jaisalmer and farmers' participation during the process will not only address sustainable rainfed production in changing climate scenario but also utilize the traditional knowledge promotion and improvement of such crops.

I am delighted that this bulletin **Seed Purpose Watermelon in Arid Zone** has come at a very appropriate time with the sincere efforts by the authors. I congratulate the authors for compilation of valuable information and hope that the concept of Seed Purpose Watermelon will provide livelihood security to the desert dwellers.

(Alok K Sikka)

August 2014

Preface

The north-western Rajasthan (61%) and north Gujarat (19.6%) covers more than 80% area of hot arid region in India. Besides well developed canal network and thousand of wells and tubewells in this region, the main kharif crops (clusterbean, moth bean and pearl millet) are grown mainly under rainfed conditions over 10 million hectare area (80% of total kharif area), but the productivity of these crops is very low due to uncertain monsoon rains and its distribution during the crop growth period. Therefore, to minimize the risk of crop failure and uncertain production under rainfed conditions, mixed/intercropping has been in practice in the region. Traditionally cucurbits are preferred choice as a mixed crop with clusterbean/pearl millet in arid regions. Among the cucurbits, watermelon (*Citrullus lanatus*) popularly known as '*Mateera'* is ideal choice as a companion crop due to its adaptive mechanism in mixed cropping and its nutritionally rich seeds in arid parts of Rajasthan and Gujarat.

Recently, the '*Mateera Beej*' is in great demand in the local market due to its protein and oil rich kernels popularly known as '*Magaz'*. The kernels contain 35-50% crude protein, 28-40% oil and minerals in appreciable quantity. Further, the oil contains more than 80.0% unsaturated fatty acids with linoleic acid (18:2) being the dominant fatty acid (68.3%). Besides, being preferred in traditional mixed cropping system desired research attention was not given for its seed yield improvement. In view of this, CAZRI initiated the work on genetic improvement of watermelon for seed yield in recent years. The preliminary evaluation and characterization of diverse germplasm has shown potential of up to 1.0 t ha^{-1} seed yield from watermelon crop under rainfed conditions with the adoption of proper moisture conservation measures. Further, it would be a better crop of choice as a sole crop in changing climate scenario in arid zone, besides its horizontal expansion in mixed cropping.

The authors are thankful to the publication committee for their critical observation for improvement of the text. The ethnobotanical information and other inputs provided by the farmers of Jaisalmer and Barmer districts during field days and discussions are gratefully acknowledged. The support extended by Dr. B.K. Mathur, Principal Scientist, CAZRI, Jodhpur for biochemical analysis of watermelon rind samples and conducting feeding trials is duly acknowledged. Drs. Suresh Kumar, R.K. Bhatt and A.K. Mishra, Heads of Divisions-II, III and IV, CAZRI, Jodhpur are sincerely acknowledged for their suggestions and critical observations for promotion of watermelon from time to time. The technical support during evaluation by Sh. Chander Prakash (T-2), Sh. Daleep Singh (Technical Officer), other supporting staff Sh. Inder Singh, Gayad Singh and Padam Singh is highly appreciated for their untiring, whole hearted and dedicated sincere efforts.

Authors

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INTRODUCTION

The hot arid region of India, covering an area of 31.70 million hectares, lies in Rajasthan, Gujarat, Harayana, Punjab, Maharashtra, Andhra Pradesh and Karnataka states. Sixty one per cent of the total arid region area falls in twelve districts of western Rajasthan, which include Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer, Jalor, Jodhpur, Jhunjhunu, Nagaur, Pali and Sikar (Table 1). The main kharif crops in the area are pearl millet, clusterbean, moth bean and mung bean (Table 2), but the productivity of these rainfed crops varies (< 100 kg to > 1000 kg ha^{-1}) over the years depending on the quantum and distribution of rainfall during crop growing season (July to September). In extreme western parts of Rajasthan comprising Barmer, Jaisalmer, Bikaner, Churu and Jodhpur districts southwest monsoon rains start very late (15th July afterwards) and return early (before 15th September), and receives only 100-300 mm rainfall with a coefficient of variation varying from 40-70%. Further, high wind velocity (15-20 km h^{-1}) just after sowing hampers germination and proper plant stand which results in uncertain production and low yield of rainfed crops.

Table 1. Details of arid zone characteristics and crops grown

Agro-climatic zone	Area (Mha)		Districts	Rainfall (mm)	Main crops
	Total	Net sown			
Ia: Arid western plain	4.74	2.34	Barmer and parts of Jodhpur	200-370	Pearl millet, moth bean, clusterbean, sesame
Ib: Irrigated northwestern plain	2.10	1.60	Ganganagar, Hanumangarh	100-350	Cotton, clusterbean
Ic: Hyper arid partial irrigated	7.70	2.44	Bikaner, Jaisalmer, Churu	100-250	Pearl millet, clusterbean, moth bean
IIa: Transitional plain of inland drainage	3.69	2.68	Nagaur, Sikar, Jhunujhunu, parts of Churu	300-500	Pearl millet, clusterbean, sesame
IIb: Transitional plain of Luni basin	3.00	1.93	Jalor, Pali, Jodhpur	300-500	Pearl millet, clusterbean, sesame

To minimize the risk of crop failure under aberrant weather situations, farmers follow mixed/intercropping depending upon the rainfall and soil types in these arid zone districts of western Rajasthan. In traditional cropping system, to cope up with the situation farmers used to mix small quantity of *Mateera* (watermelon) seeds with main

Table 2. Area, production and productivity (5 years average) of main rainfed kharif crops in 12 arid zone districts of Rajasthan

District	Pearl millet			Clusterbean			Moth bean			Mung bean		
	Area (ha)	Production (t)	Yield (kg ha^{-1})	Area (ha)	Production (t)	Yield (kg ha^{-1})	Area (ha)	Production (t)	Yield (kg ha^{-1})	Area (ha)	Production (t)	Yield (kg ha^{-1})
Sikar	298265	257533	863	76853	27419	357	9396	1514	161	15139	3794	261
Jhunjhunu	277400	209195	754	65555	12322	188	1595	227	142	20200	5826	286
Nagaur	473314	330888	699	129945	50545	389	202226	49444	244	247346	83721	338
Bikaner	219123	67107	306	625439	164784	263	283843	40723	143	1722	655	380
Churu	422449	161260	382	350526	38347	109	276243	55003	199	32861	10684	325
Jaisalmer	136779	12148	89	321932	14691	46	463	75	162	2394	262	109
Ganganagar	9958	15181	1525	151855	98123	646	1722	653	379	17281	10526	609
Hanumangarh	79272	90359	1140	275609	178210	647	37740	11380	302	11261	5271	468
Jodhpur	577520	171624	297	154794	10559	68	165357	20940	127	98634	22289	226
Barmer	958883	105227	110	370921	35806	97	211532	22720	107	49362	2996	61
Jalor	343806	169144	492	59594	22558	379	33604	15969	475	89249	20599	231
Pali	89015	43643	490	53550	22680	424	2956	439	149	82527	18533	225
Arid zone	3885784	1633309	420	2636573	676044	256	1226677	219087	179	667976	185156	277
Rajasthan	5088480	3239343	637	2813480	791838	281	1230205	219661	179	896217	248152	277
% in arid zone	76.4	50.4	-	93.7	85.4	-	99.7	99.7	-	74.5	74.6	-

Source: Rajasthan Agricultural Statistics at Glance for the year 2010-11, Commissionrate of Agriculture, Rajasthan, Jaipur. pp. 1-163.

crop (pearl millet/clusterbean) while sowing. *Mateera* vine utilizes the available space created by edaphic factors and grows profusely in association with these crops (Fig. 1). This traditional system provides substantial seed yield of *Mateera* besides the yield of main crop. In normal rainfall year, 3-4 q of clusterbean seed or 5-6 q of pearl millet grain yield could be obtained from one hectare along with 40-50 kg of *Mateera* seed under rainfed mixed cropping situations (Mahla and Singh, 2013). However, watermelon for its seed purpose potential has been overlooked for relatively long time by research and development organizations while it persists in the farming systems of Indian arid zone, since long. The major impetus to consider watermelon for seed purpose comes from a persistent recognition that such crops play collectively vital role in the farming systems and in the well-being of desert dwellers as it assures livelihood security and income generation.

Fig. 1. Mixed cropping of *Mateera* with Clusterbean under rainfed conditions.

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai) belongs to family Cucurbitaceae. Cucurbits are among the economically most important vegetable crops worldwide and are grown in both temperate and tropical regions (Pitrat *et al*., 1999; Paris, 2001; Bisognin, 2002; Sanjur *et al*., 2002). In sub-Saharan Africa, the native species are prized for their oleaginous seeds consumed as thickeners of a traditional soup called *egusi* soup in Nigeria. Cucurbits cultivated for seed consumption are reported to be rich in nutrients (Oyenuga and Fetuga, 1975; Akobundu *et al*., 1982; Samant and Rege, 1989; Badifu and Ogunsua, 1991; Badifu, 1993; Schafferman *et al*., 1998; de Mello *et al*., 2000, 2001), well adapted to extremely divergent agro-ecosystems and various cropping systems characterized by minimal inputs (Eyzaguirre, 1995; ElTahir and Taha Yousif, 2004). In Indian arid zone, cucurbits are regarded as an important source of vegetables and desserts. Their seeds, which contain oil and protein as reserve foods are eaten and seed oil of a few cucurbits are also used in Ayurvedic system of medicines (Singh, 1964). Despite their agronomic, cultural and culinary importance, these plants lack attention from research and development agencies and treated as orphan crops. More research attention, especially to their nutritive value, methods of production, preservation, and utilization would result in wider cultivation, food security and increased income for farmers.

Cultivation of watermelon is now widespread in all tropical and sub-tropical regions of the world and is mostly grown for fresh consumption of the juicy and sweet flesh of mature fruit. In Indian sub-continent, it is being grown during summer months as a cash crop under assured irrigation as well as on conserved moisture in river beds of Indo-Gangetic plains for its fresh dessert fruits commonly known as '*Tarbuj'* (Fig. 2a & b). The '*Tarbuj'* fruits can be seen on road side across the country from north to south and east to west during summer months (April to June), while, '*Mateera'* (Fig. 2c & d) represents the land race of watermelon widely grown in north western parts of Rajasthan under mixed cropping during kharif season. On the other hand, it is an integral part of mixed cropping with dominant kharif crops valued for highly priced nutritious seeds in sub-Sahara region of Africa (Munshee *et al*., 2011; Matanyaire, 1998) and Indian Thar desert (Mahla and Singh, 2013). The concept of seed purpose watermelon in Indian Thar desert has been advocated by Mahla and Singh (2013) and Mahla and Choudhary (2013) following the rigorous evaluation of watermelon germplasm under rainfed condition of Jaisalmer (Fig. 3). This seed purpose watermelon locally known as '*Kalingada'* (Fig. 2e & f) in Gujarat and Rajasthan, grouped under underutilized crops with great potential for oil and protein rich seed yield in Indian Thar desert. The *Kalingada* has the potential to provide seed yield upto 10 quintals per hectare with more than 30% crude protein and oil (Raiger *et al*., 2014).

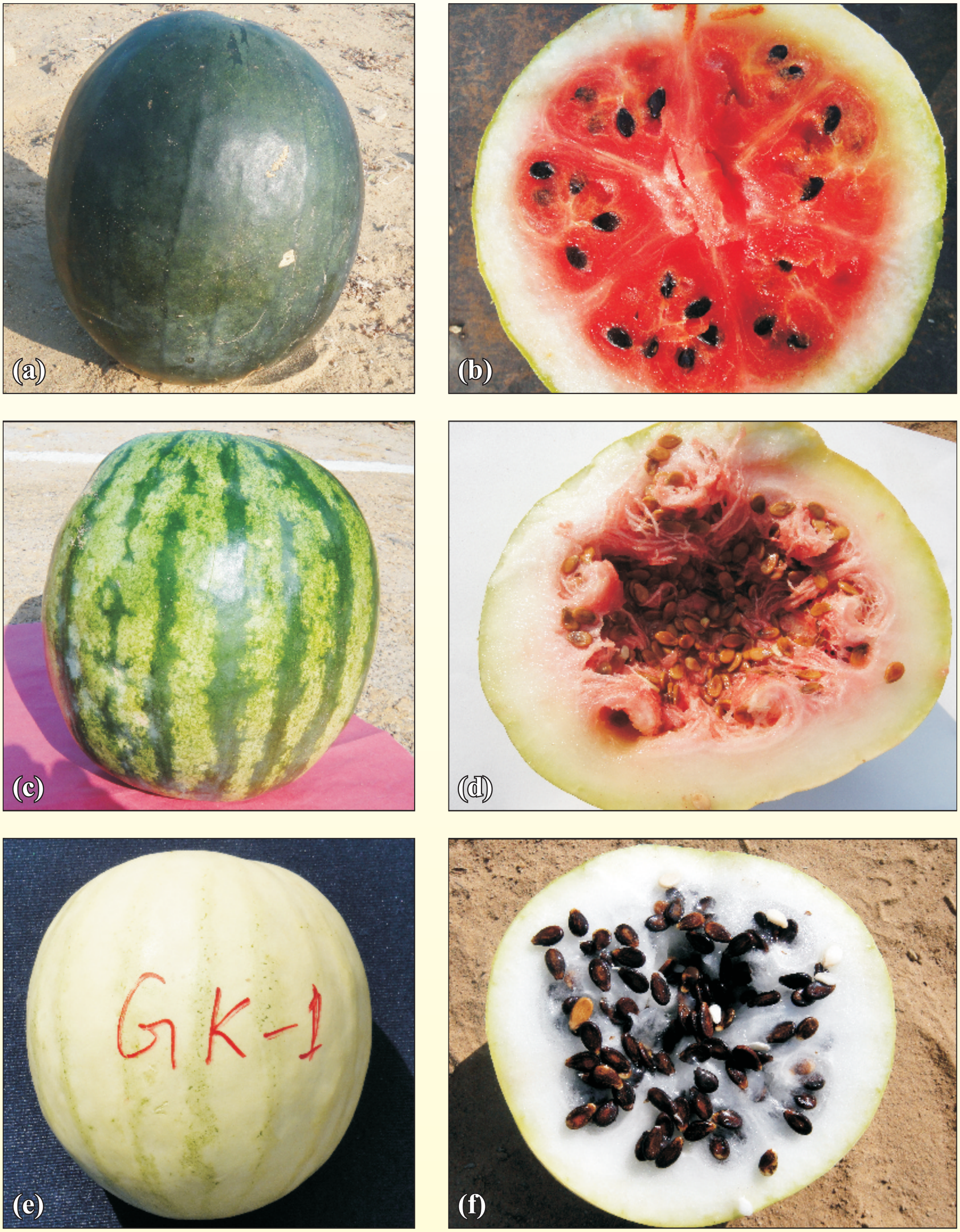

Fig. 2. Watermelon fruits: *Tarbuj* (a & b), *Mateera* (c & d) and *Kalingada* (e & f).

The proximate composition and other quality parameters of the watermelon seeds have been reported to be comparable with sunflower and groundnut oil and hence seed purpose watermelon has a great potential not only as oilseed crop but also in livelihood and nutritional security under resource constraint situation of Indian Thar desert.

Fig. 3. Evaluation of seed purpose watermelon germplasm under rainfed condition at Jaisalmer.

ORIGIN AND DISTRIBUTION

Citrullus lanatus is one of three diploid (n = 11) species that belongs to xerophytic genus *Citrullus Schrad. ex Eckl. & Zeyh.* and has a haploid genome size of 4.25×10^8 base pairs (bp) (Arumuganathan and Earle, 1991). These species are:

i. *Citrullus lanatus* (Thunb.) Matsumura and Nakai is a cultivated species, originated in Africa. According to Whitaker and Davis (1962) its secondary diversification occurs in India. The species is characterized by large green leaves with three to five deep lobes on the edges, medium-sized flowers with short pedicels, medium to large size fruit (3-5 kg) with smooth skin and pink to red flesh with a high water content, and oval to oblong black or brown color seeds. Fursa (1981) reported three subspecies of *C. lanatus* viz., (i) *lanatus*, (ii) *vulgaris* which has two varieties, var. *vulgaris* and var. *cordophanus* and (iii) *mucocospermus*.

ii. The *egusi* watermelon (*C. lanatus* var. *egusi*) is widely cultivated in Nigeria (Anuebunwa, 2000; Ezeike and Otten, 1989, 1991; Jolaoso *et al*., 1996), where the protein- and carbohydrate-rich seeds are used as a regular part of the diet. The *egusi* watermelon fruit is not edible because of its bitter, hard, white flesh, and the seeds are often called kernels (Oyolu, 1977). The origin of the *egusi* phenotype is uncertain and the developmental genetics of this seed phenotype is unknown.

iii. *C. lanatus* var. *citroides* is a wild form found in South Africa, commonly known as fodder watermelon. It is also known as citron melon and often referred to as stock melon and preserving melon. The fruits are round to oval up to 15 cm long, light green with darker green stripes, and have a smooth surface. The flesh is white or yellowish and so tough that the fruits can be bounced on the floor with small chance of bursting. The seeds are not marbled as often as those of watermelons. Because of the close relationship to watermelon, cross-pollination between the two forms occurs quite often.

Watermelon is thought to have originated in southern Africa, as growing wild throughout the region, and showed maximum diversity (Vander Vossen *et al*., 2004). It has been cultivated in Africa for over 4,000 years. The citron (*Citrullus lanatus* (Thunb.) Matsum. & Nakai subsp. *lanatus* var. *citroides* (Bailey) Mansf. ex Greb.) grows wild in sub Sahara region of Africa and probable progenitor of watermelon (Navot and Zamir, 1987). The natives knew about sweet as well as its bitter forms growing throughout southern Africa. One probable gene centre is in the Kalahari Desert region where the species can still be found in the wild forms but its origin is in the Sahel Region in northern Africa (Wasylikowa and vander Vossen, 2004). Watermelon spread from Africa to Asia about 800 AD and to Europe in 961 AD and was subsequently brought to America by Europeans in the 17th Century (Wehner, 2008).

Based on cytogenetical investigations, intercrossing compatibility and dissemination in Africa and Asia, Whitaker (1933), Shimotsuma (1960) and Anghel (1969) proposed *C. colocynthis* as the ancestor of *C. lanatus*. The extremely bitter flavored white flesh of this wild species caused by high concentration of a glycoside-cucurbitacine E. (Herrington *et al.,* 1986) or colocynthine (Mohr, 1988) is controlled by a (*Bi*) gene dominant over the non-bitter character (Robinson *et al.*, 1976).

The red color of the flesh is influenced by a recessive (red) gene but its inheritance is more complex (Navot *et al.,* 1990). These characters have been the two most important ones in the domestication process as there is strong pressure for red flesh and a non-bitter taste. According to Navot *et al.* (1990), selection for the rare mutants, which have eliminated the bitterness and added red color, has been responsible for domestication of cultivated watermelon. Natural hybrids between *C. lanatus* and *C. colocynthis* have been reported (Singh, 1978). *Citrullus lanatus*, called locally 'Matiro', *C. colocynthis* called '*Tumba*' and other intermediate forms called '*Khar*' or '*Tatumba*' have been found growing close to each other where both species are well represented in the arid and semi-arid regions of Rajasthan. Morphological and cytological observations reinforce the close relationship between both species (Joshi and Solanki, 1995; Sain *et al*., 2002).

Watermelon cultivated in warmer parts all over the world (Robinson and Decker-Walters, 1997; Jeffrey, 2001), but truly native of the sandy, dry areas of Tropical Africa. In sub-Sahara region of Africa, it is grown in Nigeria, Benin, Mozambique, Namibia and Mali. It is also grown in China, Turkey, Iran, Egypt, Mexico and South Korea. In the United States, watermelon is a major vegetable crop that is grown primarily in the southern states of Florida, California, Texas, Georgia and Arizona. The crop was grown in India by at least 800 AD in different parts of the country for multipurpose uses. It is grown from North (Himachal Pradesh) to South (Tamil Nadu) and from West (Gujarat) to East (Assam) in India.

PLANT CHARACTERISTICS AND REPRODUCTIVE BIOLOGY

***Citrulls lanatus* (Thunb.) Matsumara & Nakai** (Family: Cucurbitaceae)

Syns. *Cucurbita citrullus* L., *Momordica lanata* Thunb., *Cucumis colocynthis* Thunb., *Citrullus vulgaris* Schrad., *Colosynthis citrullus* (L.) O. Kuntze.

Vernacular names: Kalind (Sanskrit); Kalingad (Marathi); Tarbooj (Hindi); *Mateera* (Western arid part of Rajasthan); Kalingda (Gujarat)

***Habit*:** It grows as annual vine that sends out long runners along the ground.

***Root*:** The roots are extensive with a highly branching taproot extending up to 1 m deep into the soil and having many lateral roots. Its root system formation begins prior to emergence of cotyledons to the soil surface and reaches maximum extension by the time of flowering.

***Stem*:** The stems are herbaceous, highly branched, vines up to 3 m long (but may be up to 8-10 m). The younger shoots are covered with long, woolly curved hairs protecting the plant from over heating. The older parts are glabrescent. Tendrils are stout, bifid and pubescent.

***Leaves*:** The leaves are dark green, with prominent veins, 6-15 x 4-10 cm, ovate or triangular-ovate, scabrous on both surfaces, deeply trifid, lobulate to pinnati-lobed, obovate, segments oblong to linear-lanceolate, central one the longest, usually acute or acuminate, lateral segments usually rounded to obtuse at apex, often more or less bilobed; petioles 3-8 cm long, sulcate, hispid. Generally, its leaf has three large lobes, each further divided into smaller lobes.

***Inflorescence*:** Flowering begins 4 to 8 weeks after seeding. Flowers are staminate (male), perfect (hermaphroditic), or pistillate (female). However, monoecious types are most common, but there are andromonoecious (staminate and perfect) types also. Flowers are yellow colored approximately 1-3 cm in diameter. Male flowers are in the axil of spoon-shaped, 8-10 x 3-4 mm bract; on an elongate, 1-5 cm long, villous peduncle. Calyx tube is broadly campanulate, villous; sepals as long as the calyx tube, narrowly lanceolate. Corolla is 2.5-3 cm in diam, usually greenish on outside, pale yellow inside, villous. Female flowers are borne at every seventh or eighth node with inferior ovary; peduncles 2-6 cm long. Ovary oblong, lanate; style slender, 4-5 mm long.

***Fruit*:** The fruit shape and appearance varies ranging from round to cylindrical, 15-60 cm in diameter. The surface of fruits varies from single color to various striped patterns. The fruit consists of exocarp, mesocarp and endocarp. The endocarp (placenta) is seed containing part that is consumed as food (edible part) and the mesocarp and exocarp are usually referred to as rind having thickness of 10 to 40 mm. The color of pulp may be white, pink or reddish-pink.

***Seed*:** Seed numerous, 6-10 mm long, pyriform, compressed, dark brown, or even black, pink, white or mottled. Seeds continue to mature as the fruit ripens and the rind lightens in color.

Reproductive Biology

The knowledge of floral biology and pollination mechanism of a plant is pre-requisite for successful crop improvement/hybridization programme. Flowers of watermelon are staminate (male), perfect (hermaphroditic), or pistillate (female), regularly borne in that order on the plant as it grows (Fig. 4a, b & c). Monoecious types are most common, but there are andromonoecious (staminate and perfect) types also. The pistillate flowers have an inferior ovary, and size and shape of the ovary is correlated with final size and shape of the fruit. Generally, the pistillate or perfect flowers are borne at every seventh or eighth node, with staminate flowers at the intervening nodes. The typical flower ratio in watermelon is 7:1 staminate: pistillate, but the ratio may vary from 4:1 to 15:1.

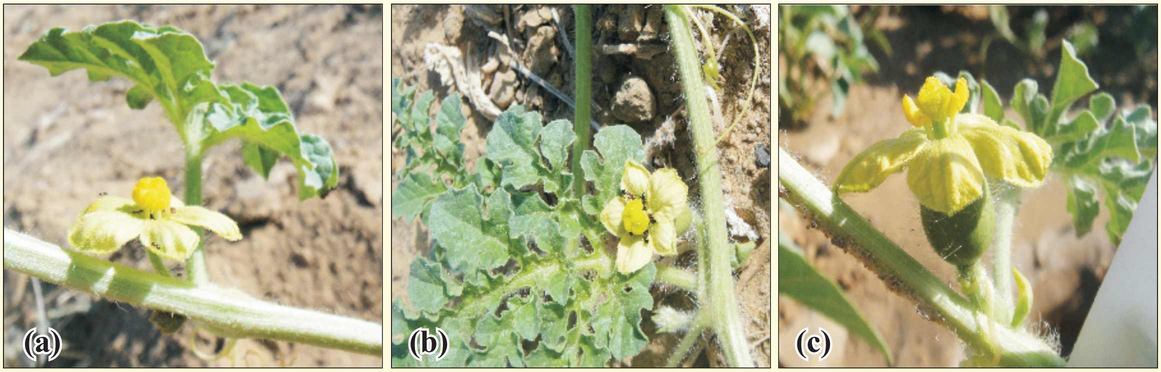

Fig. 4. (a) Staminate/male (left), (b) pistillate/female (middle) and (c) perfect/hermaphrodite (right) flowers in different watermelon genotypes.

Sex expression in watermelon is highly influenced by environmental factors (temperature, humidity, light) and nutrition besides being genetically controlled by a single pair of alleles. Locus 'a' determines sex producing monoecious (AA) vs. andromonoecious (aa) flowers (Guner and Wehner, 2004; Kumar *et al*., 2013). Monoecious (staminate and pistillate flowers on the same plant) sex expression promotes allogamy, while andromonoecious (staminate and perfect flowers on same plant) sex expression favors autogamy (Martin *et al*., 2009). During domestication watermelon is supposed to be more autogamous than allogamous because it originated from small populations grown in isolation through inbreeding and elimination of deleterious recessive alleles. Natural outcrossing in watermelon is influenced by pollinators, plant spacing, genotype and climatic conditions (Kumar and Wehner, 2011). Cross pollination is mediated by honey bees and bumble bees. The movement of pollinators in the field is directional, within the rows rather than across rows (Cresswell *et al*., 1995; Walters and Schulthesis, 2009). In the field, natural pollination in watermelon is usually carried by honeybees visiting the flowers to collect pollen and nectar. But in arid climate (like Jaisalmer) during August-September hardly any bee is visible in the field particularly under mixed cropping. Under this climatic condition, ants play a major role in pollination and favor self-pollination as they move on the same plant (Fig. 5).

Fig. 5. Ants visiting watermelon flowers and promoting autogamy on the same vine.

Hand pollination in watermelon flowers is usually less effective than natural pollination. To ensure controlled pollination, it is necessary to protect the flowers from the visiting bees. Generally, flowers open shortly after sunrise and remain open for whole day. Usually a pistillate flower and the staminate flower proximal to it open on the same day, making self pollination possible through ants. Many breeders observed that hand pollination is more effective between 6 am to 9 am than later in the day. The two main methods for protecting controlled pollinations from insect pollination in the field are: (i) to complete pollination process before bees become active in the morning, and (ii) to cover the flower buds in the previous afternoon. For the first method, pollinations can be made on newly-opened flowers, which are then covered to keep bees away. This method requires less time per pollination, but care must be taken to stop pollinating when bees are observed in the field. Staminate and pistillate flowers can be covered with cotton wool, plastics caps, or paper bags (Fig. 6 and 7).

Fig. 6. Proper stage of flower buds for emasculation and controlled pollination.

In the second method, flowers predicted to open the next morning be capped the previous afternoon. These flowers will be one or two nodes above the flowers (toward the shoot apex) that are newly opened, and should have some yellow color in the petals. Generally, flowers more than three nodes above the newly opened ones that are completely green will probably not open the next day. Capping of flowers is most useful if done on sunny days, since the pollen does not shed freely after rainy or cloudy days. The following morning, flowers are pollinated after removing the caps; further the caps are replaced to keep bees away. After pollinating a pistillate flower, a tag is placed on the peduncle or on the stem just below the peduncle. The tag usually has the plot number of the female and male parents and the date of pollination. Controlled pollination is performed by removing a recently opened staminate flower from the plant to be used as the male parent. The petals of the staminate flower are bent back until they break. The flower can then be used like a paintbrush to pollinate a recently-opened pistillate flower on the plant to be used as the female parent. The setting of one fruit inhibits other fruit on the same plant from setting, so it is desirable to remove pistillate flowers that have not been used for controlled pollinations as the pollinating crew moves through the field in the afternoon.

Fig. 7. Covered flower buds after making crosses in experimental vines.

Watermelon offers several advantages and disadvantages to the breeder, as it is grown as indeterminate plant types, which typically offer plenty of large flowers to work with over a fairly long period of time (Wehner, 2008). The greatest disadvantage with large trailing vines is that it requires abundant field space for proper examination of the most agronomically important traits. Since most selections are for seed yield and related traits, so pollinations must be made before selection of desired phenotypes.

RESEARCH STATUS ON SEED YIELD AND QUALITY TRAITS

Watermelon is being cultivated in all tropical and sub-tropical parts of world since centuries for its edible flesh. A lot of research attention has been paid worldwide for improved fruit yield, disease resistance and other quality traits of consumer preference. In developing countries, fruits for fresh consumption are regular part of their diet. In spite of the fact, many researchers in sub-Sahara Africa, China and other watermelon growing regions either realized the importance of seed or for academic interest studied the seed related aspects of watermelon. On the basis of seed size, watermelon has traditionally been divided into qualitative categories as being large, medium and small size. High correlations among seed weight, seed length and seed width were reported (Poole *et al*., 1941; Zhang, 1996; Hawkins *et al*., 2001). Many genes controlling seed characters in watermelon have been identified, and their segregation patterns studied (Abd el Hafez *et al*., 1981; Tanaka *et al*., 1995; Zhen Qing and Jin Hua, 1995; Kang *et al*., 2000). Levi *et al*. (2001) assessed genetic diversity through molecular markers for disease and pest resistance. The concept for edible seed watermelon with low soluble solids content, high ratio of seed to flesh and small in size (2.5 to 3.5 kg) was developed by Zhang and Jiang (1990) in northwest China. The importance of watermelon as seed purpose crop is very well recognized in sub-Sahara region of Africa due to its livelihood supportive role (Jensen *et al*., 2011; Munshee *et al*., 2011; Matanyaire, 1998). An unusual seed mutant in watermelon (*C. lanatus* var. *lanatus*) having seeds with a fleshy pericarp, commonly called *Egusi* seeds (Gusmini *et al*., 2004) is widely cultivated in Nigeria for the high protein and carbohydrate content (Ezeike and Otten, 1989, 1991). The *Egusi* type fruit is not edible because of its bitter, hard and white flesh (Oyolu, 1977). However, seeds of *Egusi* type are roasted and eaten directly, or ground into flour.

Studies on genes of watermelon were critically reviewed by Guner and Wehner, (2004). In watermelon, three major genes control seed coat color: t (McKay, 1936), r (Poole *et al*., 1941) and w (Poole *et al*., 1941) for tan, red and white seed coat, respectively. The genes interact to produce six phenotypes: black, clump, tan, white with tan tip, red, and white with pink tip. The genes (s) and (l) for short and long seed length control seed size with 's' epistatic to 'l' (Poole *et al*., 1941). The genotype LL SS gives medium size, ll SS gives long and LL ss or ll ss gives short seeds. Gusmini *et al*. (2004) studied the inheritance of unusual seed mutant in watermelon with a fleshy pericarp, commonly called *Egusi* seeds by crossing normal seeded Charleston Gray and Calhoun Gray with PI 490383w and PI 560006 having the *egusi* seed type. They concluded that *egusi* seed type is controlled by a single recessive gene (eg). However, the *egusi* seeds are difficult to distinguish from normal seed type after washing and drying.

Chemical composition of watermelon seed oil was reported as early as in 1940s (Dhingra and Biswas, 1945), followed by Sao and Potts (1952) and most recently by Jarret and Levy (2012). El Adawy and Taha (2001) analyzed watermelon seed kernel and reported 35.7% crude protein and 50.1% crude oil. They further analyzed seed kernel flour for mineral composition and reported considerable amount of phosphorus (1279 mg/100 g), potassium (1176 mg/100 g), magnesium (542 mg/100 g) and calcium (150 mg/100 g). In Kalingda seeds, Das *et al*. (2002) reported 28% crude fat and 23% crude protein while in kernel corresponding values observed were 49 and 40%, respectively. The extracted oil had 10.7, 10.6, 11.1 and 67.3% palmitic, stearic, oleic and linoleic acid, respectively. Baboli and Kordi (2010) evaluated composition of watermelon seed oil for fatty acid profile and reported 81.6% unsaturated fatty acids with linoleic acid (18:2) being the dominant fatty acid (68.3%). Jarret and Levy (2012) analyzed seeds of 96 accessions consisting of *C. lanatus*, *C. colocynthis*, *C. ecirrhosus*, *C. rehmii* and *Benincasa fistulosa* and reported significantly higher oil content in *egusi* type (35.6%) as compared to var. *lanatus* (23.2%) and var. *citroides* (22.6%). *Egusi* types had significantly lower hull/kernel ratio as compared to others. They also reported linoleic acid (43.6-73%) as principal fatty acid in all *C. lanatus* materials. High level of linoleic acid was also reported in *C. colocynthis* (71%), *C. ecirrhosus* (62.7%), *C. rehmii* (75.8%) and *B. fistulosa* (73.2%).

Prothro *et al*. (2012) developed a mapping population derived from strain II (PI 279461) of the Japanese cultivar Yamato-cream with normal seed type and low (25.2%) seed oil percentage (SOP) and an *egusi* type from Nigeria [Egusi (PI 560023)] with high SOP (40.6%). Further genetic analysis confirmed that the *egusi* seed trait is controlled by a single recessive gene (eg) and the location of the gene was mapped to 57.8 cm on linkage group II. Four main quantitative trait loci (QTL) were identified for SOP in the population with the 'eg' locus contributing 84% of the explained phenotypic variation. Meru and McGregor (2013) studied the relationship among seed oil percentage (SOP), kernel percentage (KP) and seed size traits in watermelon to identify quantitative trait loci to facilitate marker assisted selection for traits correlated with seed oil percentage. They further reported that SOP in watermelon is correlated with KP and seed size, but KP was found associated with different loci in normal and *egusi* seed phenotypes.

However, limited information is available on genetic improvement of watermelon for higher seed yield in Indian Thar desert. Inter-specific hybridization in *Citrullus* was attempted at Agriculture Research Station, Mandor, Jodhpur (Joshi and Solanki 1995; Sain *et al*., 2002) for cytogenetical studies. Sain and Joshi (2002) attempted crosses between two accessions of *C. colocynthis* (GP 177 and GP 3), three cultivars of *C. vulgaris* (RW 177-3, AHW 19 and Kalinga) and four inter-specific derivatives (TD 7, TD 11, TD 18 and TD 22) and observed varied pollen fertility in the hybrids of *C. colocynthis* x *C. vulgaris* with different cultivar combinations. Among three cross-combinations, the F_1 hybrid of combination *C. colocynthis* x *C. vulgaris* var. *kalinga* showed maximum (average) pollen fertility (40.1%) followed by *C. colocynthis* x *C. vulgaris* var. *matira* (34.3%) and *C. colocynthis* x *C. vulgaris* var. watermelon (21.5%).

Raiger *et al*. (2009) reported significant genotypic differences in *Kalingada* for seed yield, oil and protein content under different environments. Recently, Mahla and Choudhary (2013) advocated the concept of seed purpose watermelon in Indian Thar desert and evaluated large number of germplasm under rainfed conditions. They characterized the seed purpose genotypes of watermelon for seed yield and other related traits and grouped them in eight clusters on the basis of genetic diversity.

GERMPLASM EVALUATION AND CHARACTERIZATION

Studies on genetic improvement of watermelon for higher seed yield were initiated at CAZRI, Regional Research Station, Jaisalmer in the year 2010. Large number of watermelon germplasm including land races and exotic collections were evaluated and characterized for seed yield and related traits under rainfed conditions.

Variability and Genetic Parameters

Ample variability in watermelon germplasm was observed for fruit size, shape, color and stripe pattern as well as for seed size, shape and flesh color (Figs. 8-10). Among 122 accessions, wide range of variability was recorded for number of seeds per fruit (243.8-1070.0), seed yield per plant (48.8-431.4 g) and 1000 seed weight (33.4-82.7 g). A close association between genotypic co-efficient of variation (GCV) and phenotypic co-efficient of variation (PCV) for fruit weight, rind weight, fruit diameter, number of seeds per fruit and test weight was observed indicating that these traits were not much affected by the environment. However, number of fruits per plant, fruit yield per plant and seed

Fig. 8. Variability for fruit size, shape and stripe pattern in watermelon germplasm.

yield per plant showed considerable difference between GCV and PCV values showing significant role of environment in expression of these traits compared to other traits (Table 3). Higher estimates of heritability (> 0.75) coupled with high genetic advance as per cent of mean (> 20%) were observed for all the traits except fruit diameter.

Fig. 9. Variability for seed size, shape and color in watermelon germplasm.

Correlation and Path Analysis

The correlation studies revealed that estimates of genotypic correlations were higher than the corresponding phenotypic correlation coefficients which indicate strong inherent association among different traits (Table 4). A significant positive association of seed yield was observed with number of fruits per plant, fruit yield per plant and test weight which suggests that these characters could be considered as major seed yield contributing characters in watermelon. Further, fruit weight, rind weight, fruit diameter and number of seeds per fruit were positively correlated with each other but showed negative correlation with seed yield. It is a well established fact that seed yield is a complex trait and depends on other component traits directly or indirectly. The number of fruits per plant, fruit yield per plant and 1000 seed weight also showed direct effect on seed yield (Table 5). Seed yield in watermelon could be increased through number of fruits per plant, fruit yield per plant and test weight. Therefore, promising genotypes having these three traits may be rewarding parents in hybridization for obtaining transgressive segregants.

The success in obtaining highly heterotic hybrids and creating variability for efficient selection of useful recombinants in breeding programme depends on the degree of divergence among the parents selected. The more diverse the parents more are the chances of pronounced heterotic effects and increased spectrum of variability in segregating generations. On the basis of cluster mean and distance, promising genotypes were identified (Table 6) for use in hybridization programme for improving seed yield in watermelon.

Fig. 10. Variability for flesh color and texture and arrangement of seeds in watermelon germplasm.

Table 3. Variability and genetic parameters for various traits in watermelon germplasm

Character	Range	Mean ± SEm	GCV	PCV	h^2	Genetic advance (GA)	GA (as % of mean)
Number of fruits per plant	3.02-20.3	11.94 ± 1.11	31.37	35.29	0.79	6.86	57.45
Fruit yield per plant (kg)	3.88-15.28	8.45 ±0.57	26.25	28.74	0.83	4.17	49.39
Fruit weight (g)	755.0-2457.0	1298.6 ±54.77	31.56	32.39	0.95	822.41	63.33
Fruit diameter (cm)	34.4-50.0	41.8 ± 0.57	7.34	7.72	0.91	6.01	14.39
Rind weight (g)	471.7-1719.7	885.1 ± 42.76	31.72	32.81	0.93	559.25	63.19
Number of seeds per fruit	243.8-1070.0	583.8 ±28.28	25.43	26.78	0.90	290.47	49.75
Seed yield per plant (g)	48.8-431.4	215.5 ±17.25	43.57	45.73	0.91	184.31	85.54
1000 seed weight (g)	33.4-82.7	62.9 ±1.87	17.45	18.19	0.92	21.68	34.48

Table 4. Phenotypic (upper diagonal) and genotypic correlation (lower diagonal) of different quantitative traits in watermelon

Character (s)	Number of fruits per plant	Fruit yield per plant	Fruit weight	Rind weight	Fruit diameter	Number of seeds per fruit	Seed yield per plant	1000 seed weight
Number of fruits per plant	1.000	0.633**	-0.423**	-0.459**	-0.181	-0.140	0.358**	0.119
Fruit yield per plant	0.647	1.000	-0.075	-0.087	0.043	0.156	0.384**	0.234
Fruit weight	-0.426	-0.077	1.000	0.983**	0.741**	0.461**	-0.297*	0.086
Rind weight	-0.464	-0.090	0.986	1.000	0.702**	0.386**	-0.278*	0.114
Fruit diameter	-0.186	0.043	0.749	0.708	1.000	0.360**	-0.232	0.211
Number of seeds per fruit	-0.142	0.160	0.466	0.393	0.397	1.000	-0.081	0.213
Seed yield per plant	0.365	0.393	-0.301	-0.282	-0.236	-0.084	1.000	0.326*
1000 seed weight	0.122	0.239	0.086	0.114	0.215	0.217	0.328	1.000

*, ** Significant at P=0.05 and P=0.01 level of significance, respectively.

Table 5. Direct (diagonal) and indirect effects of various quantitative traits on seed yield of watermelon

Characters	Number of fruits per plant	Fruit yield per plant	Fruit weight	Fruit diameter	Rind weight	Number of seeds per plant	1000 seed weight
Number of fruits per plant	**0.149**	0.031	-0.021	-0.009	-0.022	-0.006	0.006
Fruit yield per plant	0.183	**0.290**	-0.022	0.012	-0.025	0.045	0.068
Fruit weight	0.064	0.011	**-0.153**	-0.114	-0.151	-0.071	-0.013
Fruit diameter	0.035	-0.009	-0.149	**-0.201**	-0.141	-0.072	-0.042
Rind weight	-0.023	-0.004	0.050	0.036	**0.051**	0.019	0.006
Number of seeds per fruit	0.008	-0.010	-0.029	-0.023	-0.025	**-0.064**	-0.014
1000 seed weight	0.039	0.074	0.027	0.066	0.036	0.067	**0.315**

Table 6. Promising genotypes identified for seed yield and related traits

Genotype	Seed yield per plant (g)	Number of fruits per plant	Fruit yield per plant (kg)	Fruit weight (g)	Fruit diameter (cm)	Rind weight (g)	Number of seeds per fruit	1000 seed weight (g)
SKGPK-24	431.4	16.4	8.84	963	40.8	633	556.4	68.8
SKNK-138	400.0	16.6	9.69	755	38.0	551	480.6	65.6
SKGPK-31	355.6	13.8	10.35	1221	43.0	773	658.8	69.7
SKNK-665	355.0	20.2	15.28	1481	45.0	1008	635.0	65.9
DRB-675	341.9	14.9	11.11	757	36.4	547	400.6	62.9
SPS-8	339.4	15.5	9.16	830	37.6	556	598.6	62.0
SKGPK-33	338.6	13.8	10.82	1207	42.4	834	514.6	67.2
SKNK-0903	317.5	14.7	8.39	875	41.4	606	539.0	69.9
SKGPK-29	311.0	16.1	9.08	1037	41.2	758	365.0	58.9
SKNK-679	310.0	12.3	12.63	2195	43.2	1371	1070.0	65.9
CAZJK-13-1	239.2	5.8	8.4	2267	42.8	1532	660.5	63.3
CAZJK-13-2	291.3	9.2	10.7	1572	40.1	1086	717.5	61.6

ETHNOBOTANICAL IMPORTANCE

The traditional rainfed farming was sustainable due to diversity in agriculture supported by animal husbandry in Thar Desert. Since ancient times, cucurbits have played a major role in subsistence farming and household nutritional security, particularly in resource constrained situations. Cucurbits like Kachri (*Cucumis callosus*), Tindsi (*Citrullus fistulosus*), Kachara (*Cucumis melo* var. momordica), *Mateera* (*Citrullus lanatus*) were the integral components of rainfed cropping. Among these species, watermelon locally known as *Mateera* is still an important constituent of traditional kharif cropping. The main reason for growing *Mateera* as mixed crop is its fast growing habit and drought hardy nature. Further, its extensive root system makes it most suitable to tolerate harsh climatic conditions. Secondly, just after sowing of the crops prolonged dry spell and high wind speed hinders the germination and proper plant stand of the main crop.

It is traditionally grown with bajra (pearl millet) and guar (clusterbean) as a mixed crop to cope with the risk of frequent crop failure in the hot arid region. Generally, about 250-300 g seeds (for one ha area) are mixed with main crops (bajra/guar) while sowing. Farmers also have preference for certain seed colors. Generally, farmers prefer brown or red color seeds to black color for cultivation. *Mateera* is also grown with rangeland arid shrubs like Phog (*Calligonum polygonoides*) and Lana (*Haloxylon salicornicum*). It is believed by the inhabitants that quality of the *Mateera* fruits improves with association of these shrubs as these species add the organic matter to the soil.

Tender fruits locally known as *Loia* are harvested by the farmers for their own consumption as vegetable and also for sale in the local market. The ripe fruits are harvested for fresh consumption and seed extraction. Generally, farmers collect the mature fruits and put in heap as all the fruits on a vine do not mature at same time (Fig. 11). The fruits are stored by the farmers easily at room temperature for quite long time. After collection of all the fruits from field, the farmer family extracts the seeds by cutting the fruits in two halves. Farmers informed that seed extraction is easier from the fruit if the fruit is held in storage (in the shade or in a room) for a few days after removing them from the vine. After cutting the fruits, the seed part along with fleshy placenta is put in a *Tasla* (iron pan) and rubbed thoroughly so that the seeds can be detached from the flesh and can be separated easily. The upper part in the *Tasla* have the flesh floating on the seed which can be drained, and lower part has the seed. The extracted seeds are kept for few days on soil for removal of moisture from the seeds and then cleaned through sieving or winnowing (Fig. 12). The rind portion of fruit is dried and used as animal feed.

Fig. 11. A farmer family extracting the seed from *Mateera* fruits.

Fig. 12. Traditional method of *Mateera* seed extraction and drying.

Food

The tender fruits of '*Mateera*' locally known as '*loia*' (Fig. 13a) are traditionally used by desert inhabitants for vegetable or '*raita*' making and very much liked in the area. These '*loia*' fruits are picked when weighing around 100-150 g, generally 8-10 days after fertilization. These tender fruits are sold in local market and fetch good price. The mature fruits of '*Mateera*' are eaten fresh and much relished (Fig. 13b). These fruits are valued as refreshing food to farmers while harvesting the main crop during the month of October-November. Generally, after eating the fruits, seeds are collected for future consumption. Its roasted seeds are generally taken as a common snack in arid region (Fig. 13c). After removal of seed coat, the kernel locally known as '*Magaj*' (Fig. 13d) is mainly used in sweets preparation and also in cooling drinks.

(a) (b) (c) (d)

Fig. 13. Utilization of *Mateera* (a): Green vegetable; (b) Fresh fruit; (c) Seed and (d) *Magaj*.

Livestock Feed

Traditionally, green as well as dry rind portion of the fruits locally called as *Khuparia* is used as livestock feed (Fig. 14). The dried rinds of fruits are stored and supposed to have good keeping quality. This feed material is crushed and boiled along with other feed concentrates as guar *churi*, and oil seed cakes. The boiled material is fed to milch animals particularly cattle and buffalo in morning and evening before milking, which is supposed to increase the milk yield.

Fig. 14. Khuparia (rind), fresh (left) and dried (right).

Medicine

Traditionally, fruit juice is used against sun strokes by the desert dwellers; regular use of fruit is supposed to cure the stone formation (Singh *et al*., 2004). In case of snakebite, the juice of fruit kept for two years in glass bottle is given to affected person, which helps in vomiting and neutralize the effect of poison (Kumar *et al*., 2003).

Social and Religious Aspects

Mateera plays an important role in culture of Thar desert and has social and religious values. Its fruits are used on Dipawali festival during 'Goverdhan Puja'. There is a verse in the region for its value:

खुपरी जाणै खोपरा बीज जाणै हीरा। (Khupri jane khopra, beej jane heera)

बीकाणा थारै देस में बड़ी चीज मतीरा। (Bikana thare des men, badi cheej mateera)

It means, its rind portion is treated as coconut and its seeds are valued equivalent to diamond, that is why in Bikaner region *Mateera* is a valued item.

PRODUCTION TECHNOLOGY

Predominantly the seed purpose watermelon is being grown as a mixed crop with pearl millet and clusterbean; therefore, it does not require special operations for its cultivation. But for better production some crop management aspects should be considered.

Climate

Watermelon requires warm and dry climate for its growth and development and can be successfully cultivated at 30-35°C temperature. Its flowering and fruit development are promoted by high light intensity and high temperature. Areas having high humidity during fruit formation stage and more rainfall particularly at maturity are not suitable for its cultivation.

Soil

It can be grown on all types of soil but sandy to sandy loam soils having pH range from 5.5-7.5 are most suitable for watermelon cultivation. The soil should be well drained. Very heavy and waterlogged soils should be avoided for its cultivation.

Field Preparation

Field preparation depends on soil types and main crop to be sown with watermelon. Generally, a deep ploughing during summer month is recommended followed by two cross harrowing before sowing.

Manures and Fertilizers

Ten to fifteen tons of well decomposed FYM is generally recommended at the time of field preparation. When watermelon is grown with pearl millet 80 kg nitrogen and 60 kg phosphorus should be applied at the time of sowing. 20 kg nitrogen and 40 kg phosphorus should be applied when watermelon is grown with leguminous crop (clusterbean). If watermelon is grown as sole crop under rainfed conditions 8-10 kg FYM and 15-20 g DAP per plant should be applied at the time of sowing.

Seed Sowing

When watermelon is grown as mixed crop 250 g seeds per hectare are sufficient for mixing with pearl millet or clusterbean assuming that 500-600 vines should be there.

If watermelon is cultivated as sole crop 1.5-2.0 kg seeds are required. Seeds should be treated with fungicide like 3.0-4.0 g carbendazim per kg of seed at the time of sowing. Under sole cropping line to line spacing should be kept 2.5-3.0 m and plant to plant 1.0 m. Seed should be sown 3-4 cm deep. Sowing of the seeds may be done with the first monsoon rains from second fortnight of June to first week of August depending on the rains. Seed germinates within 48 hr and continues up to two weeks depending on temperature and moisture conditions. There is no dormancy in watermelon seeds, so they can be harvested on one day, cleaned, dried, and planted on the next day. The optimum germination temperature is 30 to 35°C.

Hoeing-weeding and Inter-culture Operations

Under mixed cropping at the time of hoeing-weeding of main crop, all undesirable plants or weeds around the vine should be removed and soil around the plants should be loosened for proper rain water and moisture conservation (Fig. 15). Proper plant stand should be maintained for getting good production, over crowding of vines and less number of vines per unit area will affect the yield adversely. If watermelon is grown as sole crop in rows, then after 15-20 days of sowing harrowing between the rows will not only help in weed control but also conserve all the rain water in the field.

Fig. 15. Hoeing-weeding around '*Mateera* vines after 15 days of sowing and harrowing between the rows (left) and crop grown on conserved moisture (right).

Insect-pest and Diseases

Under rainfed conditions of arid zone no serious problem of insect-pest and diseases occur, particularly in mixed cropping situations. But when crop is grown as sole crop, some fungal and bacterial diseases can affect the crop.

Powdery mildew: Symptoms of this disease first appear on leaves and stem in the form of white or grey spots and afterwards turns into powder which covers the whole plant in severe attack of fungus and ultimately all leaves drop (Fig. 16). The fruits remain smaller in size with few shrivelled seeds and cause severe yield loss. To control this fungal disease field should be kept clean and affected plants should be burnt immediately. Spray of Dinocap (0.1%) should be done at the interval of 15 days.

Downy mildew: At initial stage, angular spots are observed on upper surface of leaves which spread rapidly on lower surface also in case of severe incidence. High relative humidity and high temperature are very congenial for development of this fungal disease. For protection, seeds should be treated with fungicide before sowing. Spray of Mancozeb (0.25%), 2.5 g in 1 litre water should be done for control of disease and if favorable environmental conditions persist for long time spray may be repeated after 15 days for effective control.

Fig. 16. A view of plant affected with powdery mildew disease.

Physiological Disorders

Physiological disorders are caused by non-pathogenic agents that affect fruit and seed quality and ultimately the yield. The cause can be either one or a combination of environmental, genetic or nutritional factors.

Deformed fruits: Deformed fruits (gourd-necked or bottlenecked) may be seen under moisture stress conditions. The fruit can also deform due to poor pollination leading to restricted growth at the stem end.

Blossom-end rot: It is a deterioration of the blossom end of the fruit. The usual order of development is softening, slight shriveling, browning, blackening and sometimes secondary decay. Hot dry winds, nematode problems, excessive fertilizer, and low levels of calcium in the soil are other contributing factors for blossom-rot.

Bursting of fruit: It may result from an uneven growth rate, which is particularly associated with heavy rainfall or irrigation when the fruit is maturing. However, the percentage of burst fruit is usually low, and round fruit types are more susceptible to it (Fig. 17).

Fig. 17. A view of the burst watermelon fruits on the vine.

White heart: In this disorder, white streaks or bands of undesirable flesh in the heart (centre) of the fruit. This is caused by excessive moisture (and probably too much nitrogen) during fruit maturation. Hollow heart is a disorder that varies among varieties. Hollow heart is marked by cracks in the heart of the watermelon fruit owing to accelerated growth in response to ideal growth conditions facilitated by ample water and warm temperatures.

***Sun scald (burn)**:* It results from exposure to intense solar radiation that leads to dehydration and overheating damage of the rind tissue. Sun scald can be avoided by covering the fruit with vines or straw material. Sunburn occurs most frequently in varieties that have dark-green rinds. Good, healthy foliage will minimize sunburn damage as well as favor good yields and quality. Strong winds can blow unprotected vines away from the developing fruit along the edges of the rows and cause full exposure of the fruit to the sun.

Rind necrosis: Rind necrosis is an internal disorder that damages the watermelon rind (Fig. 18). Symptoms are brown, corky, or mealy textured spots on the rind which may enlarge to form large bands of discoloration that rarely extend into the flesh. The cause of rind necrosis is unknown. Bacterial infection has been reported for necrosis. Drought stress also is reported to predispose melons to rind necrosis.

Fig. 18. A view of the fruits affected with rind necrosis.

Fruit Harvesting and Seed Extraction

The maturity of fruit on a vine can be judged by color change from green to dark brown or the dryness of tendril near the fruit. The other maturity index is the complete color change of lower part of fruit touching the ground. It is beneficial to keep the fruit for one more week on vine after maturity to enhance the seed quality (Fig. 19**).** Generally, mature fruits are put in heap as all the fruits on a vine do not mature at same time (Fig. 20). Seed extraction is easier from the fruit if the fruits are stored in the shade or in a seed processing room for few days after removing them from the vine. It is better to dry the seeds on very thin used cloth as it will absorb the excess water and also prevent the seed and flesh getting soiled (Fig. 21).

Fig. 19. Mature fruits on vines in the field.

Fig. 20. Harvested '*Mateera*' fruits.

Fig. 21. A view of seed extraction (left) and drying (right) in the field.

FARMER PARTICIPATORY RESEARCH APPROACH

Watermelon is being grown as a mixed crop in arid regions since everlasting time. Therefore, the farmers have better knowledge of the crop and its diversified uses. Further, farmers' role in conservation and management of biodiversity particularly of 'Landraces' conservation and maintenance is very well recognized in India. It is vital to involve the farmers in selection of varieties that correspond to communities needs through farmers' participatory approach. Therefore, during primary evaluation and selection of parents/germplasm farmers' views were taken by creating awareness through field visits at the experimental site (Fig. 22) and field days at experimental site (Fig. 23) and at farmers' field also (Fig. 24). During the field days and interactions with the farmers, indigenous technical knowledge (ITK) with regard to cultivation practices and other related aspects was also gathered for watermelon improvement programme.

Fig. 22. Farmers visiting experimental site at Jaisalmer.

Further, seeds of promising genotypes of *Mateera* were provided to farmers of Jaisalmer and Barmer districts for sowing with guar/pearl millet for on-farm evaluation. The feedback information for these genotypes was collected from the farmers. The yield data of crops/*Mateera* from the farmers' field (Table 7) showed substantial increase in net returns with improved *Mateera* genotypes under rainfed conditions.

Fig. 23. Farmers' viewing the diverse germplasm during *Mateera* Field Day at Jaisalmer.

Fig. 24. A view of *Mateera* Field Day at Farmer's field at Jogasar Kuan, Barmer.

Table 7. Seed yield of pearl millet, guar and *mateera* under rainfed conditions of Jaisalmer

Crop and their sowing combination	Grain yield (kg ha^{-1})	*Mateera* seed yield (kg ha^{-1})	Additional income from *Mateera* seeds (Rs.)	Deviation from profit in main crop	Net additional income (Rs.)
Sole pearl millet	350	-	-	-	-
Sole guar	205	-	-	-	-
Pearl millet + Desi *Mateera*	320	35	1750	360	1390
Pearl millet + Improved *Mateera*	315	125	6250	420	5830
Guar + Desi *Mateera*	185	50	2500	1700	800
Guar + Improved *Mateera*	180	135	6750	2200	4550

[Sale price of pearl millet grain Rs. 12.0/kg, guar grain Rs. 100.0/kg and *mateera* seed Rs. 50.0/kg] (during the year sale price of guar was exceptionally high, otherwise it hovers around Rs. 30-40 per kg).

The demonstrations executed at farmers' field clearly showed that if improved genotypes of *Mateera* having higher seed yield potential introduced with main crop, it would provide additional income of Rs. 5830 with pearl millet and Rs. 4550 with guar per hectare. The future of seed purpose watermelon as a mixed crop is undoubtedly dazzling as it fits very well in traditional rainfed system as well as a sole crop due to its multifarious uses and ability to cope with the harsh climatic conditions of arid zone. Further, introduction of improved genotypes of seed purpose watermelon may yield 3-4 times more seed yield and ultimately income to the farmers.

FUTURE PROSPECTS OF SEED PURPOSE WATERMELON CULTIVATION

Indigenous traditional vegetables are perceived as potentially useful for income generation and food security insurance. With the introduction of cash crops, traditional crops are usually confined to marginal areas with poor soil fertility or are reduced in terms of cultivated area. This situation happens whilst farmers face difficulties in transmitting knowledge to the young generations who are rather oriented towards off-farm activities (Meagher, 1997). The erosion of traditional subsidiary crops may put local agro-biodiversity at risk, which is otherwise very important for sustainability in fragile ecosystem. The value of such crops in the changing agricultural system of many developing countries is therefore suggested by their persistence in the farming system where alternative cash crops dominate (Mertz *et al*., 2005). Thus, in a changing climate scenario, awareness about the importance of these indigenous crops such as watermelon is vital for sustainable rainfed production and their contribution to people's livelihood in arid region. The importance that farmers assign to watermelon may then help to identify strategies for ensuring the promotion and the sustainable production of watermelon for its seed yield potential with minimal cost. Watermelon can be used in different ways in different forms at various stages of development and post-harvest.

Source of Green Vegetable

Young fruits of *Mateera* locally known as *loia* are relished by the inhabitants as green vegetable. In local market, its tender fruits fetch very premium prices (Rs. 30-40 kg^{-1}) and also have the enormous demand. Hence, farmer can get good income after 40-50 days of crop sowing particularly under aberrant weather situations where crop failures are very common phenomenon.

Seed as Source of Protein and Fat

Its seed are rich in nutrients and minerals. It contains crude protein and oil besides other minerals in appreciable quantity (Table 8). The seed oil contains > 80.0% unsaturated fatty acids with linoleic acid (18:2) being the dominant fatty acid (Table 9). Presently the kernels (*Magaj*) of the seeds are used in restaurants/hotels as source of flavor and thickeners in vegetable preparation. It not only increases the viscosity and luster of the preparation but also the taste of the dish. Its seed can be used for oil extraction for household use and byproducts after seed extraction may serve as a quality animal feed.

Table 8. Proximate composition of dehulled, undehulled and flour of watermelon seed on dry weight basis

Nutrients	[A]Dehulled watermelon seeds	[A]Undehulled seeds	[B]Seed flours
Crude protein (%)	38.59 ± 0.04	28.50 ± 0.01	30.11 ± 0.32
Fat/crude lipid (%)	17.78 ± 0.01	10.65 ± 0.01	45.05 ± 0.12
Carbohydrate (%)	33.08 ± 0.03	48.35 ± 0.01	17.62 ± 0.02
Total ash (%)	3.17 ± 0.02	2.23 ± 0.02	3.75 ± 0.11
Crude fibre (%)	7.32 ± 0.01	10.30 ± 0.01	3.47 ± 0.009
Calcium (mg/100 g)	-	-	86.75
Phosphorus (mg/100 g)	-	-	1073.3
Potassium (mg/100 g)	705.37 ± 5.28	421.86 ± 1.70	598.95
Magnesium (mg/100 g)	526.58 ± 2.26	594.11 ± 3.61	1118.0
Iron (mg/100 g)	1.94 ± 0.03	4.27 ± 0.05	10.70
Zinc (mg/100 g)	19.55 ± 0.03	18.62 ± 0.03	9.65

Source: [A]Ibeanu *et al*., 2012 and [B]Samia *et al*., 2012.

Table 9. Fatty acid composition of watermelon seed

Linoleic	Oleic	Palmitic	Stearic	Reference
68.3	13.0	8.8	5.6	Nolte and Loesecke, 1939
48.7	35.3	7.6	6.1	Dhingra and Biswas, 1945
62.0	19.0	10.5	6.1	Sao and Potts, 1952
48.7-73.0	7.9-25.7	5.1-11.5	9.7-14.4	Jarret and Levi, 2012
67.3	11.1	10.7	10.6	Das *et al*., 2002
45.1-51.2	20.2-23.0	11.2-13.8	14.3-16.2	Raziq *et al*., 2012
59.6	18.1	11.3	10.2	El Adawy and Taha, 2001
68.0	11.0	13.0	8.0	Sabahelkhier *et al*., 2011
68.3	13.2	11.4	7.0	Baboli and Kordi, 2010
62.1	13.7	10.6	8.3	Edidiong *et al*., 2013

Source of Energy to Farmers as Refreshing Fruit

Since ancient times, its ripe fruits are well known in the region and have great value in the life of desert inhabitants. The fruits are supposed to have cooling effect in the body. Besides, providing instant energy, it provides nutrients and quenches thirst under field conditions and farmers can work for extended period of time and hence increases their efficiency while working.

Health Benefits

Regular use of *Mateera* fruits relieve constipation, and also useful in cardiac and kidney troubles. The seeds are supposed to regulate blood sugar levels, increase energy, maintain the nervous system and promote healthy skin. The seeds are also used in pharmaceuticals.

Source of Livestock Feed

Animal husbandry is the integral part of the arid zone agriculture. After seed extraction, its rind portion locally known as '*Khuparia'* can be very well utilized as animal feed since it improves the quality and quantity of milk and animal health also. On dry weight basis *Khuparia* contains 12-15% crude protein, 22-30% ether extract and 9-14% ash. It may substantially replace the costly concentrate and thereby reduce the feeding cost.

Livelihood Security

After harvest of the main crop, farmer family collects the left over fruits of '*Mateera'* and extracts the seeds from fruits. Seed price varies from Rs. 5000-8000 per quintal (sometimes $\geq$ Rs. 10000) in local market, which is remunerative among rainfed kharif crops thus supporting the livelihood in a big way (Table 10).

Table 10. Comparative price of kharif (Rainfed) crops in Rajasthan

Crops/Commodities	Price (Rs.) per quintal
Til	8000-10000
Mateera Beej	5500-6000
Mung bean	5300-6000
Clusterbean	4200-4700
Moth bean	4000-4500
Jowar	1600-2000
Pearl millet	1250-1400
Maize	1200-1350

Source: As per Daily News Paper 2014.

FUTURE RESEARCH NEEDS

It has been very well recognized that *Mateera* (watermelon) is an integral component of rainfed mixed cropping that supports the livelihood of desert dwellers in a big way. But little attention has been paid for its commercial cultivation due to various obvious reasons. Therefore, the targeted breeding program and in-depth diagnostics of quality traits of seed will help to identify factors that would boost its production. In the changing climate scenario, concerted scientific efforts on following aspects are very much required to support the arid zone economy.

Development of high seed yield varieties and availability of seeds to farmers

Biochemical analysis for detailed proximate composition of watermelon seeds for multifarious uses viz., food, pharmaceuticals and industrial applications

Standardization of package of practices for higher seed production

Designing and fabrication of seed extractor for easy and quick seed extraction

Evaluation of dry rind as supplement livestock feed to costly concentrate, and

Value addition to *Mateera* derived products for its wider acceptability

The cultivation of improved genotypes of seed purpose watermelon in arid region not only increases the income of the farmers but also diversifies the cropping system which leads to sustainable rainfed production. Further, higher seed production and assured supply of raw material to processing units will provide congenial environment for industries and opportunities for employment generation at the door step in the region.

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