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RESEARCH ARTICLE

Characterization and Utilization of Potential Genetic Resources for Improvement of *Citrullus lanatus* Under Desert Ecosystem

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Abstract

Mateera is an indigenous type of drought-hardy watermelon and is extensively grown with mixed cropping on sand-dunes landscape in the *Thar* Desert. Its tender and ripe fruits and seed kernels are liked by desert dwellers and sold at a high premium. Earlier, due to the absence of *mateera* varieties, farmers used heterozygous seeds collected from their own fields, which resulted in uninsured quality. From 1994 to 2012, diverse *Citrullus* germplasm was collected, evaluated, conserved, and utilized and intensive research work was carried out at ICAR-CIAH, Bikaner, Rajasthan, India. A close correspondence between PCV and GCV values with respect to characters under study indicated that the testing environment has very little influence on the expression of the attributes. Thus, selection based on phenotype can be effective with an equal probability of success. On the evaluation of a wide range of germplasm, it was found that standard watermelon genotypes failed to express their potential under high temperatures and rainfed conditions of arid regions. Thus, the use of indigenous and generated variability and the promotion of varieties from native germplasm is found to be beneficial. *Mateera* lines AHW-18 (IC-430201), AHW-19 (IC-430202), AHW-65 (IC-430208), AHW-108 (IC-430215), AHW-140 (IC-430225), AHW-RSS-1 (red seeded isolate from germplasm of Churu district) and AHW-BSM-1 (black seeded isolate from AHW-19) were found promising for use in breeding or trait-specific selections. The developed *mateera* varieties, *i.e.,* AHW-19 and Thar Manak are early in harvesting, producing better quality fruits and of multiple-use, and recommended for cultivation under resource constraints in a hot arid climate.

Keywords: *Citrullus*, Desert ecosystem, Drought-tolerant, Hot arid climate.

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Introduction

Indian sub-continent is rich in cucurbitaceous crop-plant diversity. The arid and semi-arid region of north-western India is endowed with a wide range of genetic variability, particularly *Citrullus* and *Cucumis* group of multiple-use attributes. Indigenous cucurbits *viz*., *kachri, kaakdia, mateera, tinda* and *tumba* are component crops of traditional farming, providing nutrition and income to the inhabitants of the desert ecosystem. *Mateera* is a drought-tolerant landrace of watermelon (*C. lanatus*) and is very useful to the growers for getting benefits from its tender and ripened fruits, seed kernels, and organic and rainfed crop commodities. *Tumba* or *Indrayan* or bitter melon (*C. colocynthis*) is non-edible and perennial, and fruits are used for pickling, medicine and seed oil. Third is tinda (*Praecitrullus fistulosus*) and is a popular vegetable for tender and dehydrated (*Phophalia*) fruits (Samadia and Pareek, 1998; Pareek *et al*., 1999; Samadia, 2007).

Entirely ripe fruits of *C. lanatus* are palatable as a febrifuge or antipyretic. Its fruit is a diuretic and can be used to treat kidney stones and dropsy. In case of diabetes and alcoholic toxicity, fruit peel is suggested. Watermelon is high in vitamins A and C, as well as vitamin B_6, beta-carotene, thiamine, and potassium (Mezzomo and Ferreira, 2016; https://www.nal.usda.gov/human-nutrition-and-food-safety/nutrient-lists-standard-reference-legacy-2018). Watermelon juice reduces SOD activity and LDL cholesterol while increasing CAT activity and HDL cholesterol, disclosing that it has antioxidant properties (Georgina *et al*., 2011). The scented, sweet and red fruit of *Citrullus lanatus* is digestible and delicious. It has roughly 40% lycopene, a cancer-fighting antioxidant. Lycopene is easy to absorb without requiring high-temperature treatment and is relatively stable when stored and refrigerated. Watermelons should be hard and symmetrical, with no cuts or indications of strikes. It contains citrulline, a substance that helps to decrease blood pressure. Watermelon juice consumption has been associated with lower insulin resistance which is beneficial to fight against metabolic syndrome and type 2 diabetes (Xue *et al*., 2015).

Non-availability of trait-specific varieties suited to abiotic stressed production sites of the arid region is the prime limiting factor in promoting *mateera* and thus, a targeted work plan was made to improve quality fruit harvest. Intensive surveys were conducted in regional diversity zones and germplasm were collected, evaluated and categorized for the breeding program. Besides, generated progenies from selected germplasm and breeding material developed through identified parentage combinations were studied over the seasons and years to conclude the results of strategic research on varietal development are described in this paper.

Materials and Methods

Agro-climate of the Study Region

In India, Rajasthan (23° 3′–30° 12′ N and 69° 3′–78° 17′ E) is geographically very big state and much agro-climatic variability is reported *viz*., arid, semi-arid and dry sub-humid. All the experimental trials were conducted at ICAR-CIAH, Beechwal, Bikaner (28° 6′ N latitude and 73° 2′ E longitudes and altitude 223 m) and this area is under a hyper-arid zone of the Indian *Thar* desert. In arid farm-lands, high temperature (35–42°C) during the *kharif* season, long drought spells (15–35 days) and the sandy soil creates an environment where very few vegetable crops reach to economic harvest under the rainfed situations and *mateera* is well known among them. Further, extremes of winter and summer seasons' temperature variability, as well as range, also determine the period of sowing and harvesting of *mateera*.

Germplasm Collection, Augmentation, Evaluation and Utilization

For the collection of regional diversity of *Citrullus*, surveys were conducted from 1994 and 2003 and it was in targeted variability pockets of arid, semi-arid and tribal areas of Rajasthan. Besides, collaborative collections were made with ICAR-National Bureau of Plant Genetic Resources (NBPGR), Regional Station, Jodhpur. Maximum *mateera* variability was collected (178) from Bikaner, Churu, Nagour, Jodhpur, Barmer, Jaisalmer, Pali and Hanumangarh districts with desert ecology, rainfed and mixed cropping during Kharif. In contrast, watermelons (28 germplasm) were explored from Sikar, Jaipur, Tonk, Ajmer, Kota, Chittorgarh, Udaipur, Sirohi and adjoining districts with semi-arid climate and summer season cultivation. In addition, introduced and national watermelon genotypes (11 entries) were assembled from ICAR-NBPGR, New Delhi, Rajasthan Agricultural Research Institute, Durgapura (Jaipur), ICAR-Indian Institute of Horticultural Research, Bengaluru and ICAR-Indian Institute of Vegetable Research, Varanasi.

Over the years collected *Citrullus lanatus* diversity was evaluated in a phase manner. For characterization, 35 attributes related to growth, flowering, fruiting, maturity, fruit yield, quality and seed components were studied for all the material. Both *mateera* and watermelon germplasm were categorized based on the prioritized traits such as earliness, number of fruits, fruit quality and marketable yield under hot, arid climates. The watermelon varieties, hybrids, purified *mateera* material and developed lines were assessed over the seasons to understand their suitability for two-season cultivation. Therefore, each germplasm or breeding material was studied at least four times in rainy and summer and rainfed and irrigated situations. For evaluation of each germplasm or line, a single row of 25 m length was kept standard throughout the experimental trials and 50 plants/genotype/row were maintained. With the start of flowering, 12 plants were tagged in each genotype and four groups were made for recording observations. A wide range of data was generated from the germplasm (155 genotypes) and it was with varying seasons and production situations of 1995–1999 and 2000–2003 at Bikaner. Initially, the purified germplasm (Table 1) was short-listed based on performance and prioritized traits. Means of two-season data of the year 2003 of the short-listed genotypes were used for assessment of genetic variability components and means of four-season crop data were analyzed for comparative performance.

For the purification of *mateera* germplasm, promising genotypes were identified based on fruit quality traits and performance. After purification, *mateera* selections were compared with standard watermelon varieties for fruit quality and yield. Simultaneously, breeding for drought-tolerant *mateera* through hybridization was taken with the objectives of improving adaptive selections for acceptable flesh quality, higher sweetness, and cultivation under water stress and high-temperature conditions. The *mateera* selections (AHW-18, AHW-19 and AHW-65) and watermelon varieties (Sugar Baby, Durgapura Meetha, Charleston Local and Mahobobi) were used in hybridization breeding (single, diallel and bi-parental mating). Developed F_1, F_2, BC_1, BC_2

Table 1: Details of *Citrullus* germplasm initially purified at ICAR-CIAH, Bikaner

S. No.	*IC number*	*Accession/collector number*	*S. No.*	*IC number*	*Accession/collector number*
1	IC-430191	DKS/AHW/01	29	IC-430219	DKS/AHW/118
2	IC-430192	DKS/AHW/02	30	IC-430220	DKS/AHW/119
3	IC-430193	DKS/AHW/04	31	IC-430221	DKS/AHW/120
4	IC-430194	DKS/AHW/05	32	IC-430222	DKS/AHW/122
5	IC-430195	DKS/AHW/07	33	IC-430223	DKS/AHW/123
6	IC-430196	DKS/AHW/10	34	IC-430224	DKS/AHW/135
7	IC-430197	DKS/AHW/12	35	IC-430225	DKS/AHW/140
8	IC-430198	DKS/AHW/14	36	IC-430226	DKS/AHW/150
9	IC-430199	DKS/AHW/16	37	IC-278416	KCM/BKP-18
10	IC-430200	DKS/AHW/17	38	IC-278417	KCM/BKP-19
11	IC-430201	DKS/AHW/18	39	IC-315281	DPY-117
12	IC-430202	DKS/AHW/19	40	IC-315283	DPY-119
13	IC-430203	DKS/AHW/30	41	IC-315284	DPY-120
14	IC-430204	DKS/AHW/40	42	IC-315288	DPY-124
15	IC-430205	DKS/AHW/43	43	IC-315290	DPY-126
16	IC-430206	DKS/AHW/50	44	IC-315304	DPY-140
17	IC-430207	DKS/AHW/56	45	IC-315306	DPY-142
18	IC-430208	DKS/AHW/65	46	IC-315313	DPY-149
19	IC-430209	DKS/AHW/76	47	IC-315321	DPY-157
20	IC-430210	DKS/AHW/80	48	IC-315324	DPY-160
21	IC-430211	DKS/AHW/82	49	IC-315328	DPY-164
22	IC-430212	DKS/AHW/85	50	EC-420978	Mahobobi
23	IC-430213	DKS/AHW/93	51	EC-420977	Charleston
24	IC-430214	DKS/AHW/100	52	IC-0590087	Thar Manak
25	IC-430215	DKS/AHW/108	53	-	AHW RSS-1
26	IC-430216	DKS/AHW/110	54	-	AHW BSM-1
27	IC-430217	DKS/AHW/112	55	-	Sugar baby
28	IC-430218	DKS/AHW/115	56	-	Durgapura Meetha

and parents were studied for their performance as rainy and summer season crop during 1999-2003. Promising segregates were selected in F_2 and, further breeding work advanced and emphasis was given to individual plant selection based on the fruit flesh quality traits and adaptability under dryland climate. From 2004–2010, the most promising lines, selections, and varieties of *mateera* and watermelon were evaluated with the varying seasons and situations. Since fruit flesh quality, cracking-free, marketable yield and tolerance to arid conditions were prioritized components for *mateera*, therefore, long-term data were assessed in various formats to conclude the research work.

Results and Discussion

Indian sub-continent is a primary, secondary and an area of regional diversity for several vegetable significant plants. Based on survey studies, it is recorded that the types of vegetables found growing in the arid and semi-arid areas of north-western India are distinctly different due to the eco-adaptations and climatic variability. The *Aravalli* range separates the desert ecosystem into two parts, namely, the Western arid and semi-arid East, where a rich variability of *Citrullus* and *Cucumis* species exists. With the facts, systematic surveys in targeted pockets and crop-specific explorations were conducted in drylands and tribal areas of Rajasthan and Gujarat for the collection of wild and

Table 2: Important characters of short-listed germplasm of *Citrullus* utilized for genetic variability component studies under hot arid climate

Genotype	*Days to first male flower (DAS)*	*Node to first male flower*	*Days to first female flower (DAS)*	*Node to first female flower*	*Days to first harvest (DAS)*	*Marketable fruits/ plant (No.)*	*Fruit yield/ plant (kg)*	*Fruit weight (kg)*	*Fruit length (cm)*	*Fruit girth (cm)*
IC-278416 (KCM/BKP-18)	40.69	5.36	53.82	13.27	84.16	1.22	2.17	1.76	22.42	48.06
IC-278417 (KCM/BKP-19)	41.94	5.13	48.29	15.29	84.53	1.55	1.90	1.62	19.16	45.49
IC-315281 (DPY-117)	43.87	5.26	53.33	12.16	85.96	1.06	7.40	6.81	44.60	70.87
IC-315283 (DPY-119)	45.79	2.76	54.22	13.27	84.19	1.13	4.80	4.30	27.02	58.15
IC-315284 (DPY-120)	47.62	5.24	54.48	9.24	88.10	1.17	8.11	2.68	29.57	51.00
IC-315288 (DPY-124)	45.17	4.70	52.08	11.20	88.60	1.45	1.94	1.32	21.28	42.01
IC-315290 (DPY-126)	47.68	4.40	55.12	12.28	95.90	1.66	2.08	1.23	19.53	42.56
IC-315304 (DPY-140)	49.05	6.50	56.18	13.23	98.11	1.33	2.06	1.51	21.62	47.35
IC-315306 (DPY-142)	47.49	5.29	54.49	12.30	91.98	1.15	4.86	4.33	25.98	60.50
IC-315313 (DPY-149)	45.01	5.55	51.05	13.98	82.04	1.34	3.60	2.73	34.19	54.58
IC-315321 (DPY-157)	50.57	7.44	55.06	15.28	85.89	1.03	4.36	4.11	29.05	60.91
IC-315324 (DPY-160)	40.97	4.21	47.02	8.22	80.90	1.75	5.09	2.89	28.24	47.20
IC-315328 (DPY-164)	44.64	6.48	50.86	10.79	85.43	1.27	0.99	0.78	16.11	35.58
IC-430201 (DKS/AHW/18)	40.45	4.53	46.12	9.12	80.62	4.01	16.18	4.17	30.67	62.75
IC-430202 (DKS/AHW/19)	36.16	4.15	44.57	6.18	78.12	4.28	16.44	3.97	35.64	59.20
IC-430208 (DKS/AHW/65)	34.02	3.12	43.77	6.05	76.02	5.45	15.47	2.84	28.12	55.24
Durgapura Meetha	49.10	5.07	63.23	15.45	101.21	1.42	4.81	3.44	24.74	67.43
Sugar Baby	47.24	6.18	55.52	14.15	96.99	1.15	3.19	2.79	24.67	61.02
EC-420977 (Charleston)	47.99	7.12	59.75	11.16	106.01	1.25	6.38	5.05	34.97	54.55
EC-420978 (Mahobobi)	54.17	10.21	67.23	21.34	114.65	1.04	2.72	2.56	19.57	49.90
IC-0590087 (Thar Manak)	34.50	4.42	44.57	10.78	76.98	4.24	17.52	4.26	23.34	58.27
Mean	44.48	5.53	52.90	12.13	88.87	1.90	6.29	3.10	26.69	53.93
CV (%)	1.03	2.09	1.21	2.28	0.78	3.06	3.87	1.98	1.73	1.42
CD (5%)	0.75	0.19	1.05	0.45	1.14	0.09	0.40	0.10	0.76	1.26

Table 3: Important characters of short-listed germplasm of *Citrullus* utilized for genetic variability component studies under hot arid climate

Genotype	*Edible flesh thickness (cm)*	*Non-edible flesh thickness (cm)*	*TSS (^{0} Brix)*	*Vine length (m)*	*Branches/ plant (No.)*	*Number of seeds/fruit*	*Seed test weight (g)*	*Seed length (cm)*	*Seed width (cm)*
IC-278416 (KCM/BKP-18)	11.33	2.05	7.20	2.50	4.12	232.56	7.61	1.13	0.64
IC-278417 (KCM/BKP-19)	12.24	1.52	6.40	2.76	4.17	109.53	8.05	1.05	0.64
IC-315281 (DPY-117)	17.68	2.49	6.12	2.64	5.05	251.16	2.30	0.72	0.43
IC-315283 (DPY-119)	15.47	2.37	8.20	3.13	5.13	63.32	4.52	0.83	0.55
IC-315284 (DPY-120)	16.35	2.78	8.44	3.11	4.05	187.61	7.62	1.26	0.75
IC-315288 (DPY-124)	11.41	1.53	5.14	2.92	5.19	74.26	6.66	1.04	0.65
IC-315290 (DPY-126)	12.47	1.50	10.23	3.18	5.09	94.56	4.11	0.80	0.56
IC-315304 (DPY-140)	12.20	0.74	8.42	3.11	5.05	157.29	4.08	0.95	0.54
IC-315306 (DPY-142)	15.14	2.07	9.11	2.56	4.15	235.73	5.16	0.97	0.64
IC-315313 (DPY-149)	14.55	1.07	10.08	2.56	6.08	135.71	5.42	1.04	0.57
IC-315321 (DPY-157)	15.18	1.52	8.26	3.12	4.13	258.04	4.31	0.95	0.55
IC-315324 (DPY-160)	13.22	1.54	10.43	2.76	5.17	190.64	4.42	0.96	0.54
IC-315328 (DPY-164)	8.15	1.12	6.32	2.89	6.18	64.61	3.52	0.86	0.55
IC-430201 (DKS/AHW/18)	14.40	2.05	8.12	4.48	6.27	319.21	8.32	1.22	0.75
IC-430202 (DKS/AHW/19)	13.43	1.65	8.20	3.69	5.46	384.28	8.50	1.23	0.74
IC-430208 (DKS/AHW/65)	13.22	1.71	8.31	2.75	5.57	418.55	8.59	1.23	0.76
Durgapura Meetha	14.55	2.13	9.11	3.75	5.50	342.12	8.62	1.26	0.83
Sugar Baby	14.94	1.55	9.11	3.73	5.12	112.90	5.06	0.86	0.55
EC-420977 (Charleston)	13.20	2.13	8.06	2.84	5.18	284.51	5.08	0.94	0.52
EC-420978 (Mahobobi)	14.13	1.24	8.51	2.65	4.12	195.14	12.10	1.35	0.85
IC-0590087 (Thar Manak)	16.36	1.91	10.92	3.50	5.39	128.13	7.50	1.25	0.55
Mean	13.79	1.74	8.32	3.08	5.05	201.90	6.26	1.04	0.63
CV (%)	1.73	2.55	1.99	2.96	2.12	1.27	0.61	1.66	0.93
CD (5%)	0.39	0.07	0.27	0.15	0.17	4.23	0.06	0.02	0.01

semi-cultivated germplasm of cucurbits. A rich variability in *mateera*, watermelon, *tinda* and *tumba* was collected, evaluated, and utilized over the years (1994 to 2012) as *Citrullus* genetic resource (254 entries) and at present, 75 germplasm/breeding material is being maintained at ICAR-CIAH, Bikaner (Samadia and Haldhar, 2019).

The arid and semi-arid region of Rajasthan is endowed with a rich diversity in dessert and non-dessert forms of melons and has unique variability patterns in the areas of cultivation. Owing to drought-tolerating capacity, *mateera* is a specific landrace of desert ecosystems. It is grown rainfed in the kharif and its seeds are uniform and *khaki* in color. Other-side, watermelon is grown in a semi-arid region with irrigations during the summer season and seeds are much variable and it is mostly developed through introduced varieties. *Mateera* is widely grown on sand dunes, and following special *Bari* practices (micro-catchments) where about 1 L of water is poured at each seed-sowing point and it is in March month to harvest rainfed crop produce (Samadia and Pareek, 2001).

The existence of diversity in watermelon-type *mateera* is unique in the *Thar* desert, where it appears to have acquired drought-hardy characteristics. During the primary surveys, 178 *mateera* collections were studied and they showed great variability in economic characters *viz*., fruit shape (round, oval, oblong, cylindrical-long), fruit size (0.5–7.5 kg), flesh content, flesh firmness, flesh color (pink, whitish-pink or reddish), TSS (3–12^0 Brix), seed content and seed color. Besides, morphological variations were also recorded for vine length, branches, leaf size, shape, color and coating, flowering, and fruiting at production sites. The performance of two *mateera* lines (AHW-19 and AHW-65) was compared with watermelon cultivars (Arka Manik, Arka Jyoti, MHW-11 and NWM-102) with twelve irrigations and under the prevalent practice in a desert ecosystem. The practice is to add about one litre of water at sowing time and later crop is supported by conserved and rain-water. In this study, watermelon genotypes failed to produce any fruits, whereas *mateera* lines yielded about three fruits per vine. With irrigations, watermelon depicted 8 to 9^0 Brix TSS compared to 7 to 8^0 Brix in *mateera*. However, commercial cultivars were often damaged by cracking. Thus, primary studies revealed the potentiality to develop drought-tolerant varieties from the existing variability to provide better economic returns to the desert farmer (Samadia and Pareek, 1996).

Realizing the importance of multiple-use of *mateera* in the Indian desert and potentialities in its period of fruit availability (April to November), systematic improvement work was taken with the objectives to develop varieties for uniform quality production, including dessert-salad, loiya and high seeds. For this, a wide range of collected germplasm was evaluated and utilized in breeding and conserved at the national gene bank. On evaluation in 1995-96, collected *mateera* germplasm (155 accessions) exhibited enough variations for morphological components of vine, fruit, flesh quality and yield. A wide range was is recorded for important characters such as days to first male flower appearance (24.5–45.2 DAS), days to first female flower appearance (40.2–55.5 DAS), node to first female flower (5.4–18.5), number of fruit-set/plant (3.5–20.85), days to first harvest (72.5–110.5 DAS), number of fruits/plant (0.85–7.45), fruit length (10.32–40.50 cm), fruit girth (25.91–73.54 cm), fruit weight (0.50–8.55 kg), TSS (2.14–12.5º Brix), number of seeds/fruit (155–965), vine length (2.20–6.50 m) and number of branches/plant (3.12–6.45). Much variability is recorded for fruit rind, stripes pattern, flesh color, content and seeds. Both collected and generated material was repeatedly studied for variability parameters and most of the attributes exhibited similar trends under the investigation, and the components of genetic diversity from twenty-one short-listed genotypes are described in Tables 2, 3, 4 and 5.

Analysis of the variance of short-listed germplasm revealed the existence of highly significant genotypic differences for most of the quantitative characters, depicting greater variability in experimental material. Days to the opening of flowers and fruit set are very important attributes for earliness under dryland conditions, and the first male and female flowers ranged from 34.02–54.17 and 43.77–67.23 from sowing, respectively. The node number of the first male and female flower appearance ranged from 3.12–10.21 and 6.05–21.34, respectively. Days to the first fruit harvest range were very high (76.02–114.65 DAS) and important trait for *mateera* and watermelon under arid conditions. The number of marketable fruits ranged from 1.03–5.45, and yield was 0.99–17.52 kg/plant. Wide variations for fruit characters, viz., weight (0.78–6.81 kg), length (16.11–44.60 cm) and girth (35.58–70.87 cm) were recorded among the tested genotypes depicting the greater scope of improvement. Similar trends were also recorded in round melon under hot arid climate (Samadia, 2007).

For PCV, GCV and other variability component studies, two seasons' data of the year 2003 of the short-listed genotypes, including checks, were used. The estimates of GCV and PCV indicated that there is ample scope for improvement in the crop targeted. In general, the estimates of PCV were higher than GCV for all the characters. The GCV, which provides a greater picture of the extent of genetic variability in the diversity, ranged from 11.28% for days to first fruit harvest to 85.23% for fruit yield/plant. The GCV estimates were considerably higher (>30%) for characters such as number of fruits/plant, fruit yield/plant, fruit weight, number of seeds/fruit and seed test weight, whereas it was moderate (>15%) for a node to the first male and female flower opening, fruit length, fruit girth, edible and non-edible flesh thickness, TSS, vine length, seed length and seed weight indicating better scope through selection. A

Table 4: Important characteristics of short-listed germplasm of *Citrullus* utilized for genetic variability component studies at ICAR-CIAH, Bikaner

Genotype	Fruit shape	Skin color	Flesh color	Seed coat color	Seed size	Fruit quality rating	Crop growth rating
IC-278416 (KCM/BKP-18)	Obovate	Light green stripes, clear	Light pink	Yellowish white	Big	C -Poor	Poor
IC-278417 (KCM/BKP-19)	Obovate	Light green stripes, clear	Light pink	Reddish	Big	C	Poor
IC-315281 (DPY-117)	Oblong	Light green stripes, very clear	Red	Light brown	Very small	C	Poor
IC-315283 (DPY-119)	Oval-round	Dark green stripes, not-clear	Pink	Brownish	Small	B - Medium	Medium
IC-315284 (DPY-120)	Obovate	Dark green stripes, clear	Red	Light brown	Big	B	Good
IC-315288 (DPY-124)	Oblong	Light green stripes, clear	Wp	Reddish	Big	C	Poor
IC-315290 (DPY-126)	Round	Light green stripes, clear	Red	Brown	Small	A - Good	Good
IC-315304 (DPY-140)	Round	Dark green stripes, clear	Light pink	Brown	Small	B	Medium
IC-315306 (DPY-142)	Oval-round	Dark green stripes, clear	Red	Brown	Small	A	Poor
IC-315313 (DPY-149)	Oval-round	Dark green stripes, clear	Pink	Brown	Small	B	Good
IC-315321 (DPY-157)	Oval-round	Dark green stripes, clear	Light pink	Brown	Small	C	Poor
IC-315324 (DPY-160)	Round	Dark green stripes, clear	Dark pink	Brown	Small	AA-Very good	Good
IC-315328 (DPY-164)	Round	Dark green stripes, not-clear	Light pink	Brown	Small	C	Poor
IC-430201 (DKS/AHW/18)	Obovate	Dark green stripes, clear	Pink	Brown khaki	Big	B	Good
IC-430202 (DKS/AHW/19)	Obovate	Dark green stripes, clear	Pink	Brown khaki	Big	B	Good
IC-430208 (DKS/AHW/65)	Round	Green stripes, not-clear	Pink	Brown	Big	B	Good
Durgapura Meetha	Round	Light green, non-stripes	Dark pink	Light brown mottled	Big	AA	Good
Sugar Baby	Round	Dark green stripes, non-clear	Red	Light brown	Small	AA	Good
EC-420977 (Charleston)	Oblong-long	Light green, non-stripe	Pink	Black brown	Small	B	Medium
EC-420978 (Mahobobi)	Round	Light green stripes, clear	Light pink	Light brown	Big	C	Medium
IC-0590087 (Thar Manak)	Oblong	Dark green stripes, clear	Red	Blackish brown	Big	AA	Good

close correspondence between PCV and GCV values with respect to characters under study indicated that the testing environment has very little influence on the expression of the attributes. Thus, selection based on phenotype can be effective with an equal probability of success. Ram *et al.*, 2023 also reported the traits having narrow differences among GCV, PCV and broad sense heritability values, suggesting low effect of environment in snowball cauliflower. Very high heritability (broad sense) estimates values were obtained for all the characters in the present study and it suggested that these traits may generally be governed by additive gene action.

The genetic advance as a percent of the mean ranged from 23.22 for days to first harvest to 175.33 for fruit yield/plant. The high value of GA (> 50%) was obtained for the node to the first male and female flower, number of fruits/plant, fruit yield/plant, fruit weight, fruit length, non-edible flesh thickness, number of seeds/fruit and seed test-weight and thus, these traits are governed by additive gene action. High heritability values accompanied by high genetic advance were found for the node to first male and female flower, number of fruits/plant, fruit yield/plant, fruit weight, fruit length, non-edible flesh thickness, number of seeds/fruit and seed test-weight suggested that these traits are predominantly under the control of additive gene action. Hence, simple selection could be effective for the improvement of these traits.

Where: DFM- Days to first male flower (DAS), NMF- Node to first male flower, DFF- Days to first female flower (DAS), NFF- Node to first female flower, DFH- Days to first harvest (DAS), MF/P- Marketable fruits/ plant (No.), FY/P- Fruit yield/plant (kg), FW- Fruit weight (kg), FL- Fruit length (cm), FG- Fruit girth (cm), EFT- Edible flesh thickness (cm), NEF- Non-edible flesh thickness (cm), TSS (^{0} Brix), VL-Vine length (m), B/P- Branches/plant (No.), NS/F- Number of seeds/fruit, STW- Seed test weight (g), SL- Seed length (cm) and SW- Seed width (cm).

High heritability value coupled with low genetic advance (>25%) were obtained for days to the first male and female flower appearance and days to the first harvest were probably due to the non-additive type of gene action and direct selection for these characters will be less effective. The traits such as number of fruits/plant, fruit yield/plant, fruit weight, number of seeds/fruit and seed test-weight possessing high GCV, heritability and genetic gain could effectively be used in selection, as it has been suggested that characters with high heritability coupled with high genetic gain would respond to selection better than those with high heritability and low genetic gain. The high variability and heritability, along with high genetic advance expressed by the above-mentioned traits indicated that the genotypes can be tested in multi-location traits and selected as donors for these characters or used as a parents in the hybridization program.

The magnitude of genotypic correlation coefficients was slightly higher than their corresponding phenotypic correlation coefficients for all the traits, indicating a strong inherent association between various traits under study. The studies indicated that fruit yield/plant had a positive and significant correlation with the number of fruits/plant (0.887), number of seeds/fruit (0.596), vine length (0.503), seed length (0.492), fruit weight (0.491), fruit girth (0.473) and fruit length (0.441), and also with edible flesh thickness (0.398), branches/plant (0.352) and non-edible flesh thickness (0.344). Days to first male flower (-0.713), node to first male flower (-0.485), days to first female flower (-0.601), node to first female flower (-0.626) and days to first harvest (-0.516) had a negative and significant correlation with fruit yield/plant. Negative and significant association of days to the appearance of the male flower (-0.819), days to the appearance of the female flower (-0.710) and days to first harvest (-0.563) with a number of fruits/plant, which clearly indicated that early genotypes bear more number of fruits/plant.

Days to the first harvest had a positive and significant association with days to the first male flower (0.822), days to the first female flower (0.924), nodes to first male flower (0.732) and nodes to the first female flower (0.672) that indicates the mutual association of these characters for their expression. Fruit girth showed a positive and significant correlation with fruit weight (0.854), fruit length (0.685), edible flesh thickness (0.811), non-edible flesh thickness (0.520) and the number of seeds/fruit (0.554). Seed test weight had a positive and significant correlation with seed length (0.923), seed weight (0.890) and the number of seeds/fruit (0.372).

Path analysis (Table 6) revealed a positive direct effect on fruit yield/plant was maximum from the number of fruits/plant (2.088) followed by seed width (1.918), fruit length (1.617), seed length (1.566), days to first harvest (1.312) and node to first female flower (1.290). Similarly, the maximum negative direct effect showed by seed test weight (-3.387) followed by the number of seeds/fruit (-1.606), edible flesh thickness (-1.519), days to first male flower (-0.923), days to first female flower (-0.915) and branches/plant (-0.880) on fruit yield/plant. The number of fruits/plant had a positive effect on fruit yield/plant due to positive indirect effects via days to first male flower (0.750), days to first female flower (0.650), number of seeds/fruit (1.101), seed length (1.045), branches/plant (0.940), vine length (0.878), seed test-weight (0.838) and seed weight/fruit (0.674). Thus, it is suggested that for effective selection for higher yield in *Citrullus*, the number of fruits/plants is an important character. But it may slightly affect the fruit weight and size. Thus, a moderate balance has to be made for a medium number of fruits, fruit weight and size to obtain better results under dryland climate.

Table 5: Genetic variability components for various characters from short-listed *Citrullus* germplasm at ICAR-CIAH, Bikaner

Traits	*Min.*	*Max.*	*Mean*	*CD (5%)*	*ECV (%)*	*GCV (%)*	*PCV (%)*	*h^2 (%) (broad sense)*	*Genetic advance (GA)*	*Genetic gain (5%SI)*
DFM	34.02	54.17	44.48	0.75	1.03	11.80	11.81	99.74	10.80	24.28
NMF	3.12	10.21	5.53	0.19	2.09	26.95	26.98	99.80	3.07	55.47
DFF	43.77	67.23	52.90	1.05	1.21	11.36	11.38	99.62	12.36	23.37
NFF	6.05	21.34	12.13	0.45	2.28	28.38	28.41	99.78	7.08	58.41
DFH	76.02	114.65	88.87	1.14	0.78	11.28	11.29	99.84	20.63	23.22
MF/P	1.03	5.45	1.90	0.09	3.06	69.67	69.69	99.94	2.73	143.47
FY/P	0.99	17.52	6.29	0.40	3.87	85.23	85.26	99.93	11.04	175.53
FW	0.78	6.81	3.10	0.10	1.98	47.89	47.91	99.94	3.06	98.64
FL	16.11	44.60	26.69	0.76	1.73	25.43	25.45	99.85	13.97	52.35
FG	35.58	70.87	53.93	1.26	1.42	16.47	16.49	99.75	18.28	33.89
EFT	8.15	17.68	13.79	0.39	1.73	15.26	15.30	99.57	4.32	31.38
NEF	0.74	2.78	1.74	0.07	2.55	28.61	28.65	99.74	1.02	58.87
TSS	5.14	10.92	8.32	0.27	1.99	17.77	17.81	99.58	3.04	36.54
VL	2.50	4.48	3.08	0.15	2.96	16.30	16.39	98.91	1.02	33.39
B/P	4.05	6.27	5.05	0.17	2.12	13.77	13.83	99.21	1.43	28.27
NS/F	63.32	418.55	201.90	4.23	1.27	52.24	52.25	99.98	217.29	107.62
STW	2.30	12.10	6.26	0.06	0.61	37.51	37.51	99.99	4.84	77.26
SL	0.72	1.35	1.04	0.02	1.66	17.26	17.29	99.69	0.37	35.50
SW	0.43	0.85	0.63	0.01	0.93	17.96	17.97	99.91	0.23	36.98

Table 6: Path analysis (direct and indirect) for various characters in short-listed *Citrullus* germplasm at ICAR-CIAH, Bikaner

CHR	DFM	NMF	DFF	NFF	DFH	MF/P	FW	FL	FG	EFT	NEF	TSS	VL	B/P	NS/F	STW	SL	SW	FY/P (GR)
DFM	-0.923	-0.704	-0.827	-0.675	-0.759	0.756	0.092	0.172	0.052	-0.044	0.114	0.041	0.145	0.358	0.270	0.131	0.230	-0.009	-0.713
NMF	0.326	0.427	0.326	0.332	0.313	-0.250	-0.007	-0.080	-0.036	-0.008	-0.114	-0.045	-0.096	-0.156	-0.091	0.043	-0.012	0.010	-0.485
DFF	-0.820	-0.697	-0.915	-0.704	-0.845	0.650	0.009	0.152	-0.052	-0.073	-0.015	0.026	0.159	0.364	0.097	-0.074	0.048	-0.142	-0.601
NFF	0.943	1.003	0.994	1.290	0.867	-0.834	-0.151	-0.446	0.015	0.104	-0.308	-0.035	-0.282	-0.561	-0.451	0.208	-0.050	0.089	-0.626
DFH	1.079	0.961	1.212	0.882	1.312	-0.739	-0.110	-0.313	-0.069	-0.044	-0.173	0.021	-0.121	-0.411	-0.123	0.182	-0.034	0.221	-0.516
MF/P	-1.711	-1.222	-1.483	-1.350	-1.176	2.088	0.271	0.301	0.370	0.087	0.049	0.426	0.878	0.940	1.101	0.838	1.045	0.674	0.887
FW	0.002	0.000	0.000	0.003	0.002	-0.003	-0.028	-0.023	-0.024	-0.021	-0.017	-0.002	-0.002	-0.000	-0.013	0.004	0.002	0.005	0.491
FL	-0.301	-0.304	-0.268	-0.560	-0.386	0.233	1.315	1.617	1.109	0.994	0.751	0.023	0.062	0.274	0.834	-0.368	-0.200	-0.335	0.441
FG	-0.038	-0.057	0.039	0.008	-0.035	0.120	0.578	0.464	0.677	0.549	0.352	0.135	0.256	0.035	0.375	0.018	0.050	0.038	0.473
EFT	-0.072	0.029	-0.122	-0.123	0.051	-0.063	-1.168	-0.934	-1.232	-1.519	-0.882	-0.558	-0.283	0.315	-0.344	-0.022	-0.114	0.035	0.398
NEF	-0.085	-0.184	0.011	-0.164	-0.091	0.016	0.418	0.320	0.359	0.401	0.690	-0.052	0.092	-0.157	0.197	0.031	0.058	0.064	0.344
TSS	-0.012	-0.030	-0.008	-0.007	0.004	0.058	0.029	0.004	0.057	0.105	-0.021	0.287	0.060	0.030	0.016	0.011	0.048	0.002	0.254
VL	-0.020	-0.029	-0.022	-0.028	-0.012	0.054	0.019	0.005	0.048	0.024	0.017	0.027	0.129	0.056	0.028	0.025	0.032	0.034	0.503
B/P	0.341	0.323	0.351	0.383	0.276	-0.396	-0.021	-0.149	-0.045	0.182	0.201	-0.094	-0.384	-0.880	-0.064	0.142	0.056	0.084	0.352
NS/F	0.470	0.344	0.170	0.562	0.151	-0.847	-0.738	-0.828	-0.890	-0.363	-0.459	-0.094	-0.352	-0.117	-1.606	-0.599	-0.749	-0.755	0.596
STW	0.480	-0.342	-0.274	-0.546	-0.471	-1.359	0.514	0.771	-0.091	-0.050	-0.151	-0.132	-0.662	0.547	-1.263	-3.387	-3.128	-3.017	0.340
SL	-0.390	-0.046	-0.083	-0.060	-0.040	0.784	-0.155	-0.194	0.117	0.118	0.132	0.264	0.391	-0.100	0.730	1.447	1.566	1.341	0.492
SW	0.018	0.045	0.298	0.133	0.324	0.619	-0.376	-0.397	0.108	-0.044	0.178	0.015	0.515	-0.184	0.902	1.708	1.642	1.918	0.262

Table 7: Comparative characters of high-quality fruit-yielding *mateera*- 'Thar Manak' with parents

Character	*Parental varieties*		*Developed variety*
	Mateera AHW-19	*Sugar baby*	*Thar manak*
Days to first female flower (DAS)	44.5	55.2	38.5
Node number to first female flower	7.1	14.2	12.7
Days to first harvest (DAS)	76.5	97.5	75.5
Number of marketable fruits/plant	4.29	1.14	3.45
Marketable fruit yield/plant (kg)	16.54	3.22	12.15
Fruit weight (kg)	3.85	2.83	3.25
Fruit length (cm)	35.5	24.1	22.5
Fruit girth (cm)	58.8	60.2	58.5
Edible flesh thickness (cm)	13.4	15.1	16.8
Non-edible flesh thickness (cm)	1.95	1.51	1.61
TSS (^{0} Brix)	8.12	10.15	10.82
Fruit characters	Oblong, dark green-green clear stripes; No fruit cracking	Round, green to dark green non-stripes rind; Severe fruit cracking	Oblong-round, dark green-green clear stripes on rind; No fruit cracking
Flesh characters	Pink, B-grade	Red, A-grade	Red, A-grade
Seed characters	High seed content, medium-sized and khaki color	High seed content, small-sized and mottled brown	Low seed content, very big sized and blackish

Figure 1: *Mateera* var. AHW-19

Figure 2: *Mateera* var. AHW-65

During characterization, *Citrullus lanatus* germplasm was categorized based on prioritized attributes and promising *mateera* lines viz., AHW-18 (IC-430201), AHW-19 (IC-430202), AHW-65 (IC-430208), AHW-108 (IC-430215), AHW-140 (IC-430225), AHW-RSS-1 (red seeded isolate from germplasm of Churu district) and AHW-BSM-1 (black seeded isolate from AHW-19) was selected for use in the breeding program. Among watermelons, Sugar Baby, Durgapura Meetha and Charleston Local were found to have the potential for flesh firmness and color under arid climates. For the first time, two *mateera* selections *viz.*, AHW-19 and AHW-65 released for immediate gains in 1998 and growers accepted it for uniform harvest under rainfed conditions. The utilization of *Citrullus* germplasm for the breeding program has been described and emphasized that native landraces would be useful under abiotic stressed conditions (Pareek and Samadia, 2002; Samadia *et al*., 2002 and Samadia and More, 2011).

However, two essential traits of commercial watermelon, *i.e.*, eye-appealing flesh quality and sweetness, were not materialized in *mateera* varieties developed by the institute (Figure 1 and 2). Therefore, intensive breeding work was carried out involving AHW-19, AHW-65, Sugar Baby, Durgapura Meetha, Charleston and Mahobobi. First, a large number of progenies were generated using selected parentage in combinations (F_1, F_2, BC_1, BC_2 and bi-parental) and evaluated. Simultaneously, requisite segregates isolated from F_2 to develop individual plant progeny and selfing precedes selection for generation advancement. Four prioritized traits such as flesh quality, earliness, tolerance to cracking and yield behavior under high temperature

Figure 3: *Mateera* var. Thar Manak

and abiotic stressed situations, were kept to screen the progenies.

The desirable progenies and their derivates were advanced over the years and evaluated both in the rainy and summer of 2000 to 2004. Fruit quality, fruiting behavior, reaction to cracking, insects and diseases were taken into consideration to screen the developed progenies. In F_6 generation, a few progenies of the cross combination of AHW-19 x Sugar Baby exhibited desirable trends for fruit flesh (color, firmness, content and TSS) and yield. After assessing fruit quality components among $F_{6/a}$ family, four blocks (F_6/a/3, F_6/a/7, F_6/a/9 and F_6/a/10) were developed and advanced for uniformity. On evaluation, these showed desirable trends for earliness, the number of marketable fruits/plants, fruit size, shape and flesh quality.

The fruit quality and yield components of advanced family F_6/a/10 were much superior and highly acceptable, depicting internally as good Sugar Baby and rind characters as *mateera* (Table 7). This was further advanced in isolation and open-pollinated progeny named F_6/a Thar Manak (Figure 3) and released in 2007. The developed variety is devoid of cracking and suitable for spring-summer and rainy-season cultivation under hot arid climates. Thus, the strategic research work in *Citrullus* was found effective in the conservation and utilization of native germplasm and also the development of breeding material for further benefits.

Conclusion

Breeding for improvement in fruit quality and productivity is a continuous nature of work to ensure genotypes for cultivation under high temperature, drought, and low rain and suitability to the organic or prolonged period of harvest. Because the present watermelon genotypes exhibit susceptibility to viruses and abiotic stresses. Based on long-term studies in germplasm utilization at ICAR-CIAH, Bikaner, future strategies were carved out for in-depth understanding and strengthening the activities: -

1. Utilization of the regional and national genetic resources of *mateera*/watermelon to breed marketable quality fruit-yielding genotypes for cultivation under high temperatures and varying production situations such as low-input, organic, rainfed, surface-covering protective technique as a mechanism of escaping severity of winter for short-spell and vertical harvesting, and
2. Utilization of Indigenous *mateera* germplasm to develop trait-specific/value-added genotypes such as *loiya* and seed-kernels for production under rainfed and abiotic stresses conditions, and its promotion through seed-chain owing to their regional preferences.

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