



Snap melon (a non-dessert form of *Cucumis melo*) germplasm variability and utilization for varietal development under hot arid climate: An output analysis

DK Samadia¹ and H Ram^{1#}

Summary

The significance of genetic diversity is widely accepted for making rapid crop improvement, and therefore, by utilizing the regional variability, we can develop genotypes of greater economic value and cultivation under the defined environmental situations. Kaakdia, phoot or snap melon (a non-dessert form of *Cucumis melo* var. *momordica*) is a much-relished cucurbit of rural India. The mature and ripe fruits are used extensively for vegetable culinary and garnishing salad. Still, it is underutilized and grown mixed or self-sown crop of traditional farming systems. Vine plants are short-duration (95-125 days) and bear variable-sized fruits (0.182–3.258 kg) that are edible at maturity, specific in taste with ripening and cracks. Semi-domesticated landraces and local cultivars of *Cucumis* melons diversity is found in abundance under the dry-land conditions of north-western parts of India. This culti-group is highly cross-pollinated and the lack of standard genotypes in snap melon resulted in mixed quality fruits and thus, low market preferences. Intensive surveys and explorations were conducted in the diverse climatic areas of Rajasthan from the year 1994 to 2001, and about 125 accessions of kaakdia type germplasm were collected. The germplasm was evaluated repeatedly, and purified, characterized, and utilized over the period (1994 to 2012) for the crop improvement work at Bikaner. The short-listed genotypes (65) were categorized based on plant growth and size, shape, quality, and utility of fruits, and maintained for conservation of the native diversity. Based on horticultural traits, genotypes AHS-6, AHS-8, AHS-10, AHS-14, AHS-19, AHS-23, AHS-42, AHS-46, AHS-50, AHS-53, AHS-54, AHS-56, AHS-57, AHS-63, AHS-64, AHS-70, AHS-81, AHS-82, DPY-216, and DKS/AHS/2011-2 were found to be potential. With a strategic work-plan, excellent fruit quality, early harvesting (67–70 DAS), high yielding (222–241 q/ha), and abiotic stress-tolerating genotypes, viz., AHS-10 and AHS-82, were developed for summer and rainy season crop cultivation. Now, ICAR-CIAH is first in the standardization of snap melon technology and recommended for harvesting of uniform quality fruits (0.876–0.942 kg weight) and fresh market availability from March to November with the defined production practices. In addition, commercial cultivation of the variety Thar Mahak (AHS-82) is beneficial and cost-efficient to the growers as climate climate-resilient crop-commodity and horti-preneurship.

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Introduction

The cucurbitaceous crop-commodity is forming a big vegetable group and is generally used in cooking, dessert-salad or processed. The Indian sub-continent is the primary, secondary or an area of regional diversity for a large number of cucurbits, and in particular, the north-western parts of India possess a wide range of variability in melons and gourds. The arid and semi-arid areas of Rajasthan and districts of nearby states are also endowed with rich diversity in *Cucumis* and *Citrullus* groups with drought-tolerating attributes. The *Cucumis melo* (L.) is polymorphic and recorded number of botanical sub-species and horticultural varieties and further, new forms have evolved due to the prolonged period of cultivation. The dessert and non-dessert

Cucumis melo forms encompass a wide variability for the sweet and non-sweet fruits, and landraces found in India belong to the latter category, and in which a large array of varieties and local types are reported (Chandra 1995; Pareek et al. 1999; Samadia 2003; More et al. 2008; Samadia & Haldhar 2020). Phoot or snap melon (*Cucumis melo* var. *momordica* Duthie and Fullar) is most popular non-dessert type, and widespread distribution do exist in the dry-lands. Its germplasm tolerates high temperature (42-45 °C) and carries resistance towards powdery mildew, downy mildew and cucumber green mottle mosaic virus (CGMMV). Another peculiar type, kachri, mat-kaachr or kachri melon (*Cucumis melo* var. *callosus*, *agrestis*) is wild, weedy and semi-domesticated, and found abundantly in arid areas of Rajasthan. Small-sized fruits are indehiscent and edible only after attaining maturity. This culti-group is

¹ICAR-Central Institute for Arid Horticulture, Bikaner, Rajasthan - 334006, India

#Corresponding author: H Ram, E-mail: hramdhanari@gmail.com

drought tolerating and the germplasm carries resistance to CGMMV and fruit-fly. Besides, there are cucumber-like forms and their tender or unripe fruits with crisp flesh used extensively for making vegetable salad and culinary uses such as tar-kakri, long melon (*Cucumis melo* var. *utilissimus*, *flexuosus*), arya-kakdi (*Cucumis melo* var. *acidulus*, *alwarensis*), and aara-kakri or wangaa (*Cucumis melo* var. *melo* or common). These non-sweet forms have wide eco-adaptability and economically much potential because they are consciously cultivated in India (Pareek et al. 1999; Samadia & Pareek 1999; Samadia & Pareek 2000; Dwivedi et al. 2003; Samadia & Haldhar 2018b).

The most measurable out-put of the long-term vegetable crop-plant genetic resource research at CIAH, Bikaner, from year 1994 to 2024 is the collection, augmentation, evaluation, and utilization of the *Cucumis* diversity (825) of north-western parts of India. For the work-plan, germplasm collected during the year 1994 to 2001 by CIAH and NBPGR (RS), Jodhpur, were enrolled first at Bikaner as basic material, and seed enhancement was done. On evaluation, the germplasm was categorized as kachri (325), mat-kaachr (105), kaakdia (125), muskmelon (74), tar-kakri, arya-kakdi, aara-kakri or wangaa (32), and intermediates or recombinants (195) of *Cucumis* melons. In addition, cucumber landraces *Cucumis sativus* (12) and the wild relatives *C. hardwickii* (11), *C. prophaterum* (2), and *C. trigonus* (1) were also collected from tribal dominating sub-humid areas of Rajasthan but the germplasm did not perform well for detailed study under a hot arid climate. The evaluation of a wide-range of the native germplasm of *Cucumis* melons under the hot arid environment and their systematic utilization at CIAH, Bikaner resulted into the stabilization of breeding lines in specific forms. Further, characterization of stable material of the targeted culti-group was done, and selected lines were studied over the seasons for economic potential and varietal recognition. The genotypes of commercial significance were described and designated as kachri (AHK-119, INGR-98013), mat-kaachr (AHK-200, INGR-98014), snap melon (ASH-10, INGR-98015 and AHS-82, INGR-98016), arya-kakdi (AHC-2, INGR-98017), aara or salad-kakdi (AHC-13, INGR-98018), and tar-kakri (AHC-1). These non-sweet *Cucumis* phenotypes are specific to the fruits, quality, utility and viability for the horticultural promotion as variety and two-season cultivation under arid conditions (Samadia 2003; Samadia 2007; Samadia 2018a). Snap melon is the most prospective cucurbit vegetable for dry-lands, and the non-availability of uniform quality and better fruit-yielding genotypes suited to production sites of hot arid region was the prime limiting factor for its systematic cultivation. Therefore, targeted work was done to improve multiple stress-tolerant native germplasm for developing varieties of desirable fruit quality attributes. The most promising varieties were tested with varying production situations for marketable fruit yield potential and climate resilience. Snap melon technology was standardized. The conclusions of the results of the strategic research programme are summarised in this paper.

Materials and Methods

Physiography and agro-climate

Geographically, Rajasthan (23° 3'–30° 12' N and 69° 3'–78° 17' E) is the largest state in India and 40 % area under hot arid (19.6 million hectares) with desert ecology. The remaining area of the state is semi-arid plains and undulating dry-lands and also hilly and tribal lands with sub-humid as the climatic variability. Here, rainfall varies from 150 to 550 mm/annum and is highly erratic (Samadia, 2016). Germplasm and breeding material of kaakdia and kakdi culti-groups were evaluated at the experimental farm of ICAR-CIAH, Beechwal, Bikaner (28° 6' N latitude and 73° 2' E longitude, and altitude 223 m), and it is located in the Thar desert of India. To assess the genetic variability and genotype performance, experiments were conducted over the seasons and years with normal dates of crop sowing i.e., onset of monsoon rains in July and mid-February, with limited irrigations.

Germplasm collection

Realizing the magnitude of native diversity of *Cucumis* melons in the north-western parts of India, intensive surveys, explorations, and short-trips were conducted from 1994 to 2001. It was performed in a phased manner, both institutional and collaborative, and also under the mission mode of NATP on sustainable management of plant biodiversity by ICAR-CIAH, Bikaner, and NBPGR (RS), Jodhpur. Kaakdia and kakdi germplasm were collected from a large geographical area of the arid and semi-arid climate, and also agro-fields of the tribal belt of Rajasthan. The passport information and basic seeds of germplasm deposited to NBPGR, New Delhi, and IC numbers were obtained by the collecting institute.

Germplasm evaluation and utilization

The collected kaakdia and kakdi melon diversity was assembled at ICAR-CIAH, Bikaner, for seed enhancement of germplasm, and evaluated in the phases from 1995 to 2001 and altogether during 2002. The minimal descriptor of 35 attributes was defined for observations on plant growth, flowering, fruit, and seed components of genotypes. Based on the marketability of fruits at tender, maturity or ripen stages, the accessions (155) were grouped into the four categories (kaakdia, tar-kakri, arya-kakdi, and aara, wangaa or salad kakdi) using the preliminary evaluation data. Specific traits such as stages of utility of fruits (very tender, pre-mature, mature and ripen); fruit size at marketable stages and maturity; fruit skin, colour and thickness; flesh colour, thickness and seed cavity; sweetness, bitterness and taste of fruits; bearing behavior, number of fruits/plant and yield patterns were prioritized for characterization of forms.

On the basis of prioritized characters, culti-group germplasm was separated for repeated evaluation and further purified for uniformity and improvement under heat heat-stressed environment. The selected lines were assessed with varying seasons to understand the potential for marketable quality, fruit yield, suitability and viability for commercial cultivation. Thus, each

germplasm and breeding line was assessed at least four times as the rainy and summer seasons crop. For evaluation, a single-row plot (25 m length x 02 m width) was kept standard throughout the experimental trials and fifty plants were maintained/genotype. With the start of flowering, twelve plants were tagged in each genotype, and four groups were made for recording the observations. A wide range of data was generated and it was including seasons and production situations of the years 1994-1999, 2000-2004, 2008-2012, and 2013-2016 at ICAR-CIAH, Bikaner. Means of the two seasons' data of short-listed germplasm and selected genotypes were used for assessment of variability component, and means of four-season crop-genotypes data were used for performance study. The promising selections were compared with the best preferred genotype of fruit quality under varying production situations. Since marketable quality, size, number of fruits/ plant, and tolerance to the abiotic stresses of the hot arid climate were the innermost targets for melon breeding, and therefore, long-term data were used with standard procedures to conclude the research work for varietal identification and technology development.

Results and Discussions

Cucumis culti-group diversity and scope

The systematic vegetable cultivation in the farmlands of the *Thar* desert of India is very negligible, and it is uncertain. Limited vegetable crop choices with seasons, unavailability of desirable genotypes in the native crop-plants, lack of appropriate production technologies and the extremeness of environmental conditions are the primary factors that restrict quality harvest from the requisite commodity in hot arid regions. Even then, the unique diversity of non-dessert forms of *Cucumis* species is found in abundance by means of the conventional farming of dry lands. Therefore, there is a particular need to utilize and maintain the regional gene-pool of *Cucumis melo* having the drought hardy characteristics for breeding varieties of multiple-use trait sources as concerned with climate change and food security (Pareek et al. 1999; Dwivedi et al. 2003; Samadia 2016; Samadia 2018a; Samadia & Haldhar 2018; Samadia & Haldhar 2020).

The non-dessert culti-group of *Cucumis melo* is the most advantageous commodity owing to the multiple utility of fruits and also considered it as the rescue vegetables of rural India. The kachri, mat-kaachr, kaakdia, tar-kakri, arya-kakdi, aara-kakri, wangaa, dosakay, budam-kay, vellarikakai and many-more are the well recognized non-dessert variety of *Cucumis melo* and ensuring nutrition rich food to the local inhabitants under diverse climatic situations. For collection of culti-group diversity, intensive surveys, explorations and short-trips were organized during the year 1994 to 2004 in the targeted areas of Rajasthan and districts of nearby states. The kaakdia and kakdi forms diversity was explored from the 22 districts and germplasm were sampled from a wide-range of climatic variability pockets (about 525 production sites) with sandy desert landscape to the heavy soil farm-lands and variable land-use systems. Open-pollinated fruits were collected both biased and random for making population samples (about 155

accessions) during the collection period. Passport data and short-notes were compiled to generate the basic information on specific-types, diversity pockets, fruit variability pattern, usable stages of fruits, plant growth behavior and cultivation practices adopted at the production sites. The intensive surveys studies in the state of Rajasthan and boundaries districts of nearby states (Gujarat, Haryana, Punjab and Madhya Pradesh) clearly demonstrated that the *Cucumis* species diversity is eco-adaptive and distribution is specific to climate conditions of the region, season and traditional farming practices. The kachri, mat-kaachr and snap melon culti-group is pre-dominantly found in the sand-dunes landscape and rainfed farm-lands of hot arid areas. In addition, phoot, kaachra, daangra or snap melon is also found during the kharif in the rainfed farm-lands of semi-arid areas with sub-humid climate. The kakdi culti-group distribution is very specific to the season (summer and irrigated) and areas of the traditional cultivation such as tar-kakri, long melon (Jaipur, Alwar, Tonk, Kota, Ajmer and nearby), arya-kakdi (Alwar, Bharatpur, Rewari, Hissar and nearby) and aara-kakri / wangaa (Sikar, Jhujhanu, Jaipur, Tonk / Hissar, Abohar, Ganganagar, and nearby areas of districts) with moderate climate. The *Cucumis* species germplasm availability in the explored area was distinct with ecological and agronomic patterns and specific culti-group accessibility is also recorded in respect to locations of western, northern, eastern, southern and central region of Rajasthan state and thus, enough opportunity is realized to understand the eco-type sources (Samadia & Haldhar 2018; Samadia et al. 2024).

First of all, the collections of ICAR-CIAH, Bikaner and NBPGR (RS) were assembled and enrolled at Bikaner, and seed enhancement was done during the preliminary evaluation period. Based on the prioritized traits, crop-germplasm were categorized, and then purified, characterized and utilized in selection breeding. With the defined objectives, crop improvement of targeted culti-group work was done involving the native landraces and semi-domesticated germplasm and a total 225 genotypes of kaakdia and kakdi melons (basic germplasm and generated lines) were studied from the year 1994 to 2014 at Bikaner. Presently, 75 germplasm of kaakdia and kakdi forma is being maintained for the conservation of native diversity and breeding uses at ICAR-CIAH, Bikaner. Snap melon is much accepted cucurbit and tremendous scope is realized for year-round fruits and cost-efficient production under resource constraints farming. Prior to year 1994, non-availability of standard genotypes that could produce the uniform quality fruits was the chief constraint and thus, restricting snap melon promotion as the vegetable crop. Therefore, targeted research was done with the objective to utilize and improve the native germplasm for developing varieties of desirable quality and marketable fruit yield under dry-land climate. The short-listed selections studied repeatedly for the marketable quality fruit yield potential and seasonal performances with the varying situations. The promising varieties were tested with diverse production environment to standardize climate resilience snap melon technology

and recommendations for commercialization (Samadia 2003; Samadia et al. 2005).

Preliminary evaluation

Prior to the identification of non-dessert melon varieties at ICAR-CIAH, Bikaner, it is documented that the farming community used to collect the kaakdia and kakdi fruits from the mixed cropping and traditional (*baaries*) farm-lands owing to the food and market values. In addition, there was no standard genotype and promotional thought on these native landraces and thus, the marketable fruit quality was un-certain and much variable in sizes within eco-type as popular viz., kaakdia, arya-kakdi, aara-kakdi and cucumber types (sawanariya, chikan-kakdi, balam-kakdi). Our primary studies accomplished that the kaakdia, kaachra, phoot, phoot-kakdi, daangra or snap melon is non-dessert form of *Cucumis melo* var. *momordica* Roxb. (Duthie and Fuller), $2n=24$ and its physiological mature and ripen fruits are marketable. The tar-kakri, serpent or long melon (*Cucumis melo* var. *utilissimus*, *flexuosus*) and arya-kakdi, arya melon (*Cucumis melo* var. *acidulus*, *alwarensis*) are monoecious, prolific bearing during the summers and their very tender and immature fruits with crisp-flesh used for garnishing vegetable salad and cooking. The aara-kakri or wangaa (*Cucumis melo* var. *melo* or common) is andro-monoecious in sex-form and their tender and pre-mature fruits used for vegetable salad and culinary. With this background, systematic research work was stream-lined to develop desirable varieties in the native eco-types so that it can be promoted as commercial vegetable crop for the dry-land farming.

In our survey studies, snap melon germplasm depicted the drought tolerating characteristic, bitterness in immature stages of fruits and ripen fruits recorded more economic usefulness with the inhabitants of arid region. Kaakdia or snap melon is found naturally during the kharif season in the wide-spread farm-lands of *Thar* desert and in particular to the mixed cropping of the sand-dunes landscape and traditional farming especially in the districts of Nagour, Churu, Bikaner, Jodhpur, Barmer and Jaisalmer. In tribal dominating sub-humid areas of Rajasthan and nearby states districts, both mature and fully ripen fruits used, and much varies for quality characters in comparison to the germplasm of desert ecology. Snap melon vines are seasonal, annual, prostrate, much branched and scattered in the field either self-sown or seeds mixed with rainfed farming. Snap melon fruits were very variable in shape (cylindrical-long, oblong, oval-round, round-flat, spindle), size (0.275 - 5.125 kg weight and 11 - 39 cm length) and taste (sour-sweet, moderate sweet and taste-less). Fruit skin smooth, blotches irregular, longitudinal lines and pale-white, yellow to orange colour with ripening. Fruit seed cavity is small to very large with many seeds. The edible flesh is white to pale yellow colour, very thin to thick pulp of soft to hard texture and 2.5–6.2^o Brix TSS. Ripen fruits cracks and gives a specific kind of odour. The wide variation in fruits and poor yield is primarily due to use of heterozygous seed material and cross-pollination within *Cucumis* melons.

The regular surveys and explorations for the *Cucumis* spp. germplasm by ICAR-CIAH, Bikaner (Earlier ICAR-NRCAH) and ICAR-NBPGR (RS) from year 1994 to 2004 resulted to collection of kaakdia and kakdi accessions (155) and these were categorized for culti-group studies during the preliminary evaluation under hot arid climate at Bikaner. The evaluated snap melon germplasm (125) recorded enough variability with respect to growth, flowering and fruiting behavior and fruit quality attributes. Besides, a good number of accessions exhibited traits of biotic and abiotic stress tolerant. On repeated evaluation, a wide-range of variations were recorded in the characters of horticultural significance such as days to opening of first male flower (24.7 - 39.1 DAS), node to appearance of first male flower (2.7 - 8.6), days to opening of first female flower (29.4 - 44.4 DAS), node to appearance of first female flower (3.1 - 13.8), days to first harvest of marketable fruits (56.4 - 75.3 DAS), number of fruits/plant harvested (2.2 - 8.4), vine length (1.50 - 2.83 m), number of branches/plant (4.5 - 10.5), fruit weight (0.250 - 2.750 kg), fruit length (10.1 - 36.0 cm), fruit diameter (5.92 - 12.24 cm), fruit cavity (3.20 - 8.70 cm) and flesh thickness (1.21 - 3.22 cm). Sufficient variability recorded in context to the fruit size (very small to extra large), shape (cylindrical-long, oblong, round, oval-flat), skin colour (whitish yellow to yellowish orange), flesh colour (whitish to whitish pink to yellowish orange), taste (sour-sweet, moderate sweet and taste-less) and seed content (few to abundant) and thus, much scope is realized for horticultural harnessing. During the course of preliminary evaluation of basic germplasm of snap melon, seasonal data were analyzed for genetic variability and correlations studies so that most desirable traits can be prioritized for purification. In this context, days to first female flower opening and fruit harvest, fruit weight, number of fruits/plant recorded their significant role in yield/plant. Thus, after insuring the marketable fruit quality of the specific germplasm and objectivity of produce, the evaluated genotypes can be short-listed based on the most prioritized traits as defined for purification and obtaining uniformity in snap melon.

Breeding for varietal development

To fulfill the objectives of varietal development in kaakdia and kakdi melons, the selected germplasm and generated lines were purified initially for two to four generations and repeatedly evaluated using the parameters on growth, flowering, fruiting and marketable fruit quality including utility, size and skin colour. Promising selections with the scope of two seasons and extended period of harvest were further advanced for stability of the material and characterized. Four season's data of 25 horticultural significant characters from the 22 selected lines were used for comparative performance studies. In addition, the most prioritized traits such as marketable fruit quality, earliness, number of fruits/plant and yield were also taken into the consideration during the assessment of uniformity and selection of superior genotypes. At field level, very few promising lines showed the minimal fruit-fly infestation, and tendency of tolerance towards

drought (dry-spells of about 15 days during August–September) and high temperature (42–46° C for 6–8 hours of day during April–May) situations of hot arid climate and therefore, purified with economic traits and advanced for evaluation.

Out of 125 preliminary evaluated snap melon accessions, 74 germplasm were advanced based on growth, flowering, fruiting, fruit quality and yield component characters under the rainfed conditions of year 1996. During summer and rainy season of 1997 and 1998, twenty-two lines were found potential and, thus further evaluated repeatedly for the priority traits of growth, maturity, quality and yield. In addition, characters of fruit size, shape, skin colour, flesh colour, thickness, texture and taste, and field level tolerance to fruit-fly, high temperature and drought situations were also taken into considerations during the advancement. The genotype AHS-57-1 (24.4 DAS) which is closely followed by AHS-50-1 (24.7 DAS) depicted earliness for male flower opening. The female flower opening was the earliest in genotype AHS-64-1 (29.6 DAS) followed by AHS-50-1 (29.8 DAS) and it was late in AHS-8-1 (44.1 DAS). Maximum number of branches/plant was recorded in line AHS-70-1 (9.4) followed by AHS-10-1 (8.6). Vine length was highest in line AHS-70-1 (2.83 m) and shortest in AHS-8-1 (1.51 m). The maximum number of fruit-set/plant was in AHS-70-1 (15.1). However, maximum number of harvested fruits/plant (6.2) was in genotype AHS-14-1, AHS-54-1, AHS-64-1 and AHS-70-1. The highest mean fruit weight was recorded in AHS-50-1 (1.61 kg) followed by 1.52 kg (AHS-64-1). The highest fruit length (30.1 cm) was in line AHS-54-1 while maximum fruit diameter was in AHS-14-1 (11.84 cm). Fruit cavity was the widest in line AHS-10-1 (7.12 cm). The maximum flesh thickness was recorded in AHS-54-1 (2.57 cm) followed by AHS-64-1 (2.49 cm). Based on four seasons of genotype evaluation, fruit quality and mean data of prioritized traits, purified lines namely AHS-6-1, AHS-10-1, AHS-14-1, AHS-19-1, AHS-50-1, AHS-54-1, AHS-64-1 and AHS-82-1 were most promising and further advanced for uniformity of material. With four generation of purification, 19 selected lines were studied for uniformity of fruit quality and yield component characters. The mean data of three seasons of evaluation revealed that the genotypes were very-much variable with regards to vine growth, maturity, number of fruits/plant, fruit size, edible flesh, pulp taste and TSS. On average of seasons, the genotype AHS-10-4-1 (77.8 DAS) closely followed by AHS-82-4-1 (78.3 DAS) exhibited the earliness for marketable fruit harvesting. The maximum number of marketable fruits/plant (6.3) was recorded highest in AHS-82-4-1 followed by AHS-10-4-1 (6.2). The heaviest weight fruit was in AHS-50-4-1 (1.62 kg). Based on marketable fruit quality preferences and yield rating, genotype AHS-82-4-1, AHS-10-4-1, AHS-50-4-1, AHS-6-4-1, AHS-54-4-1 and AHS-19-4-1 were found potential for performance trials.

Mean while, further selected 18 genotypes were tested for yield potentials with the varying production situations viz., rainfed kharif and summer season under limited irrigations. Maximum fruit yield (260.2 q/ha) was

recorded in genotype AHS-82-b followed by AHS-82-a (245.7 q/ha) and AHS-10-b (245.4 q/ha). In three high yielding genotypes, numbers of marketable fruits/plant were in the maximum range of 5.64 - 6.12 and acceptability of fruits was very high (average 900 g weight). Based on over the seasons performance studies and varietal trials, the ranked genotype AHS-82-b (225–248 & av. 239.2 q/ha) and AHS-10-b (202–222 & av. 216.5 q/ha) were compared with the best preferable fruit quality genotype AHS-6-a (137–159 & av. 143.4 q/ha). Both the out yielded genotypes possessing best attributes for fruit uniformity, quality and taste, and crop growth traits for cultivation under the heat stressed and dry-land conditions. Both the genotypes depicted field level tolerance towards the normal drought (dry-spells of about 15 days during kharif) and least fruit-fly infestation (<12 %) under hot arid climate. The excellent in fruit quality, high marketable fruit yielding, early harvesting and abiotic stresses tolerating kaakdia varieties namely AHS-10 and AHS-82 were developed and recommended as the open-pollinated genotypes of snap melon for commercial farming. With varying production situations and seasonal means, first harvesting of the ripen fruits after sowing was the earliest in AHS-82 (67.45 days) followed AHS-10 (68.24 days). The average yield of variety AHS-82 is 241.5 q/ha, and a vine bears 5.91 marketable fruits (4.67 kg/plant). The average yield of variety AHS-10 is 222.5 q/ha, and a vine bears 5.62 marketable fruits (4.37 kg/plant). Both the varieties are multiple-stresses tolerating and thus, sowing can be done during February–March and June–July months to harvest summer and rainy season crops under the resource constraints arid environment, respectively (Samadia & Pareek 1999; Pareek & Samadia 2002; Samadia et al. 2005; Haldhar et al. 2017).

Description of developed varieties

Kaakdia-AHS-10: It is a selection from the native snap melon germplasm of western districts of arid areas of Rajasthan and recommended for uniform quality fruit bearing and higher yield under dry-lands. Opening of first male and female flower starts at 25–28 days and 35–39 days after sowing, respectively. First harvesting of ripen fruits starts at 65–70 days and it is continued to 110 days of sowing. Fruits are oblong, medium sized and 0.853–0.942 kg weight, 17–20 cm length and 7.74 – 10.51 cm diameter. Edible flesh thickness of fruits is 2.1–2.6 cm and cavity 5.5–6.1 cm wide. The whitish-pink colour flesh is sweet in taste, specific-flavor and TSS is 4.16–5.27° Brix. The vine plants are medium in growth habit with 2.5 m length and 8.5 branches. On an average, it bears 4.27–5.92 marketable fruits/plant and 215–230 q/ha yield.

Kaakdia-AHS-82 (Thar Mahak): It is a selection from the native snap melon germplasm of western districts of arid areas of Rajasthan and recommended for uniform, early bearing and higher fruit yield under dry-lands. Opening of first male and female flower starts at 25–29 and 34–41 days from sowing, respectively. First harvesting of ripen fruits starts at 66–72 days and it continues to 115 days of sowing. Ripen fruits are attractive, oblong, medium sized and 0.843–0.998 kg weight, 21–24 cm length and 8.85–9.72 cm diameter.

Edible flesh thickness of fruits is 2.1–2.4 cm and cavity 5.4– 6.0 cm wide. The light pink colour edible flesh is very sweet in taste, specific-flavor and TSS is 4.35–4.92 °Brix. Plants are moderate in growth habit with average vine length of 2.25 m and 6.5 branches. On an average, it bears 4.53–6.46 marketable fruits/plant and yield is 234–248 q/ha.

Arya-kakdi-AHC-2: It is a selection for tender fruits (salad-kakdi) and recommended for unique quality of fruits and higher yield under high temperature conditions. Botanically, this variety is developed from arya melon (*Cucumis melo* var. *acidulus*, *alwarensis*) germplasm and that was collected from the north-eastern districts of semi-arid areas of Rajasthan. It is early in tender fruit harvesting and bearing uniform long-slender fruits of the specific quality at immature stages for vegetable salad or making raayta's and culinary uses. The tender fruits are attractive in shape, straight, solid, medium-long and light-green colour skin without furrows. Opening of first male and female flower starts at 32.5 and 37.6 days after sowing, and first fruit at 6.45 nodal position and 29.22 fruit-sets/plant. Harvesting of tender fruits for vegetable salad purposes is done at 8–12 days after pollination. Both tender and pre-mature fruits are harvested for multiple-uses starting from 47–55 days and picking continues to 105 days of crop sown. Immature fruits weighing 275–300 g is best for quality salad and slicing and at this size it is 30–35 cm length and 3.0–3.5 cm diameter. The flesh is crisp, solid, 1.4–1.5 cm thick and cavity is 1.5–1.6 cm wide. Plants are vigorous in growth habit with average vine length of 2.27 m and 6.91 branches. On average, a vine bears 12–15 tender fruits and recorded 4.15 kg marketable harvest and yield potential is 175–202 q/ha with varying production situations and seasons under dry-lands.

Salad-kakdi-AHC-13: It is a selection for very tender fruits (salad-kakdi) and recommended for unique quality fruits and higher yield under high temperature conditions. Botanically, this variety is developed from non-sweet / common melon (*Cucumis melo* var. *melo*) germplasm and that was collected from the north-eastern districts of semi-arid areas of Rajasthan. It is very early in flowering (andro-monoecious) and highly productive variety with profuse hermaphrodite flower and fruit setting. For making salad or slicing, the tender fruits are harvested at very early stage of growth (3–6 days after pollination) and the immature fruits used for making raayta's or vegetable culinary. Opening of first male and female flower starts at 30.1 and 35.6 days after sowing, and first fruit at 6.1 nodal position and 35.21 fruit-sets/plant. The first fruit harvesting starts at 45–50 days and it continues to 110 days of crop sown. About 20–25 tender fruits are harvested/vine and regular picking results into higher yields of A-grade fruits. The tender fruits weighing 75–105 g are best for salad making and this stage size is 5.5–7.2 cm length and 4.4–5.1 cm diameter. The flesh is cucumber-taste, crispy, juicy, 1.14 cm thick and cavity is 1.8–1.9 cm wide. Plants are vigorous in growth habit with average vine length of 2.12 m and 6.72 branches. On average, a vine bears 2.15

kg tender fruits and yield potential is 85–125 q/ha with varying seasons and production situations.

Tar-kakdi-AHC-1: It is a selection for tender fruits (salad-kakdi) and recommended for its known fruit quality and higher yield under high temperature conditions. Botanically, this variety is developed from serpent or long melon (*Cucumis melo* var. *utilissimus*) germplasm and that was collected from the central-eastern districts of semi-arid areas of Rajasthan. It is early in tender fruit harvesting and bearing uniform long-slender fruits of vegetable salad quality at immature stages or making raayta's and culinary uses. The tender fruits are attractive in shape, slightly curved, soft and light-green colour skin with furrows. Opening of first male and female flower starts at 39.4 and 48.5 days after sowing, and first fruit at 6.85 nodal position and 18.15 fruit-sets/plant. Harvesting of tender fruits for vegetable salad purposes is done at 7–11 days after pollination. Both tender and moderate-mature fruits can be harvested for multiple-uses starting from 58–62 days and picking continues to 115 days of crop sown. Immature fruits weighing 146–187 g are best for quality salad and slicing and at this size it is 27–29 cm length and 2.45–3.11 cm diameter. The flesh is crisp, soft, 0.76–1.09 cm thick and cavity is 1.14–1.42 cm wide. Plants are moderate in growth habit with average vine length of 2.15 m and 5.76 branches. On average, a vine bears 11–13 tender fruits and recorded 1.75 kg marketable harvest and yield is 98–105 q/ha with varying production situations and seasons under dry-land conditions.

Genotype maintenance and variability studies

Snap melon germplasm collection, augmentation, evaluation and maintenance is curator's responsibility so that the native crop diversity can be conserved and utilized for social benefits. The short-listed germplasm and selected generated lines seed of the research programme was used to develop diversity samples (65 genotypes) and stored for the further studies. The seed was packed in the gene-bank standard poly-bags and stored in deep-freeze (–20° C) facilities at Germplasm Conservation Laboratory of CIAH, Bikaner. For random monitoring, *Cucumis* spp. germplasm samples stored in refrigerator and deep-freeze conditions with the variable packaging was used for the viability and seed crop evaluation studies through regeneration at 5, 10, and 15 years intervals. The results demonstrated that the gene-bank stored snap melon seed can safely be useable for the cyclic maintenance of varieties and breeding material at an interval of five and ten years, respectively. Therefore, the 65 genotypes seed which was enhanced during the crop evaluation of year 2002 and harvested as fresh germplasm lines seed was stored using the gene-bank standard poly-bags under deep-freeze (–20° C) facilities at CIAH for conservation of regional diversity. During kharif season of 2012 and 2013, the conserved genotypes seed was used for studies on storage behavior, crop vigour, trait-specific evaluation and maintenance cycles for varieties and breeding lines. The snap melon genotype crop was raised both rainfed under channel system of cultivation and drip technology with life-saving irrigations. With ten years of storage, all

the germplasm and varieties seeds exhibited prompt germination (78–85 % within 4–6 days from field sowing) and the initial plant vigour was very good. The snap melon genotypes (65) exhibited normal growth and fruiting behavior and evaluated with prioritized traits for variability component studies.

Enough genotype seeds was enhanced during kharif season of 2012 and stored for conservation and further breeding uses. The genotypes recorded a wide-range of variations for days to appearance of first male flower (25.32–36.24 DAS), node number to first male flower opening (1.61–3.13), days to appearance of first female flower (29.82–43.45 DAS), node number to first female flower opening (2.63–3.81), days to first harvest of ripen fruits (52.72–70.35 DAS), number of marketable fruits/plant (3.47–6.52), fruit yield/plant (0.951–5.312 kg), average fruit weight (0.195–1.251 kg), fruit length (9.51–25.22 cm), fruit girth (19.53–36.14 cm), fruit flesh thickness (0.92–2.53 cm), fruit seed cavity (3.24–7.61 cm), number of seeds/fruit (287.55–705.25), weight of seeds/fruit (2.948–12.729 g), seed yield/plant (15.25–61.85 g), weight of 100 seeds (0.958–1.948 g), seed length (0.53–1.08 cm) and seed width (0.31–0.52 cm). The data on variability components is presented in the tables. The analysis of variance of germplasm under the study revealed the existence of highly significant genotypic differences for most of the quantitative characters depicting greater variability in the snap melon material maintained.

The snap melon germplasm and varieties exhibited variations for several prioritized traits such as ovary length (1.51–2.72 cm), ovary diameter (0.59–1.02 cm), male flower size (1.71–3.28 cm x 2.79–4.49 cm), female flower size (2.49–3.82 cm x 2.88–4.21 cm) and leaf size (9.48–13.32 cm x 13.69–16.82 cm). The plant growth of the evaluated material was recorded from very less to vigorous nature vines (1.75–3.25 m) and having moderate to good numbers of branches (3.54–8.27). For characterization, genotypic variations were recorded and found distinctness for fruit size (very small to very large), shape (oval, round, oblong, oblong-obovate and long) and skin colour (saffron-yellow, greenish-yellow, whitish-yellow, yellowish-green, yellowish and saffron) with or without spots. Besides, fruit quality attributes such as pulp taste, colour and TSS (2.21–8.52⁰ Brix) were assessed and ranked. All the material screened for field level diseases incidence and variable results were recorded (10.25–80.55 %). Similarly, genotypes were studied for fruit-fly infestation. It was recorded at fruit maturity stages and total numbers of marketable fruits/plant were considered, and infestation level was ranged from 7.52–38.57 percent.

Based on the two-season genotype evaluation and attributes of earliness, fruit size, shape, quality and yield, and over-all field performance, snap melon breeding material namely AHS-6, AHS-10, AHS-23, AHS-50, AHS-56, AHS-82, DPY-216 and DKS/AHS-2011/2 were most potential for breeding uses. The maintained genotypes exhibited diverse attributes and variability and therefore, there is ample scope of crop improvement for developing trait-specific and nature's resilient varieties of snap melon. The genotypes with

more number of fruits at lower nodes along with earliest fruit-sets and harvest should result into higher early yields and such genotypes must tolerate high temperature and aridity conditions in the later stages of growth for quality fruits and extended yield on secondary and tertiary branches. Similar results were also obtained in the arid vegetable crop-diversity such as round melon, kachri melon and mateera germplasm maintenance studies under hot arid climate (Samadia 2007; Samadia et al. 2024).

Genetic variability components

Under the maintenance studies of snap melon germplasm, the estimates of genotypic and phenotypic coefficient of variation (GCV and PCV) indicate that there is an ample scope for improvement of this crop (table). In general, the estimates of PCV were higher than GCV for all the characters. The GCV values that gives a picture for extent of genetic variability in population ranged from 3.97% (seed width) to 27.32% (fruit yield/plant). The GCV estimates were moderate (>15%) for characters such as fruit yield/plant, fruit weight, fruit length, number of seeds/fruit, weight of seeds/fruit and seed yield/plant and thus, indicating better scope of improvement through selection. A close correspondence between PCV and GCV values in respect to most of the characters indicate that experiment's site environment has very little influence on the expression of the characters. In such situation, the selection can be effective based on phenotypic alone with equal probably of success. With the help of GCV alone it is not possible to determine the amount of variation that is heritable. Heritable variation can be found out with greater degree of accuracy when heritability (h^2 , broad sense) is taken into consideration along with genetic advance (GA). Hence, both heritability and genetic advance were determined to get a clear picture for scope of improvement in various characters through selection. Heritability estimate ranged from 17.39% (seed width) to 99.96% (seed yield/plant). High heritability estimates were recorded for most of the characters. The genetic advance in the present study ranged from 3.41 - 56.07% of mean (genetic gain). The study revealed that the economic character i.e. fruit yield/plant could be improved by 1.56 units under 5% selection intensity (SI) which would be 55.19 percent higher to the mean.

High heritability value coupled with high genetic gain for fruit yield/plant, fruit weight, weight of seeds/fruit and seed yield/plant indicated additive type of gene action. High heritability estimates along with low genetic gain in respect of days to appearance of first male and female flowers, node to first male and female flower, days to first harvest, fruit girth and fruit seed cavity was probably due to non-additive type of gene action and thus, direct selection for these traits would be less effective. It is clear from the data that the traits like fruit yield/plant, fruit weight, weight of seeds/fruit and seed yield/plant possessing moderate GCV, high heritability and genetic gain could be effectively used in selection. Since, it is 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 moderate variability and high heritability along with high genetic gain expressed by the above-mentioned traits indicated that the genotypes

could be tested multi-locations and selected as donor for the characters or used as parent in hybridization programme.

Table 1. Genetic variability components of snap melon germplasm (65) maintained at ICAR-CIAH, Bikaner

Characters	Range		Mean	CD (5%)	CV (%)
	Minimum	Maximum			
Days to male flower (DAS)	25.32	36.24	29.25	1.38	2.92
Node to male flower	1.61	3.13	2.26	0.13	3.73
Days to female flower (DAS)	29.82	43.45	35.21	1.41	2.48
Node to female flower	2.63	3.81	3.24	0.12	2.46
Days to first harvest (DAS)	52.72	70.35	61.25	1.36	1.37
Number of fruits/plant	3.47	6.52	4.91	0.37	4.75
Fruit yield/plant (kg)	0.951	5.312	2.834	0.36	7.89
Fruit weight (kg)	0.195	1.251	0.593	0.18	19.15
Fruit length (cm)	9.51	25.22	16.97	2.38	8.68
Fruit girth (cm)	19.53	36.14	26.69	3.41	7.91
Fruit flesh thickness (cm)	0.92	2.53	1.74	0.33	11.81
Fruit seed cavity (cm)	3.24	7.61	4.93	0.66	8.36
Number of seeds/fruit	287.55	705.25	504.33	28.73	3.52
Weight of seeds/fruit (g)	2.948	12.729	6.844	0.43	3.92
Seed yield/plant (g)	15.25	61.85	34.32	0.52	0.95
Weight of 100 seeds (g)	0.958	1.948	1.397	0.05	2.57
Seed length (cm)	0.53	1.08	0.77	0.16	13.38
Seed width (cm)	0.31	0.52	0.37	0.09	14.98

Table 2. Genetic variability components of snap melon germplasm (65) maintained at ICAR-CIAH, Bikaner

Characters	GCV (%)	PCV (%)	h^2 % (broad sense)	Genetic advance	Genetic gain (5% SI)
Days to male flower (DAS)	8.52	8.69	96.23	5.04	17.23
Node to male flower	11.06	11.27	96.25	0.51	22.37
Days to female flower (DAS)	7.48	7.62	96.45	5.33	15.15
Node to female flower	7.07	7.21	96.09	0.46	14.27
Days to first harvest (DAS)	6.30	6.35	98.44	7.88	12.87
Number of fruits/plant	12.96	13.24	95.70	1.28	26.11
Fruit yield/plant (kg)	27.16	27.54	97.26	1.56	55.19
Fruit weight (kg)	27.32	29.47	85.93	0.31	52.17
Fruit length (cm)	17.02	17.74	92.02	5.71	33.64
Fruit girth (cm)	9.49	10.53	81.20	4.70	17.62
Fruit flesh thickness (cm)	10.81	12.77	71.50	0.32	18.82
Fruit seed cavity (cm)	11.48	12.45	84.97	1.07	21.81
Number of seeds/fruit	20.04	20.14	98.98	207.15	41.07
Weight of seeds/fruit (g)	26.71	26.81	99.29	3.75	54.83
Seed yield/plant (g)	27.22	27.23	99.96	19.25	56.07
Weight of 100 seeds (g)	14.11	14.18	98.90	0.40	28.90
Seed length (cm)	8.89	11.78	56.97	0.11	13.83
Seed width (cm)	3.97	9.52	17.39	0.01	3.41

Table 3. Characterization of promising snap melon germplasm (over the seasons) under arid climate

Germplasm	Days to opening of first male flower (DAS)	Node number to first male flower	Days to opening of first female flower (DAS)	Node number to first female flower	Days to first harvesting (DAS)	Vine length (m)	Number of branches / plant
AHS-6	39.1	4.1	43.4	9.4	74.1	2.14	5.9
AHS-10	26.9	3.9	36.2	6.9	74.0	2.25	8.6
AHS- 14	25.6	3.9	32.4	13.5	75.1	2.51	6.8
AHS-19	26.3	3.0	32.1	12.2	65.1	2.15	5.1
AHS-50	24.7	3.4	29.8	7.2	69.7	2.50	5.9
AHS-54	26.8	3.4	32.2	3.7	62.5	2.14	5.2
AHS-64	25.2	3.1	29.6	5.4	61.4	2.15	6.1
AHS-82	27.3	3.1	44.6	4.2	78.3	2.10	5.4
DPY-216	34.6	2.5	39.5	3.4	65.5	2.17	6.3
DKS/AHS/2011/2	27.5	2.9	35.4	3.4	60.5	2.15	6.1

Table 4. Characterization of promising snap melon germplasm (over the seasons) under arid climate

Germplasm	Number of fruits set/ plant	Marketable fruits / plant	Fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Fruit cavity (cm)	Flesh thickness (cm)
AHS-6	8.1	3.8	0.65	10.9	8.42	6.02	1.74
AHS-10	9.1	4.7	0.85	15.2	9.87	7.12	2.14
AHS- 14	9.4	6.2	1.25	20.7	11.84	7.10	2.34
AHS-19	9.0	5.1	1.23	21.2	9.87	5.54	2.37
AHS-50	5.9	3.2	1.61	28.6	11.04	5.17	2.43
AHS-54	9.4	6.2	1.25	30.1	9.87	4.52	2.57
AHS-64	9.9	6.2	1.52	22.8	10.42	6.42	2.49
AHS-82	8.9	6.3	0.85	24.4	8.89	5.41	1.81
DPY-216	8.7	3.7	0.51	14.6	9.5	4.91	1.76
DKS/AHS/2011/2	10.5	5.8	0.26	9.9	9.7	4.61	1.66

Table 5. Mean performance of snap melon var. Thar Mahak with channel and drip technology

Characters	Channel technology	Drip technology
Days to opening of first male flower (DAS)	38.99	40.49
Node number to first male flower	3.78	4.31
Days to opening of first female flower (DAS)	43.51	44.31
Node number to first female flower	4.85	5.32
Days to first harvesting (DAS)	69.84	72.21
Fruit weight (kg)	0.751	0.856
Fruit length (cm)	17.97	19.31
Fruit girth (cm)	28.15	29.66
Flesh thickness (cm)	2.23	2.43
Fruit cavity (cm)	4.71	5.07
Number of marketable fruits/plant	5.65	6.71
Fruit yield/plant (kg)	4.86	6.24
Fruit yield (q/ha)	235.66	274.65
Number of branches/plant	5.53	6.01
Vine length (m)	2.52	2.69
Seed length (cm)	0.99	1.09
Seed width (cm)	0.41	0.47
Weight of 100 seeds (g)	1.91	2.29
Number of seeds/fruit	560.93	591.51
Weight of seeds/fruit (g)	12.91	14.75
Seed yield/plant (g)	51.89	73.61
Seed yield (q/ha)	2.594	3.679

Table 6. Genotypic (above) and phenotypic (below) correlation coefficients among various characters of snap melon genotypes (65)

CHR	DMF	NMF	DFF	NFF	DFH	NF/P	FY/P	FW	FL	FG	FFT	FSC	NS/F	WS/F	SY/P	W100S	SL	SW
DMF	1.000	0.178	0.953	0.312	0.879	-0.373	-0.324	-0.199	-0.084	-0.267	-0.048	-0.246	-0.303	-0.210	-0.219	-0.003	-0.114	0.029
NMF	0.167	1.000	0.178	0.451	0.182	0.084	-0.156	-0.133	-0.115	-0.135	-0.112	-0.132	-0.089	-0.063	-0.057	0.012	0.244	0.292
DFF	0.895	0.175	1.000	0.347	0.845	-0.357	-0.266	-0.109	-0.043	-0.239	-0.067	-0.199	-0.314	-0.207	-0.224	0.008	0.007	0.066
NFF	0.303	0.422	0.333	1.000	0.331	0.081	-0.274	-0.281	-0.201	-0.192	-0.284	-0.176	-0.084	-0.172	-0.187	-0.219	-0.182	0.380
DFH	0.861	0.179	0.815	0.315	1.000	-0.312	-0.378	-0.266	-0.120	-0.319	-0.148	-0.318	-0.320	-0.241	-0.253	-0.063	-0.040	0.109
NF/P	-0.362	0.064	-0.339	0.079	-0.305	1.000	0.085	-0.328	-0.316	0.007	-0.235	0.113	0.122	0.142	0.123	0.005	-0.029	0.317
FY/P	-0.312	-0.149	-0.259	-0.269	-0.371	0.086	1.000	0.992	0.693	0.748	0.845	0.617	0.571	0.491	0.496	0.195	0.088	-0.056
FW	-0.173	-0.114	-0.116	-0.259	-0.235	-0.304	0.912	1.000	0.791	0.610	0.797	0.460	0.513	0.437	0.451	0.203	0.084	-0.308
FL	-0.081	-0.110	-0.038	-0.194	-0.115	-0.289	0.661	0.758	1.000	0.038	0.391	-0.108	0.334	0.238	0.261	0.147	0.237	0.179
FG	-0.238	-0.116	-0.219	-0.171	-0.281	0.009	0.670	0.627	0.105	1.000	0.708	0.928	0.379	0.411	0.403	0.244	-0.015	-0.679
FFT	-0.034	-0.093	-0.062	-0.237	-0.118	-0.188	0.714	0.741	0.399	0.687	1.000	0.442	0.364	0.335	0.330	0.173	0.126	-0.323
FSC	-0.228	-0.125	-0.181	-0.161	-0.284	0.112	0.564	0.475	-0.037	0.871	0.464	1.000	0.388	0.510	0.493	0.362	-0.055	-0.405
NS/F	-0.297	-0.087	-0.307	-0.084	-0.315	0.122	0.557	0.475	0.319	0.342	0.314	0.360	1.000	0.803	0.793	0.115	-0.129	-0.134
WS/F	-0.204	-0.062	-0.205	-0.168	-0.239	0.137	0.484	0.405	0.231	0.375	0.283	0.469	0.794	1.000	0.998	0.649	0.212	0.115
SY/P	-0.216	-0.057	-0.219	-0.183	-0.251	0.120	0.489	0.418	0.249	0.362	0.279	0.455	0.789	0.994	1.000	0.647	0.213	0.142
W100S	-0.003	0.012	0.009	-0.212	-0.064	0.005	0.193	0.185	0.139	0.217	0.142	0.331	0.114	0.641	0.643	1.000	0.543	0.533
SL	-0.066	0.161	-0.002	-0.118	-0.024	-0.019	0.071	0.093	0.159	0.025	0.124	-0.007	-0.105	0.164	0.162	0.407	1.000	0.187
SW	0.022	0.099	0.024	0.166	0.053	0.119	-0.025	-0.072	0.059	-0.195	-0.082	-0.121	-0.058	0.052	0.060	0.222	0.322	1.000

Where: DMF–Days to appearance of first male flower (DAS); NMF–Node number to first male flower; DFF–Days to appearance of first female flower (DAS); NFF – Node number to first female flower; DFH–Days to first harvest (DAS); NF/P–Number of fruits/plant; FY/P–Fruit yield/ plant (kg); FW–Fruit weight (kg); FL–Fruit length (cm); FG–Fruit girth (cm); FFT–Fruit flesh thickness (cm); FSC–Fruit seed cavity (cm); NS/F–Number of seeds/fruit; WS/F–Weight of seeds/fruit (g); SY/P–Seed yield/plant (g); W100S–Weight of 100 seeds (g); SL–Seed length (cm) and SW–Seed width (cm).

Correlation coefficient

In general, the magnitude of genotypic correlation coefficient was slightly higher than their corresponding phenotypic correlation coefficient for all the characters (table) and thereby indicating a strong inherent association among the traits under study. Yield is a dependent character and highly influenced by environment. For improvement of this trait, information on its association with its main components is beneficial in formulating the breeding programme. A strong positive and significant correlation was recorded between fruit yield/plant with fruit weight (0.912), fruit flesh thickness (0.714), fruit girth (0.670), fruit length (0.661), fruit seed cavity (0.564), number of seeds/fruit (0.557), seed yield/plant (0.489) and weight of seeds/fruit (0.484). The number of fruits/plant, weight of 100 seeds and seed length showed a non-significant positive correlation with fruit yield/plant. Days to first female flower appearance and days to first harvest showed negative and significant correlation with fruit yield/plant. Days taken to the first harvest, which is a character of earliness or late had positive and significant association with days to first male and female flower appearance and nodal position of female flower which clearly an indication of mutual association of these traits for their expression. Fruit girth showed positive and significant correlations with fruit weight, fruit flesh thickness, fruit seed cavity, number of seeds/fruit, weight of seeds/fruit and seed yield/plant. Negative and significant association of days to appearance of female flower and days to first harvest with number of fruits/plant which clearly indicated that early genotypes bear more number of fruits/plant. For effective selection, it is suggested that for higher yield in snap melon number of fruits/plant is an important character. But, it may slightly affect on fruit weight and size, and thus moderate balance has to be made for medium number of fruits, fruit weight and size to achieve better results in snap melon under arid environment.

Product and uses studies

Snap melon is the much-liked cucurbit vegetable of rural India. Fully mature and ripen fruits are used extensively for vegetable culinary, dessert-salad, value-addition and dehydrated products. Traditionally, fruits used for making vegetable-raayta's (curd based) and vegetable cooking or mixed culinary with tender pods of cluster bean, moth-bean and cowpea. Ripen fruits relished as dessert-salad and also dehydrated (*khelera* or *kheleri*) on large-scale for year-round uses and it is in trade (@125–225 Rs/kg). Seed kernels are extracted commercially and the *magaz* used in sweets, bakery, ice-creams and soft-drink products. Seed is also used to prepare the cooling medicine. The ready to use products such as RTS, ketch-up and puree from ripen fruits has opened the new market and branding is in queue for entrepreneurship. The snap melon recorded a great significance in the social, cultural, religious and regional facts of the desert dwellers. Flaks of fruit's (*khelera* or *kheleri*) used in the extraordinary gift-pack "*Dibadi*" and it is sent to kith and kin of the traditional families and that containing dehydrated products of arid vegetables and fruits such as kachri, khelera, phophalia, ker, sangri,

gunda, guarphali, phogla, kumat-seeds and many-more from the familism farming of *Thar* desert.

The diverse snap melon genotype fruits were harvested at ripen stages and composite sample was formulated for the food value analysis. The ripen fruits are juicy and have a unique flavor with sour-sweet taste and rich in nutraceutical values. On 100 g fresh weight basis, snap melon fruits contains 79.93 g water, 15.60 g carbohydrate, 0.37 g crude protein, 1.12 g fat, 1.34 g crude fibre, 1.64 g total minerals, and calcium (0.76 mg), phosphorus (0.088 mg), iron (0.843 mg), copper (1.04 mg), zinc (0.202 mg), manganese (0.097 mg) and vitamin C (18.6 mg) and 79.29 K cal energy. For dehydration, marketable harvest stages ripen fruit samples of snap melon variety *Thar Mahak* were assessed. On fresh weight basis, ripen fruits contain 94.65 % moisture and 5.35 % dry-matter recovery as *khelera*, and total dry-matter contain 69.56 % carbohydrate, 2.37 % protein, 1.85 % fat, 5.34 % crude fibre, 3.44 % calcium, 0.38 % phosphorus and 1.64 % trace elements.

Production technology studies

The restrictions imposed by nature in the north-western Indian arid zone such as extremes of high and low temperature conditions; low, erratic and un-certain rains; sandy soils and limited water, and all these in-together do not permitting to harness the benefits of crop-genotypes and therefore, productivity and quality of vegetables is marginal. Systematic experimentation on snap melon varieties along with use of preliminary output data of the arid vegetables cultivation under the sandy soils resulted in standardization of techniques and practices for resource-based farming. Here, HBCPSMA concept (Samadia, 2016) of cultivation plays a critical role as crop-genotype-environmental interaction benefits, however sowing time, method and spacing; use of nutrients, bio-regulators, irrigation water and micro-climate management practices needs some extent of modifications to maximize fruit yield and resources productivity.

For normal seed sowing, on-set of monsoon rains in July and February month is the best period to raise the rainy and spring-summer season crop of snap melon, respectively. Surface-channel, arch or tent-type structure covering technology developed at ICAR-CIAH for protected cucurbits sowing in first week of January is an excellent mechanism to minimize the ill-effects of winter severity and result to early crop harvest and higher income from snap melon. After selecting the proper plot, marked area should be cross-ploughed followed by planking or use rotavator, and field preparation should be started 10–15 days prior to the sowing. About 50–60 cm wide and 20–25 cm deep channels (furrows) are made at 2.0 m distances for snap melon. For uniform water distribution, crop-sown channels should be 25 m in length on one-side of the delivery-line and 50x50 m plot size is appropriate. Similarly, the one-side length of lateral pipes should not exceed 25 m and unit plot should be 50x50 m size with control valves. A four-hectare vegetable block area can be managed with a drip-unit through diggi-based water supply system and PVC pipe-line net-working of main (110mm), sub-main

(75mm) and plotline (63 mm) for pressurized irrigation as projected at ICAR-CIAH. In addition, integration of over-head water-storage reservoir (one lakh litre capacity) and solar-pumping system is no-pole-electricity and water resource utilization concept is much more practical for insured crop production under dry-lands.

Based on soil fertility build-up studies at 0, 3, 6 & 9 years of arid vegetable cultivation fields at ICAR-CIAH, Bikaner, it is established that only channels as seed-bed needs to be fertilized and mixed thoroughly. For a hectare plot, basal dose of FYM (50q), vermin-compost (5q), DAP (100kg), SSP (100kg), urea (50kg), MOP (50kg) and neem-leaf powder (10kg) is enough to maintain field productivity. With the pre-monsoon rains during second fortnight of June and immediately broad-casting of mixed grains @ 15 kg/ha (cluster bean, cowpea, moth bean, amaranth, and dhencha) followed by harrowing resulted to very good growth of greens, and further ploughing for field preparations with the end of July resulted to improvement in soil properties over the years. For drip technology of cultivation, here, the manure-fertilized channels converted into seed-beds and on which laterals are laid-down. Snap melon seeds are sown at 50 cm distances and sowing is done only at inner down-side of northern slope of channels or near to drippers of lateral pipes.

For a hectare sowing, 1.25 kg seed is enough. Prior to sowing, seed should be soaked in water for 2–4 hours and also treated with fungicide. At each sowing point, 2–3 seeds are sown. After good germination and when the seedling attaining 8–10 cm height or 18–21 days age-old, thinning is done keeping one or two healthy plants at each point. The crop should be irrigated at intervals of 7–9 days by flood method only in the channels or 3–4 days for 1.0–1.5 hours with drip technology (laterals 16 mm and 4 lph in-line emitters) under the sandy soils. Manual hoeing, weeding and inter-culture in channels and seed-bed is done at 18–21, 30–35 and 45–55 days of crop growth. Similar schedule is recommended for application of urea (50 kg/ha) in three split doses i.e. early plant growth, flowering and fruit setting stages and also spraying of insecticides to manage minor insect-pests. For improving the fruit and seed yield potentials, a series of treatment combinations were studied adopting the methods of snap melon cultivation and khejri based crop production site management approaches from the year 2002 to 2016. On average, 17 % higher fruit yield in snap melon variety Thar Mahak was obtained with drip technology (laterals at 2.0 m and emitters at 0.50 m apart) over the channel method of cultivation with limited irrigations, and it was 38 % higher from the rainfed crop. Similarly, seed yield was improved 42 % under the drip technology over channel method and it was 63 % higher from rainfed crop. Single lateral-line drip system recorded 12.5 % higher fruit yield over mini-sprinklers. Similarly, channel technology recorded a 19.5 % higher yield over open-furrows and bed-method of rainfed crop cultivation. Use of locally available dry-grasses and weeds as mulching material improved fruit yield (22.4 %) and foliar

application of GA₃ (19.5 %) in comparison to control (normal rainfed crop under furrow and channel method). Excellent results for managing of fruit-fly was obtained following the insecticide sprays schedule i.e. at 2–4 true-leaf stage, first male flowers opening and start of fruit-sets, and 18.5 % improvement obtained in marketable fruit yield. In addition, sowing of snap melon in the first week of January with surface-channel covering protected technology of ICAR-CIAH is an option for the earliest fruit harvesting from the second week of March under dry-lands of north-western parts of India. This technology is cost-efficient, and performance of variety Thar Mahak ranked first (275 q/ha) with extended fruit harvesting.

Prospects and impact of technology

Realizing the benefits of climate resilience cucurbits vegetable cultivation in the dry-lands of north-western parts of India, genotype development for the extended period of fruit harvesting (March to November) and organic production potentials and therefore, strategic research work of ICAR-CIAH on non-dessert forms of *Cucumis melo* was analyzed. The objectives of native germplasm collection and utilization for the conservation of regional diversity and varietal development clearly demonstrated that present research out-put can convert the snap melon into unique commodity to promote nature's resilient farming and entrepreneurship for value-add products. In conclusion, the varieties seeds and production technologies of the snap melon are cost-efficient and worthy for commercialization under resource constraints arid environment.

The recommendations of snap melon variety Thar Mahak and crop production practices as the cultivation methods such as deep-furrow, channel and drip technology resulted into the better-quality marketable yield (155–275 q/ha) and uniform fruit harvest during rainy and spring-summer seasons. Now, developed snap melon technology is widely accepted by growers as sole crop. With HBCPSMA concept and khejri based crop production models namely KM-3, KM-9 and KM-11 recorded the high resources productivity, regular family employment and income @ Rs 75,000–2,25,000 in comparison to the conventional cropping (Rs. 23,000–42,000) per ha/year and also showed feasibility to adopt both rainfed and intensive farming approaches for eco-system services.

Promotion of technological advancements and seed-chain in snap melon resulted in its wide-spread recognition as main vegetable crop not only in arid and semi-arid areas of Rajasthan but also in Punjab, Haryana, Gujarat and Madhya Pradesh. Annually, 2–3 q truth-fully label seed is being made available to growers through different agencies and further it is multiplied by progressive farmers for their own and associate's uses. About 5000 hectare/year area is with ICAR-CIAH technology and farmers are getting much benefits from the snap melon cultivation as two season, off-season, inter-crop, low-input and less-water requiring commodity (Samadia 2018a).

Plate 1. *Cucumis* melons diversity, varieties, lines and production technology

Field evaluation of snap melon



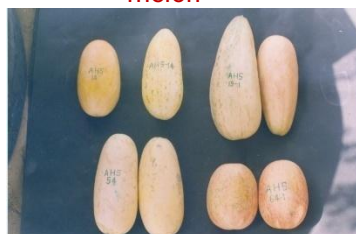
Fruit variability in snap melon



Fruit variability in kakdi



Fruit variability in kakdi



Promising snap melon genotypes



Immature fruits of snap melon



Mature fruits of snap melon



Snap melon AHS-82 fruits



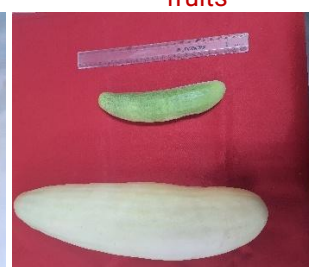
Snap melon AHS-10 in bearing



Fruit bearing in Arya melon



Fruit of kakdi AHC-2



Intermediate fruits of melons



Salad kakdi AHC-13



Bearing in salad kakdi AHC-13



Fruits of wangaa



Fruit of native cucumber



Field of snap melon crop



Products of snap melon



Dehydrated snap melon



Seeds of snap melon

Declaration of interests

The authors do not have any conflict of interest, and the research was conducted in the absence of any commercial relationship with anyone.

Data Sharing

All relevant data are within the manuscript and are available from the first author.

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