8 Crop Improvement

Abstract

Among the Asiatic *Momordica*, the majority are dioecious (*M. dioica*, *M. subangulata*, *M. sahyadrica*, *M. cochinchinensis*, *M. denticulata*, *M. denudata*, *M. rumphii* and *M. clarkeana*) and a few are monoecious, which are otherwise considered to be of African origin (*M. balsamina*, *M. charantia* and *M. cymbalaria*). Anthesis takes place early in the morning in all *Momordica* spp. except *M. dioica* in which anthesis takes place during the evening hours. Polylectic bees and oil bees are the major pollinators of *Momordica* species. Exogenous application of plant growth regulators like MH, ethrel, etc., can alter the sex ratio and sequence while chemical treatment with silver nitrate can modify the sex. Exogenous application of 2, 4-D (100 ppm), α-NAA (100 ppm) and physical stimulus provided by false pollination also induced parthenocarpic fruit development in *Momordica* spp. The first genetic linkage map of bitter gourd was developed using a set of 146 F_2 progenies derived from an inter-botanical variety cross and 7 Quantitative Trait Loci (QTLs) were identified for different traits like fruit number and yield, fruit length, fruit diameter and weight. The wild species of *Momordica* offer great resources for improvement of cultivated bitter gourd for desirable edible/ quality traits, biotic and abiotic stress. An efficient protocol for *Agrobacterium* mediated genetic transformation of bitter gourd using leaf disc as explants was reported and this optimised transformation system could be used for the genetic improvement of bitter gourd. Microsatellite markers were isolated and characterised from the genome of *M. charantia* and these markers will have potential utility for applications in genetic diversity evaluation, molecular fingerprinting, identification, comparative genomics analysis and genetic mapping in *Momordica*. Yield and quality are the major focus of *Momordica* species improvement and methods like selection, heterosis, mutation and polyploidy breeding have been utilised to develop high yielding varieties. There are about 300 varieties of bitter gourd found around the world and some of the popular varieties have been described in this chapter.

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Floral Biology

The breeding system depends upon the reproductive system of the plant. Information about floral biology is the basic need before setting up a breeding programme. There is very little information available about the floral biology and genetic system (number of genes and chromosomes, details of meiosis and pairing, breeding system, sex determination and sex modification, regulation of gene actions) in these species except for bitter gourd *(M. charantia*) and to some extent in *M. dioica*. The monoecious species have been shown to be self-compatible (Palada and Chang 2003; Lokesha and Vasudeva 2001; Schaefer and Renner 2010), and self-incompatibility is unknown in Cucurbitaceae.

In *M. charantia* the first flowers appear 45–55 days after sowing, and under long-day conditions male flowers bloom 2 weeks before the first female flowers; the female to male flower ratio is 1:25, and flowering lasts up to 6 months (Palada and Chang 2003). *M. dioica* starts flowering 30–40 days after planting depending upon prevailing weather conditions (Dod et al. 2007) and lasts up to 4–5 months (LKB, pers. obs.). Teasel gourd comes to flowering in 50–60 days after planting (Vijay et al. 1977). Among the *Momordica* species of Indian occurrence *M. cochinchinensis* come to flowering very late, i.e. 90–100 days after planting (LKB, pers. obs.). Usually anthesis takes place in the early morning hours. There are *Momordica* species which flower later in the day as in *M. cymbalaria* (10.30–11.30 AM) and in the late evening hours as in *M. dioica* (6.30–8.30 PM). Opening of flower (anthesis), dehiscence of anthers, pollen viability and stigma receptivity are influenced by the environment and there is deviation at different locations (Table 8.1).

In bitter gourd, (*M. charantia*), staminate flowers offer nectar and pollen while pistillate flowers are rewardless (Bahadur et al. 1986). These pistillate flowers mimic the staminate flowers and are in most cases pollinated by deceit (Baker 1976; Dafni 1984). *Momordica* species relies heavily on pollinators for fruit set. However, in case of *M. subangulata* subsp. *renigera*, though the flowers are bigger in size and showy with three black spots in petals there is no effective pollinator and natural fruit set is recorded up to 50 % only. Studies on pollinator diversity and their influence on the yield of *M. charantia* are scanty (Free 1993). Natural pollination of balsam apple and bitter gourd in the field is usually by polylectic bees while spine gourd is pollinated by moth and teasel gourd, sweet gourd and other Asiatic *Momordica* spp. by oil bees (Schaefer and Renner 2010). Honey bees (Roubik 1995) and halictids (Grewal and Sidhu 1978) have been reported as the principal pollinators of *M. charantia* in Tropical America and India respectively. Other important pollinators include *Apis florea, A. cerana* and *A. dorsata* (Apidae) in India (Behera 2004), *Diabrotica speciosa* (*Coleoptera*, *Chrysomelidae*) in Brazil (Lenzi et al. 2005). Deyto and Cervancia (2009) recorded *A. mellifera, A. cerana, Trigona* sp. (Apidae) and *Halictus* sp. (Halictidae) foraging on *M. charantia* in Philippines and Oronje et al. (2012) reported *Plebeina hildebrandti* and *Lasioglossum* sp. as the most important pollinator in Kenya.

Sex Form

In *Momordica*, plants produce three types of flowers: staminate, pistillate and hermaphrodite. Among the Asiatic species, the majority is

Table 8.1 Floral biology of Asiatic *Momordica* species

Species	Anthesis	Dehiscence	Pollen fertility	Stigma receptivity	Reference
M. charantia	09.00–10.30 h	7.00–8.00 h	5.00–12.00 h	One day before to one day after anthesis	Agarwal et al. (1957)
	04.00–07.30 h	06.10–08.55 h	–	8 h before to 12 h after anthesis	Pal and Singh (1972)
	03.00–12.00 h	–	–	–	Deyto and Cervancia (2009)
M. dioica	19.00–20.00 h	18.00–19.00 h	19.00 h	12 h before to 18 h after anthesis	Shikhalia et al. (1990)
	20.30 h	16.00 h	–	12 h before and after anthesis	Dubey et al. (2007)
	20.00–21.30 h	17.00–21.00 h	20.00–08.00 h	Up to 18 h after anthesis	Dod et al. (2007)
	18.00–20.00 h	–	–	–	LKB, Pers. obs.
M. sahyadrica	04.00–06.00	–	–	–	LKB, Pers. obs.
M. subangulata subsp. *renigera*[a]	05.50–06.20 h	22.45–12.00	–	18 h before and after anthesis	Vijay et al. (1977)
M. cymbalaria	11.00–12.00 h	–	–	–	LKB, pers. obs.
M. cochinchinensis	07.00–08.00 h	–	–	–	LKB, pers. obs.

[a] Reported as *M. dioica* in the original paper

dioecious bearing staminate flowers and pistillate flowers in different plants and few species are monoecious bearing staminate and pistillate flowers in the same plant. Gynoecious lines originating in India were identified (Ram et al. 2002; Behera et al. 2006) for use in hybrid development programmes. *M. charantia*, *M. balsamina* and *M. cymbalaria* are monoecious, while *M. dioica*, *M. subangulata* subsp. *renigera*, *M. subangulata* subsp. *subangulata, M. cochinchinensis*, *M. sahyadrica*, *M. denudata*, *M. rumphii*, *M. clarkeana* and *M. denticulata* are dioecious. However, natural occurrence of hermaphrodite flowers in *M. dioica* (Jha and Roy 1989), *M. subangulata* subsp. *renigera* (Fig. 8.1a) and *M. charantia* (Fig. 8.1b) (per. obs.) has been observed. Trivedi and Roy (1973) have reported the appearance of various intermediate sex forms like andromonoecious, gynoecious and trimonoecious in colchicine treated plants of *M. charantia*, but remaining as diploids.

Sexual mechanism in *M. dioica* is an incipient type of sexual dimorphism (an intermediate stage towards X/Y chromosome basis), in which a pair of autosomes is responsible for sexual dimorphism (Jha 1990). However, Seshadri and Parthasarathi (2002) considered the differentiation of sex in *M. dioica* to be entirely genic or genetical without any cytological evidence of heterogamety. Wang and Zeng (1998) speculated that two predominant 11 and 30 kD protein bands which are present in pistillate and staminate flowers, respectively, may be directly associated with sex expression while Sinha et al. (2001) reported the presence of a sex linked 22 kD polypeptide (p-22) only in the female sex, which was not detected in its male counterpart.

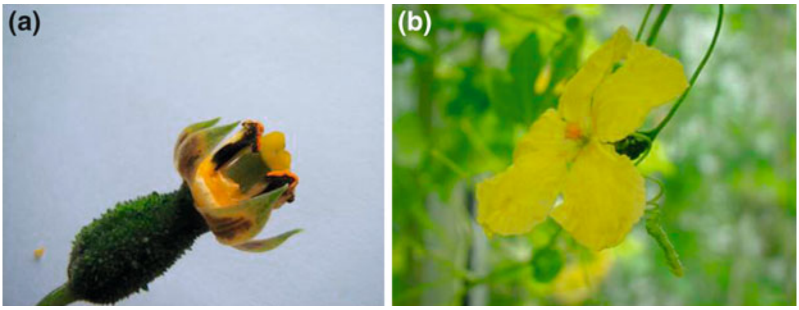

Fig. 8.1 Naturally modified sex in flower of a monoecious and dioecious species. **a** *M. subangulata* subsp. *renigera* **b** *M. charantia*

Alteration of Sex Expression

Environmental factors, endogenous levels of auxins, gibberellin, ethylene and ascorbic acid, at the time and seat of ontogeny determine the sex ratio and sequence of flowering. Sex expression is affected by environmental conditions under which *M. charantia* seedlings grow (Prakash 1974; Yonemori and Fujida 1985; Wang et al. 1997; Thomas 2008). Although sex modification in plants can often be achieved by altering mineral nutrition, temperature, photoperiod and phytohormones (Durand and Durand 1984; Wang et al. 1997; Wang and Zeng 1997a) phytohormones play a key role in modifying the sex (Thomas 2008; Rebecca and Jessica 2011). The concentration of endogenous growth regulators and polyamines (e.g. spermine, spermidine, cadaverine and putrescine) in shoot meristems of bitter gourd may change sex ratio (Wang and Zeng 1997a, b). Foliar application of growth regulators can also modify sex expression (Ghosh and Basu 1982). For example, foliar application of gibberellic acid (25–100 mg/l) can dramatically increase gynoecy in bitter gourd, while cycocel (50–200 mg/l) promotes staminate flower development and the effects of GA and CCC are sustained for over 80 days, which allows for their use in genetic experiments, the increase of gynoecous lines and in commercial hybrid production (Wang and Zeng 1996). The appearance of the first staminate flower is delayed and pistillate flower initiation is promoted by relatively low concentrations (0.04–4 mg/l) of GA_3 (Wang and Zeng 1997c). Foliar application of ethrel, malic hydrazide (MH), GA_3, naphthalene acetic acid (NAA), kinetin, indole acetic acid (IAA), 3-hydroxymethyl oxindole (HMO), morphactin, silver nitrate and boron when applied at 2- and 4-leaf stage of bitter gourd plants can dramatically affect sex expression (Prakash 1976). Dramatic increases in early pistillate flower appearance can result from foliar application of MH (250 ppm) and ethrel (200 ppm), and staminate flower development can be promoted by application of 50–75 ppm GA_3 (Damodhar et al. 2004). Although exogenous application of GA_3 @ 20–40 mg/l increases pistillate and staminate flower number, comparatively high concentrations of GA_3 (60 mg/l) increases only pistillate flowers (Ghosh and Basu 1983).

Sex Modification

Sex modification is highly useful in case of dioecious species where crossing between genetically female plants is difficult. Selfing is very difficult for the breeding materials (female plants) of dioecious species for generation advancement and to combine the desirable characters through intergenotypic crossing between two female genotypes. However, self-fertilisation and intergenotypic crossing (between female clones) have been made possible in *M. subangulata* subsp. *renigera* through sex modification. In dioecious species, intergenotypic crosses were made possible through the induction of bisexual flowers (Ali et al. 1991; Hossain et al. 1996) to facilitate recombination of desirable characters of parents in homosexual hybrid. Selection of high yielding clones from such homosexual hybrids may lead to establishing a variety in a short period as the dioecious species are vegetatively propagated. Alteration of sex to the desired direction has to be manipulated by exogenous application of plant growth regulators at critical stage. Foliar sprays with $AgNO_3$ (400 ppm) at preflowering stage could induce 70–90 % hermaphrodite flowers in *M. dioica* (Rajput et al. 1994). Application of ethephon to male plants of kakrol did not affect the plants at any level of concentration tested while application of $AgNO_3$ (400 ppm) produced the highest number of bisexual flowers per vine (Ali et al. 1991). Application of 500 mg/l $AgNO_3$ on female plants produced the maximum proportion of induced hermaphrodite flowers in *M. cochinchinensis* and the pollen viability was similar to that of normal male plant (Sanwal et al. 2011). However, a perusal of the photographs and description of the material used in the study by the authors indicates the target taxa as *M. subangulata* subsp. *renigera* and not *M. cochinchinensis*. Foliar application of silver nitrate (i.e. 250 mg/l at 5-leaf stage or 400 mg/l at 3-leaf stage) induces bisexual flower formation in *M. charantia*, where ovaries and petals are larger than typical pistillate flowers (Iwamoto and Ishida 2005).

Parthenocarpy

In case of sweet gourd (*M. cochinchinensis*) and teasel gourd (*M. subangulata* subsp. *renigera*) the young and developing seed coat is whitish, soft and delicate but subsequently it turns ash coloured to black and hard, which is a major thaw in consumer acceptance and it is obvious that the development of parthenocarpic fruit will greatly enhance its food value and consumer acceptability (Handique 1988). However, in case of spine gourd (*M. dioica*) it is observed that the fruit taste is attributed to its seeds. Singh (1978) reported the induction of parthenocarpy in *M. dioica* with pollen of related taxa (*M. charantia* and *Lagenaria leucantha*) and mixture of the pollens from these two species. The parthenocarpic fruit setting was higher with the stimulus of extraneous pollen (66 % against 36 %), compared to natural pollination. The lower fruit setting in natural pollination may be attributed to non-synchronisation of anthesis and duration of corolla opening. Bharathi et al. (2012a) observed that the pollen of dioecious species induced satisfactory parthenocarpic fruit set in *M. charantia* which is desirable from the consumer point of view and can be further exploited for production of parthenocarpic fruits. A high parthenocarpic fruit set (>70 %) was also observed in an inter-specific hybrid between *M. dioica* and *M. cochinchinensis* when the F_1 was pollinated with pollen from *M. cochinchinensis* (unpublished). In the absence of natural or genetic parthenocarpy, alternate methods should be adopted to have seedless fruit. Treatment with α-NAA 100 ppm induced parthenocarpic development up to 95 % in case of *M. cochinchinensis* (but the taxa used in this study is *M. subangulata* subsp. *renigera*) but physical stimulus provided by false pollination is ineffective in inducing parthenocarpic development (Handique 1988). Exogenous application of 2, 4-D @ 100 ppm at anthesis produced around 90 % fruit set in teasel gourd (Vijay and Jalikop 1980; Rasul et al. 2008). However, the fruits were smaller than normal fruits.

Current Goals of Breeding

Yield and quality are the major focus of *Momordica* species improvement.

Yield. Yield has been a focus of bitter gourd improvement for a number of years. In other species, like *M. dioica* and *M. subangulata*, as they are in domestication interface yield being the primary objective it becomes the focus of many studies.

Quality. Bitter gourd comes in a variety of shapes and size. It is green to white in color. Between these two extremes there are a number of intermediate forms. Fruit colour preference varies in different regions. For example, green fruits are in demand in Southern China, whereas white fruits are preferred in Central China. Likewise, dark green to glossy green fruits are preferred in Northern India and some parts of South India, while white fruited types are highly preferred in Kerala (Behera et al. 2010). Some bear miniature fruits of only 6–10 cm length, which may be useful as stuffed vegetables. Fruits with medium bitterness and soft tubercles are preferred in most parts of India. Development of varieties suitable for canning and dehydration is also an objective of bitter gourd breeding.

Earliness. Earliness indicate emergence of first female flower at the earliest nodes in case of monoecious species while appearance of first female flower in case of dioecious species with early fruit maturity at marketable stage.

High femaleness. High female to male ratio in case of monoecious species, resulting in higher number of fruits per plant.

Pest and disease resistance. Development of varieties resistant to diseases like *Fusarium* wilt, anthracnose, powdery mildew, downey mildew and insect pests like root knot nematode, red pumpkin beetle, ladybird beetle, fruit fly and fruit borer.

Stress resistance. There are several environmental factors like high and low temperature, drought, excessive moisture, salinity, alkalinity, etc., which affect cultivation and development of variety with improved abiotic stress resistance could be beneficial.

Breeding Methods and Techniques

Selection. The most effective method for the improvement of quantitative traits, such as yield in *Momordica* spp. may be individual plant recurrent selection. However, the initial populations must possess the necessary genetic diversity for selection. Wide range of diversity has been reported in bitter gourd and spine gourds (Rasul and Okubo 2002; Ram et al. 2004; Rasul et al. 2004; Joseph and Antony 2009; Islam et al. 2009; Macusi and Rosario 2009; Paul et al. 2010; Bharathi et al. 2010; Promote et al. 2011; Dalamu et al. 2012; Laxuman et al. 2012). Selection from a local cultivar has been the most commonly adopted breeding method in bitter gourd, spine gourd and teasel gourd.

Single plant selection and mass selection were followed to develop most of the high yielding varieties in bitter gourd in India. In *M. charantia*, the number of fruits per plant and fruit length showed high genotypic coefficient of variation (GCV), high heritability and expected genetic advance (Singh et al. 1977). High heritability with high genetic advance was observed for yield per plant and vine length indicating that this trait was under additive gene control and selection for such trait would be effective (Islam et al. 2009). A perusal of the literature shows that yield had a positive correlation with different traits such as number of leaves per plant, number of primary branches per plant, leaf area, number of flowers per plant, vine length, days to first harvest, fruit length, fruit girth, fruit volume, number of fruits per plant and number of seeds per plant (Ramachandran 1978; Indiresh 1982; Pal and Vani 1986; Geetashri et al. 1995). Among these traits fruit traits like number of fruits/plant, fruit weight, fruit length, etc., were repeatedly reported as high correlated characters with yield/plant. Simple selection strategies focusing on flowering duration, harvesting span, fruit length and diameter, fruit rind thickness, average fruit weight, number of fruits per vine, dry matter per vine and harvest index could be used to improve bitter gourd yield (Behera et al. 2010).

Selection of high yielding clones is commonly practiced in dioecious crops like teasel gourd and spine gourd. Though the dioecious species are vegetatively propagated sexual reproduction becomes possible which is helpful in mass selection for improvement. The estimates of GCV and phenotypic coefficient of variation (PCV) indicated that selection can be done on the basis of phenotype alone for yield improvement in spine gourd (Bharathi et al.

2010) and selection for characters such as number of fruits per plant, individual fruit weight and fruit volume are more important for yield improvement in *M. dioica* (Bharathi et al. 2006).

Heterosis breeding. As all the species of *Momordica* are cross-pollinated, there is ample scope for exploitation of heterosis. Heterosis breeding utilises mainly the dominance variance. It involves three important steps in cross-pollinated crops (a) production of inbred lines, (b) testing the combining ability of inbred lines and (c) production of seeds in bulk. Techniques used for hybrid development in bitter gourd are similar to those of melons and cucumber (Behera 2004). In bitter gourd, vigorous parental inbred are maintained routinely by selfing without inbreeding depression (Behera 2004). As there is no or negligible inbreeding depression reported, the homozygous varieties can be directly used for production of F_1 hybrids unlike production of inbred and hybridisation in other cross-pollinated crops like onion. It is comparatively easier to produce the seeds of F_1 hybrids of bitter gourd (through bagging and hand pollination) than in self-pollinated crops (through emasculation and hand pollination) like tomato, brinjal, etc. In case of dioecious species inbreeding is not possible. Sib mating is possible but there is often loss in vigour on sib mating. However, through induction of bisexual flowers (as described earlier under the section sex modification) inbreeding is possible to produce inbred lines which can be used for production of F_1 hybrids.

More pronounced hybrid vigor could be observed with the inclusion of diverse parents (Behera et al. 2011). However, moderate genetic diversity is most desirable to produce highly heterotic hybrids (Laxuman et al. 2012). Heterosis for earliness, high number of fruits and bearing at each flowering node should be exploited. Selection for divergent parent based on number of fruits, fruit weight, fruit length, inter-nodal length and yield will be useful as these characters were the major traits contributing to divergence and selection of parents based on number of fruits per plant and individual fruit weight is more important for spine gourd (Bharathi et al. 2005; Bharathi et al. 2006).

Heterosis in *M. charantia* was investigated at the Indian Agricultural Research Institute, New Delhi as early as 1943 (Pal and Singh 1946). Extensive work on various aspects of heterosis in bitter gourd has been carried out over the past several years (Table 8.2). Heterosis for yield per vine varied from 1.30 (Singh and Joshi 1980) to 98.21 % (Singh et al. 2001) over the standard parent depending on genotype. This heterosis is likely attributable to earliness, first node to bear fruit (first female flowering node), and total increased fruit number (Celine and Sirohi 1998). Genetic dominance and complementary gene action associated with some of these traits combined with their low narrow sense heritability indicate that hybrid breeding would be an advantageous strategy when breeding for increased yield in these crop species (Celine and Sirohi 1998; Mishra et al. 1998).

Mutation breeding. Sudden change in a gene on chromosome known as mutation which is heritable occurs spontaneously in crop plants. A white bitter gourd mutant ‘Pusa Do Mausami’ was developed through spontaneous mutation from the natural population of ‘Pusa Do Mausmi’ (green-fruited type) at the Indian Agriculture Research Institute, New Delhi. Mutations can also be induced by irradiation through mutagens like X-rays, gamma rays, ethylmethane sulphonate (EMS), etc. Mallaiah and Nizam (1986) induced variability in bitter gourd with gamma irradiation and EMS treatment. In *M. charantia*, M_1 progeny derived from radiation mutagenesis can possess economically important unique characters, which are controlled by single recessive genes (Campose 1963). One such promising variety is developed in bitter gourd, i.e. MDU 1, developed as a result of gamma radiation (seed treatment) of the landrace MC 103 which was found to possess improvement for yield (Rajasekharan and Shanmugavelu 1984). A study to induce restricted vine growth habit in bitter gourd indicated that gamma ray irradiation of seed at 9 kr and pollen between 3 and 5 kr were

Table 8.2 Heterosis in bitter gourd

Character	Mid parent	Better parent	Standard parent	Reference
Vine length	1.66–23.37	–	–	Sirohi and Choudhary (1978)
	2.10–22.30	–	–	Singh and Joshi (1980)
	4.26–57.81	–	–	Chaudhari and Kale (1991)
	–	–	23.44–24.63	Ranpise et al. (1992)
	0.99–20.98	1.41–4.21	–	Munshi and Sirohi (1993)
	0.23–18.20	–	−7.27 to 24.99	Celine and Sirohi (1996)
	–	−29.29 to 41.23	–	Ram et al. (1997)
	–	2.36–33.33	9.15–43.79	Singh et al. (2001)
No. of primary branches/vine	–	35.60–57.10	–	Lal et al. (1976)
	7.80–37.00	–	–	Singh and Joshi (1980)
	3.30–25.85	–	–	Singh et al. (1997)
	–	–	−31.80 to 18.50	Chaubey and Ram (2004)
Internodal length	–	–	−9.9 to 22.9	Chaubey and Ram (2004)
Days to opening of first male flower	–	−7.02 to −1.40	–	Lal et al. (1976)
	−5.29 to 12.90	0.12–12.90	−9.53 to 23.65	Celine and Sirohi (1996)
	−10.47 to 3.5	–	−11.47 to −3.49	Tewari and Ram (1999)
	−8.29 to 26.8	–	−7.21 to −15.91	Singh et al. (2000)
	–	–	−1.4 to 17	Chaubey and Ram (2004)
Number of nodes at first male flower	−19.70 to 8.33	10.9–6.72	–	Ram et al. (1997)
	−5.29 to 7.75	−0.12 to 12.90	−9.53 to 23.65	Celine and Sirohi (1996)
	−8.92 to 26.80	–	−7.21 to −15.94	Singh et al. (2000)
	2.8–17.46	–	−5.19 to 7.79	Tewari and Ram (1999)
	–	–	19.1–86.40	Chaubey and Ram (2004)
Days to opening of first female flower	54.00–66.00	–	–	Lawande and Patil (1989)
	–	–	−5.40 to −5.18	Ranpise et al. (1992)
	–	−17.02 to −0.57	–	Khattra et al. (1994)
	−3.15 to 9.11	1.23–7.67	−7.63 to 33.44	Celine and Sirohi (1996)
	–	−15.72 to 7.48	–	Ram et al. (1997)
	−4.40 to 10.00	–	−18.50 to −8.33	Tewari and Ram (1999)
	−6.08 to −18.3	–	–	Singh et al. (2000)
	–	−0.12 to −6.50	−3.61 to 14.02	Singh et al. (2001)
	–	–	−3.1 to 12.10	Chaubey and Ram (2004)

(continued)

Table 8.2 (continued)

Character	Mid parent	Better parent	Standard parent	Reference
No. of nodes at first female flower	–	0.00–54.50	–	Lal et al. (1976)
	–	–	−24.72 to −20.37	Ranipse et al. (1992)
	−14.71 to −27.80	–	−14.44 to −27.80	Singh et al. (2000)
	–	–	18.00–52.20	Chaubey and Ram (2004)
Days to first fruit harvest	0.30–0.85	–	–	Sirohi and Choudhury (1978)
	−3.81 to −43.92	–	–	Chaudhari and Kale (1991)
	–	–	−4.32 to −2.78	Ranipse et al. (1992)
	−0.40 to −0.50	0.00 to −2.07	–	Munshi and Sirohi (1993)
	–	−15.06 to −0.42	–	Khattra et al. (1994)
	−1.98	−7.72 to −4.47	–	Celine and Sirohi (1996)
	−0.42 to 15.06	–	–	Singh et al. (1997)
	−6.19 to −22.20	–	0.00 to −6.20	Singh et al. (2000)
	–	–	−2.03 to 19.30	Chaubey and Ram (2004)
No. of fruits/vine	–	20.00–45.00	–	Lal et al. (1976)
	21.40–78.99	–	–	Sirohi and Choudhury (1978)
	13.70–34.40	–	–	Singh and Joshi (1980)
	5.20–62.92	–	–	Lawande and Patil (1989)
	5.20–62.92	–	–	Lawande and Patil (1990)
	32.12–73.28	–	–	Chaudhuri and Kale (1991)
	–	–	29.35–32.70	Ranipse et al. (1992)
	0.86–44.44	0.39–35.02	–	Munshi and Sirohi (1993)
	–	2.38–75.59	–	Khattra et al. (1994)
	–	−51.97 to 119.2	16.20–9.00	Mishra et al. (1994)
	2.18–44.85	2.18	6.47–51.65	Celine and Sirohi (1996)
	–	−66.67 to 30.61	–	Ram et al. (1997)
	2.38–75.59	–	–	Singh et al. (1997)
	−21.64 to 59.1	–	2.15–59.14	Tewari and Ram (1999)
	13.15–130.0	–	25.39–86.20	Singh et al. (2000)
	–	4.46–74.05	1.91–53.84	Singh et al. (2001)

(continued)

Table 8.2 (continued)

Character	Mid parent	Better parent	Standard parent	Reference
Fruit length	–	16.70–31.20	–	Lal et al. (1976)
	1.25–38.90	–	–	Sirohi and Choudhury (1978)
	1.60–29.90	–	–	Singh and Joshi (1980)
	−43.36 to 10.20	–	–	Lawande and Patil (1989)
	−43.33 to 10.00	−55.60 to 22.3	–	Lawande and Patil (1990)
	18.11–85.70	–	–	Chaudhari and Kale (1991)
	–	–	15.81–26.02	Ranipse et al. (1992)
	0.32–24.04	0.00–1.01	–	Munshi and Sirohi (1993)
	–	0.90–17.75	–	Khattra et al. (1994)
	–	−51.62 to 35.24	−11.00 to −39.40	Mishra et al. (1994)
	0.25–12.90	–	–	Celine and Sirohi (1996)
	–	−73.07 to 0.00	–	Ram et al. (1997)
	0.90–17.75	–	–	Singh et al. (1997)
	3.54 to −12.22	–	−26.24 to 37.08	Tewari and Ram (1999)
	–	1.40–25.46	10.19–53.16	Singh et al. (2001)
	–	–	64.6–82.3	Chaubey and Ram (2004)
Fruit girth	–	10.00–29.40	–	Lal et al. (1976)
	1.15–32.13	–	–	Sirohi and Choudhury (1978)
	−8.48 to 12.13	–	–	Lawande and Patil (1990)
	35.64–77.19	–	–	Chaudhari and Kale (1991)
	–	–	12.93–13.95	Ranipse et al. (1992)
	0.32–24.04	0.00–1.01	–	Munshi and Sirohi (1993)
	–	0.29–8.98	–	Khattra et al. (1994)
	–	−25.18 to 8.35	−12.50 to −42.10	Mishra et al. (1994)
	7.67–9.11	19.84–32.44	–	Celine and Sirohi (1996)
	–	−51.84 to 0.00	–	Ram et al. (1997)
	0.29–8.98	–	–	Singh et al. (1997)
	−1.72 to 14.33	–	−22.98 to −8.95	Tewari and Ram (1999)
	–	0.28–16.49	0.01–14.06	Singh et al. (2001)
	–	–	−19.8 to 2.60	Chaubey and Ram (2004)

(continued)

Table 8.2 (continued)

Character	Mid parent	Better parent	Standard parent	Reference
No. of seeds/fruit	1.83 to −10.43	1.43–38.44	1.83–61.86	Celine and Sirohi (1996)
Flesh thickness	2.94–26.63	–	–	Sirohi and Choudhary (1978)
	–	–	32.55–43.18	Ranipse et al. (1992)
	1.45–20.16	1.45–18.55	–	Munshi and Sirohi (1993)
	6.13–16.26	1.47–6.27	6.13–11.16	Celine and Sirohi (1996)
Fruit yield/vine	–	39.00–139.1	–	Lal et al. (1976)
	0.08–128.41	–	–	Sirohi and Choudhary (1978)
	1.30–18.80	–	1.30–7.70	Singh and Joshi (1980)
	15.00–86.09	−1.50 to 35.00	–	Lawande and Patil (1990)
	24.47–235.9	–	–	Chaudhari and Kale (1991)
	–	–	93.96	Ranipse et al. (1992)
	1.62–95.82	0.03–58.03	–	Munshi and Sirohi (1993)
	–	4.35–64.28	–	Khattra et al. (1994)
	–	−28.69 to 139.9	46.70	Mishra et al. (1994)
	0.47–54.00	0.47–54.00	1.63–55.80	Celine and Sirohi (1996)
	–	−71.88 to 98.17	–	Ram et al. (1997)
	4.35–64.28	–	–	Singh et al. (1997)
	−10.31 to 50.02	–	2.15–50.14	Tewari and Ram (1999)
	25.85–200.0	−38.13 to 100.0	–	Singh et al. (2000)
	–	4.85–95.31	3.57–98.21	Singh et al. (2001)
	–	–	4.80–41.90	Chaubey and Ram (2004)

Source Somnath (2008)

effective, but the plants were not stable after M_4 generation (Reyes and Rasco 1994).

Polyploidy breeding. The natural polyploids recorded in this genus are *M. subangulata* subsp. *renigera* with 2n = 56 (Bharathi et al. 2010), *M. dioica* 2n = 42 (Agarwal and Roy 1976) and *M. charantia* 2n = 33 (Roy 1985). Teasel gourd (tetraploid) has been adapted to vegetative propagation through adventitious tubers to overcome the barriers of sexual propagation (Singh 1979). The reported occurrence of tetraploid forms in *M. dioica* (Roy et al. 1966) may probably be a misidentification of *M. subangulata* which is an allotetraploid derived from spine gourd and sweet gourd. Artificial tetraploids and triploids of bitter gourd (Saito 1957; Kadir and Zahoor 1965; Wanjari and Phadnis 1971; Trivedi and Roy 1973; Roy et al. 1966) and octoploids of teasel gourd (Cho et al. 2006) have been produced. However, artificial induction of polyploidy for economic exploitation has not resulted in evolving superior types over their diploid counterparts though the plants seemed to be vigorous (Roy et al. 1966). One of the practical uses of polyploidy is to overcome inter-specific and inter-generic fertility barriers (Laptev 1973). At CHES, Bhubaneswar, a fertile inter-specific hybrid was developed by crossing induced tetraploid (spine gourd) with the natural tetraploid (teasel gourd) (unpublished).

Colchicine is the most widely used chemical for chromosome doubling. The method of treatment and the optimum concentration of colchicines varies with the plant part used. Artificial induction of polyploidy for economic exploitation has not evolved superior types over their diploid counterparts. Polyploids can be produced by treating the seedlings at the cotyledon stage with an emulsion of 0.2 % colchicine. Cho et al. (2006) reported that seed treatment 0.4 % colchicines and 0.003 % with amiprophos-methyl was effective for chromosome doubling, in *M. dioica* (probably *M. subangulata* subsp. *renigera*) and produced octoploids. Amiprophos-methyl treated seeds showed high rate of germination. The octoploid plants showed bigger leaves and guard cells while leaf shape index (leaf length/leaf width) was lower than the tetraploids. Colchicine treatment (0.2 % for 18 h) of bitter gourd seedlings (shoot tip) produced tetraploids (Kadir and Zahoor 1965). However, the polyploids were inferior to diploids in terms of economic characters though it is possible that by suitable treatment it may be possible to raise fertile gynoecious, androecious and trimonoecious types of sex forms in bitter gourd (Trivedi and Roy 1973).

Genetic mapping and Molecular breeding. The primary utility of genetic maps in crop improvement is their deployment in marker-assisted selection and breeding. Genetic differences between *M. charantia* var. *charantia* and *M. charantia* var. *muricata* accessions indicated that they are potential parents for the establishment of mapping populations (Behera et al. 2008a). Kole et al. (2010a, b) detected many AFLPs linked to fruit quality traits employing association mapping. The first genetic linkage map of bitter melon was developed by Kole et al. (2012) using a set of 146 F_2 progenies derived from an inter-botanical variety cross between Taiwan White (*Momordica charantia* var. *charantia*) and CBM12 (*M. charantia* var. *muricata*). They identified four Quantitative Trait Loci (QTLs) for fruit number and yield, two QTLs for fruit length and one QTL each for fruit diameter and weight.

Although bitter gourd has a long cultivation history, molecular research and breeding efforts were started later than the other cucurbitaceous vegetables. In recent years, variation in DNA fractions has been extensively used to study the diversity of *M. charantia*. The identification of molecular markers may augment phenotypic selection if markers are identified that are closely linked to or at genes controlling the traits of interest. Although DNA marker analysis can assist in diversity analyses (Behera et al. 2008b), only a few polymorphic markers have been identified in bitter gourd (Dey et al. 2006; Singh et al. 2007; Gaikwad et al. 2008) and teasel gourd (Rasul et al. 2007). Species and genotype-specific fragments detected by the random markers would be useful in introgression breeding for genetic improvement of *Momordica* cultivated in India (Bharathi et al. 2012b).

Genetic Engineering. To date, the genetic improvement of bitter gourd has been mainly achieved by conventional plant breeding methods. Somatic embryogenesis in suspension is an effective aid for genetic transformation studies. Reports on somatic embryogenesis in cell suspension culture are not extensive. Few reports on somatic embryogenesis through cell suspension culture for bitter gourd have been published (Thiruvengadam et al. 2006; Sultana and Rahman 2012). Among the available gene transfer systems, *Agrobacterium*-mediated gene transfer is considered more efficient for the stable integration of genes into plant genome. *Agrobacterium*-mediated *β*-glucuronidase expression was detected in explants of immature cotyledonary nodes in *M. charantia* (Sikdar et al. 2005). An efficient protocol for *Agrobacterium*-mediated genetic transformation of bitter melon using leaf disc as explants was reported (Thiruvengadam et al. 2012) and this optimised transformation system could be used for the genetic improvement of bitter melon.

Breeding for pests and disease resistance. Very little work has been attempted towards breeding for insect pests and disease resistance though there is wide diversity available in the local germplasm. In bitter gourd, several genetic studies have shown that an association exists between morphological traits and insect resistance and that these associations may be useful for indirect selection during resistance breeding (Dhillon et al. 2005a).

M. balsamina was reported to be highly tolerant to most of the typical cucurbit diseases and pests like ladybird beetle, red pumpkin beetle, pumpkin caterpillar, gall fly, root knot nematode, cucurbit yellow mosaic and little leaf disease (Joseph and Antony 2008) may contribute to *Aulocophora* tolerance in *Momordica* species (Behera et al. 2011). *M. dioica* had been found to be tolerant to pumpkin caterpillar, gall fly and root knot nematode, whereas *M. sahyadrica* was highly tolerant to pumpkin caterpillar, root knot nematode and fruit fly. *M. subangulata* subsp. *renigera* is resistant to cucurbit yellow mosaic and little leaf diseases (Joseph 2005). These resistance sources along with wild African species like *M. foetida* and *M. rostrata* may play a role in resistance breeding programmes.

Fruit fly is a major pest of bitter gourd and other *Momordica* species like *M. dioica*, *M. cochinchinensis* and *M. subangulata* subsp. *renigera*. The strain 'Green Rough' (Fernando and Udurawana 1941), more prickly variety 'Phule BG 4' (Anon 1990) of bitter gourd was comparatively resistant to fruit fly. Tewatia and Dhankhar (1996) suggested reciprocal recurrent selection to develop fruit fly resistant varieties after studying the inheritance of fruit fly resistance. The wild variety *M. charantia* var. *muricata* shows high level of tolerance to fruit fly and it crosses with the cultivated var. *M. charantia* var. *charantia*. However, the wild variety has a dominant trait in F1 for fruit shape and size, which is not desirable (Behera et al. 2010). Wild African species like *M. foetida*, *M. rostrata* may play a major role in resistance breeding programmes of *M. charantia* (Njorge and van Luijk 2004) and *M. balsamina* may contribute to *Aulocophora* tolerance in *Momordica* species (Behera et al. 2010). The resistant source for bitter gourd fruit fly is presented in Table 8.3. Out of 13 genotypes screened against fruit fly, Col-II and FSD-long were found to be resistant and can be used as a source of resistance for developing bitter gourd genotypes resistant to melon fruit flies (Gogi et al. 2009).

Among the accessions maintained at the Institute of Plant Breeding, Philippines, the accessions 83-003, 83-006 and 9-32 were found to be bacterial wilt resistant and none of the accessions was resistant to root knot nematode and *Cercospora* leaf spot (Alcazar and Gulick 1983). Out of 86 genotypes screened against bitter gourd distortion mosaic virus (BDMV), nine genotypes from northern and central parts of Kerala were identified as resistant viz, IC 68296, IC 68335, IC 68263B, IC 68275, IC 68250A, IC 85620, IC 68285, IC 68312 and IC 68272 and suggested scope for exploitation

Table 8.3 Sources of resistance to fruit fly

Genotype	Remarks	Reference
IIHR 89, IIHR 213	Resistant, thick and tough fruit rind	Pal et al. (1984)
Hisar 11, Acc. 3, Ghoti	Resistant	Srinivasan (1991)
Acc. 23, Acc. 33	Resistant	Thakur et al. (1992)
C96	Stable yield, resistant	Thakur et al. (1992)
BBT 1	Stable resistance	Thakur et al. (1994)
BG 14	Resistant, High yield	Thakur et al. (1996)
Kerala Collection 1, Faizabad collection 17	Resistant, High yield	Tewatia et al. (1997)

Source Dhillon et al. (2005b)

of heterosis with resistance to BDMV (Arunachalam 2002). Khaire et al. (1987) reported BG 598 and BG 102 as resistant to pumpkin beetle. Biophysical characteristics of the plants play an important role in affecting infestation of foliage feeding insect pests.

Mandal et al. (2012) reported that the higher the length of trichome and density the lower the incidence of the foliage feeding insect pests and the cultivars having dense trichome showed tolerance against foliage feeding insect pests. Females of leaf miner are often deterred from ovipositing on *M. charantia* leaves due to the presence of momordicin I (Mekuria et al. 2005) and momordicin II which was found to elicit feeding deterrent activity against red pumpkin beetle (Chandravadana 1987). Selecting/screening plants with high trichome density and high momordicin I, II can reduce the incidence and be used in further resistance breeding programmes.

Breeding for stress tolerance. Sundaram (2009) evaluated eight genetically diverse parents of bitter gourd under saline soil and it was found that BGS 1 was the best as it had recorded significant performance for five of the eight characters studied and could be better utilised in further breeding programmes for improvement of yield under saline conditions. The preponderance of dominant gene action for node of first male flower appearance, vine length, yield of fruits per vine and leaf sodium: potassium ratio revealed the importance of heterosis breeding for simultaneous improvement of yield as well as saline tolerance in bitter gourd (Sundaram 2007).

Utilisation of wild species for Momordica breeding. Inter-specific hybridisation is used to improve crops by transferring specific traits such as pest and stress resistance from their wild relatives (Bowley and Taylor 1987) to their cultivated counterparts and is one of the most important challenges for breeders, but the genetic resources of wild *Momordica* species have not been explored yet. The wild species of *Momordica* offer great resources for improvement of cultivated bitter gourd for desirable edible/quality traits, biotic and abiotic stress (Joseph 2005). In *M. dioica* the tubers do not have the capacity to perpetuate indefinitely and cannot be used for mass multiplication while the adventitious root propagation in *M. subangulata* subsp. *renigera* is unique to the species and can be used fruitfully in the breeding of *Momordica* (Joseph et al. 2009). Ali et al. (1991) highlighted the scope for transfer of useful traits from the related species of *Momordica* to *M. dioica* through inter-specific hybridisation.

There are a few reports of inter-specific hybridisation between *M. dioica* and *M. cochinchinensis* (Mohanty et al. 1994; Mondal et al. 2006), *M. charantia* and *M. balsamina* (Singh 1990), *M. charantia* and *M. dioica* (Roy et al. 1966; Dutt and Pandey 1983; Vahab and Peter 1983; Anon. 2004), *M. balsamina* and *M. dioica* (Roy et al. 1966) and among the species of Indian occurrence (Bharathi et al. 2012a). However, the poor germination of F_1 seeds, unsatisfactory growth and flowering in F_1 seedlings, and partial to complete sterility in F_1 indicate the rather limited potential of inter-specific hybrids from these species in conventional crop improvement (Bharathi et al. 2012a). In many cases, this sterility was associated with meiotic abnormalities, and was a large obstacle that followed hybridisation and hindered utilisation. When chromosomes are doubled, each chromosome will have a homologous partner for pairing during meiosis; if there is no cytoplasmic incompatibility, the chromosome-doubled F_1 hybrid may produce viable gametes and fertility restoration is anticipated. Among various agents, colchicine is one of the antimitotic substances most frequently used for this purpose (Bharathi 2010).

At CHES, Bhubaneswar, during 2008–2011, several attempts were made to restore the fertility of inter-specific hybrids between spine gourd and teasel gourd. First, triploid F_1 hybrid was backcrossed to both the parents and after several attempts (>1000) a fruit with few seeds were obtained. Substantial heterosis for vine length, number of flowers per plant and yield per plant was observed in BC_1F_1. In BC_1F_1, fruit set was significantly higher (99 %) when dusted with teasel gourd pollen while the fruit set was very less and fruits were of deshaped and not of commercial importance when selfed (35 %) or dusted with spine gourd pollen (65 %). The BC_1F_1 expressed the favourable traits of teasel gourd (earliness and adventitious root tubers) and spine gourd (fruit texture, flavor and taste). Also, the fruits were less seeded and soft with good cooking quality (in pollinations with teasel gourd) when compared to its parents indicating its potential to be exploited as a new variety (Bharathi et al. 2012c). Another attempt was made to double the ploidy of spine gourd and then crossed with the natural tetraploid teasel gourd. The F_1 was highly fertile and combined the desirable traits of both the species (Unpublished).

Inter-generic Hybridisation. In a cross between *M. charantia* and *Trichosanthes anguina* more than 50 % fruit set as well as seed germination has been reported (Patrude and Krishnamurthy 1934). The floral and vegetative traits of *M. charantia* were dominant. However, the above observation needs further experimentation for confirmation (Patrude and Krishnamurthy 1934). Of late, there were newspaper reports of an innovative farmer in Kerala cultivating F1 hybrid of bitter gourd and snake gourd as a new vegetable crop (personal communication, Dr. Joseph John K).

Varieties

Bitter gourd. Bitter gourds can be divided into three basic groups—small triangular, long dark green and the light green types that are less bitter. There are about 300 varieties found around the world. However, a few important varieties are described here.

India

Public Sector Varieties/Hybrids

(1) *Pusa Do Mausmi*. Developed at the Indian Institute of Agricultural Research (IARI), New Delhi. Fruits are long, dark green, medium thick, club-shaped with 7–8 continuous ridges. First picking begins 55 days after sowing and individual fruit weighs around 100–120 g. Suitable for spring–summer and rainy season cultivation. It gives an average yield of 12–15 t/ha in 120 days.
(2) *Pusa Vishesh*. A selection from a local variety of Hapur, Uttar Pradesh, India developed at IARI, New Delhi suitable for spring–summer season. Fruits are medium thick, dark green in colour, fusiform with regular unbroken ridges. It takes 55–60 days for first fruit harvest and gives an average yield of 15 t/ha. Because of its dwarf habit, more number of plants can be accommodated per unit area. Fruits are suitable for pickling and dehydration.
(3) *Pusa Hybrid 1*. Developed at the Indian Agricultural Research Institute (IARI), New Delhi. Pusa Hybrid 1 is proved to be superior to its parents Pusa Do Mausami and Pusa Vishesh. It gives 42–58 % higher yield than the parents. Vines are of medium growth with broad dark green leaves. The fruits are attractively green, medium long and medium thick (fruit length, 13.5 cm and breadth, 5.0 cm and flesh thickness of 7.3 mm) with irregular smooth tubercles on the surface and on an average it weighs

about 100 g. The fruits are suitable for making curries, pickles and also for dehydration purpose. Its average yield is about 21.8 t/ha.

(4) *Pusa Hybrid 2*. Fruits are dark green, medium-sized (length: 11.25 cm; breadth: 4.5 cm) with irregular smooth ridges, and individual fruit weighs around 110 g.

(5) *Kalyanpur Baramasi*. Fruits are 20–25 cm long, thin, dark green with 8–10 seeds per fruit. It is tolerant to mosaic and fruit fly under field conditions. Average yield is about 10–12.5 t/ha.

(6) *Co 1*. It is a selection from a local type collected from Thudiyalur, Tamil Nadu (Long Green). The vines are moderate in growth with a length of 130 cm and 5–7 branches per vine. The fruit is dark green, medium long (25–30 cm) and thick (6–8 cm) with characteristic warts. Each vine produces 20–22 fruits each weighing 100–120 g. Each fruit contains 24–30 seeds. Vines flower in 45–50 days and first harvest can be had in 55–60 days after sowing. The variety produces about 14.4 t/ha of fruits in crop duration of 115 days with 6–8 harvests.

(7) *MDU 1*. It is an induced mutant developed by gamma irradiation of local cultivar (MC 103). It is early in flowering (60 days) with a sex ratio of 1:20 of female and male flowers. The fruits are long with a mean length of 40.3 cm and a girth of 17.5 cm and each fruit weighs 410 g on an average. Fruits contain less seeds and each vine yields an average of 16.6 fruits. Total fruit yield is about 32.19 t/ha.

(8) *COBgoH1*. It is an F_1 hybrid developed from a cross of MC 84 × MDU 1 with high momordicine content (2.99 mg/g). The variety is suitable for cultivation in Kharif (June–Sept) and Rabi (Dec–March) seasons. Fruits at vegetable maturity are useful for making stir fry, porial and stuffed vegetable. It recorded an average yield of 44.4 t/ha with a potential yield up to 51.29 t/ha in crop duration of 115–120 days.

(9) *Coimbatore Green*. It is a selection from the Coimbatore collection and fruits are 60 cm long and dark green in colour. Individual fruits weigh between 300 and 400 g. It gives a yield of 15–18 t/ha.

(10) *Coimbatore Long White*. Developed by National Seeds Corporation. Fruits are long, tender, white in colour and suitable as a rainy season crop with an average yield of 25–30 t/ha.

(11) *VK 1 Priya*. A selection from local type developed by Kerala Agricultural University (KAU), Thrissur, India. The fruits are green with white tinge at stylar end and 35–40 cm long, heavy bearing variety with first picking in 60 days. Yield potential is up to 30 t/ha.

(12) *Preethi*. It is a selection released by KAU, Thrissur, India. Fruits are medium, white, 30 cm long and a single fruit weighs around 310 g. The yield ranged from 15 to 34 t/ha depending on location and environment.

(13) *Priyanka*. A local selection from KAU centre, Thiruvalla, Kerala, India. Fruits are uniformly white, spindle shaped with spiny ridges, medium long, average fruit weight is 300 g with yield potential of 28 t/ha.

(14) *Arka Harit*. Developed at Indian Institute of Horticultural Research (IIHR), Bangalore, India. The fruits are attractive, spindle shaped with glossy green colour, small in size with smooth regular ribs. The average yield is about 12 t/ha with crop duration 100–110 days.

(15) *Phule Green Gold*. Developed at Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India. Fruits are 25–30 cm long, dark green coloured with tubercles and suitable for the export market.

(16) *Phule Priyanka*. Developed at MPKV, Rahuri, Maharashtra, India. It is a hybrid variety with dark green colour fruits. Fruits are 20–25 cm long with tubercles. Average yield is 35–40 t/ha.

(17) *Phule Ujwala*. Developed at MPKV, Rahuri, Maharashtra, India. Fruits are 18–20 cm long, dark green in colour with tubercles and produces about 30–35 tonnes fruits per hectare suitable for export market.

(18) *RHR BGH 1*. It is an F_1 hybrid developed at MPKV, Rahuri, Maharashtra, India and is tolerant to downy mildew. It is suitable for cultivation in both summer and rainy season. Fruits are tubercled with 20 cm length and dark green in colour. The average yield of this variety is about 20 t/ha.

(19) *Hirkani*. Developed by selection from a local type at MPKV, Rahuri, Maharashtra, India. Fruits are dark green, 15-20 cm long. Average yield is 13.8 t/ha in a crop duration of 160 days.

(20) *Pant Karela 1*. Developed at Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar, Uttaranchal. It is highly resistant to red pumpkin beetle.

(21) *Pant Karela 3*. An early and high yielding variety developed at GBPUAT, Pantnagar, Uttaranchal. Its fruits are cylindrical 24 cm long of dark-green colour, and are suitable for plain and hilly areas of north India. Yield potential of this variety is 16 t/ha.

(22) *Konkan Tara*. Developed by Konkan Krishi Vidyapeeth, Dapoli, Maharashrtra, India. Fruits are green, prickly medium long (15 cm) and spindle shaped. Yield potential is 24 t/ha.

Private Sector Varieties/Hybrids

(1) *Chaman*. F_1 hybrid developed by Nunhems India Pvt. Ltd., Bangalore. It is an early maturing and prolific bearing hybrid. Fruits are attractive, shining and green coloured (Fig. 8.2a) with prominent tubercles.

(2) *Sarkar*. F_1 hybrid developed by Nunhems India Pvt. Ltd., Bangalore. Plants are vigourous with strong vines and more branches. Fruits are traditional jhalari type, attractive, shining and dark green (Fig. 8.2b). It shows intermediate resistance to downy mildew.

(3) *Amanshri*. F_1 hybrid developed by Nunhems India Pvt. Ltd., Bangalore. Prolific bearer, fruits are attractive, shining, green to dark green in colour (Fig. 8.2c). It has extended harvesting period, good shipping and keeping quality.

(4) *Racer*. Predominantly female bearing F_1 hybrid developed by Nunhems India Pvt. Ltd., Bangalore. Fruits are spindle shaped, dark green coloured and 8–10 cm long (Fig. 8.2d).

(5) *Visesh*. F_1 hybrid developed by Golden seeds, India. Fruits are dark green with prominent tubercles. Individual fruit weighs around 100–125 g.

(6) *Prachi*. F_1 hybrid developed by East–West seeds, India. Plants are vigorous bearing short spindle shaped fruits of 5–6 cm length. Fruits are dark green coloured with medium tubercles. This hybrid is suitable for stuffed preparations.

(7) *Vivek*. F_1 hybrid developed by Sungro seeds, India. Fruits are straight, dark green coloured with sharp tubercles and weighing 125 g.

(8) *NS 1024*. F_1 hybrid developed by Namdhari seeds Pvt. Ltd., Bangalore, India. It is an early hybrid that starts fruiting at 45–50 days of sowing. Fruits are long (25–30 cm), dark green with shining skin and sharp tubercles.

(9) *NS 463*. F_1 hybrid developed by Namdhari seeds Pvt. Ltd., Bangalore, India. Plants are vigorous, early and good yielders. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 30–35 cm in length and weighing 350–400 g with blunt ends. Perform well in Thailand and is recommended for South–East Asia.

(10) *NS 469 (H 2069)*. Developed by Namdhari seeds Pvt. Ltd., Bangalore, India. The plants are vigorous and early. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 35–40 cm in length with blunt ends and weighing 700–750 g.

(11) *NS 473 (H 63)*. F_1 hybrid developed by Namdhari seeds Pvt. Ltd., Bangalore, India. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 22–25 cm in length having attractive spindle shape. Early and

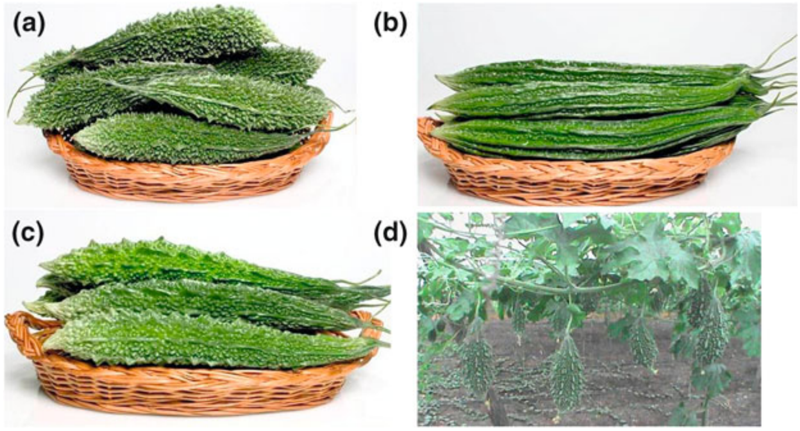

Fig. 8.2 Improved varieties/hybrids of bitter gourd. **a** Chaman, **b** Sarkar, **c** Amanshri, **d** Racer (*Source* Nunhems India Pvt. Ltd., Bangalore)

vigorous plants of this hybrid are high yielding and recommended for cultivation in India.

(12) *NS 497*. F_1 hybrid developed by Namdhari seeds Pvt. Ltd., Bangalore, India. Vigorous plants, early and good yielders. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 30–35 cm in length and weighing 350–400 g with blunt ends. Performs well in Thailand and is recommended for South–East Asia.

(13) *NS 487*. F_1 hybrid developed by Namdhari seeds Pvt. Ltd., Bangalore, India. Vigorous plants, early and good yielders. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 30–35 cm in length and weighing 350–400 g with blunt ends. Perform well in Thailand.

(14) *NS 469T*. Developed by Namdhari seeds. The plants are vigorous and early. Fruits are shiny light green with continuous attractive ribs and few bubbles. Fruits are 35–40 cm in length with blunt ends and weighing 700–750 g.

China

(1) *Xiang Kugua 1*. Developed in Hunan Vegetable Research Institute, China. It is an early maturing, high yielding variety of good quality.

(2) *Cuilii*. It is an F_1 hybrid developed by crossing gynoecious line 19 with Jiang Xuan 105. It is early maturing and high yielding suitable for cultivation in southern China in spring and autumn.

Some other remarkable bitter gourd varieties/hybrids are Darouyihao, Guinongke 1, Guinongke 2, Yu 5, Zaoyoukugua, Zaolukugua, Nongyou 1, Xinke 3 Kugua, Hongkong Green, Large Top, Hybrid Beauty Winner-1, Green Lover and strong-female varieties Q11-2 and Yuqiang-2.

Australia

(1) *Kiew Yoke 59*. Productive cultivar with long, smooth light green fruit. Fruit weight 500–600 g.

(2) *Kiew Yoke 68*. Vigorous, disease tolerant cultivar with large and broad shouldered, glossy fruit. Single fruit weighs around 500–600 g with good shelf life and recommended for rainy season production.

(3) *Known You Green*. A Taiwanese cultivar with a smooth, shiny, beautiful green skin. Plants are early, vigorous and prolific. Fruit has ribbed stripes and weighs 400–700 g. The flesh is green and mildly bitter. Fruit is good for salad and frying.

(4) *Verdure*. An early, vigorous, productive, high yielding cultivar. Fruits are short,

beautifully shaped with a maximum weight of 500 g. Its green skin and light green flesh are suitable for stewing.

(5) *Moonrise*. Plants are early, vigorous and prolific. Fruits are long, with light green skin and flesh and weigh up to 700 g. It has an excellent crispy and tender taste and is ideal as a fresh vegetable and also for stir frying.

(6) *Moonlight*. An early, prolific cultivar which produces medium-long fruit that seldom cracks. Fruits weigh up to 650 g and have light green skin and flesh. This cultivar is suitable for use as a fresh vegetable and for stir frying.

(7) *Moon Beauty*. Plants are early, vigorous and high yielding. Fruits are oblong shaped and have shiny white skin with a wart-like surface. Moon Beauty fruits are 30 cm long and 9 cm wide and weigh 700 g. It has thick and crispy flesh with good taste.

Philippines

Popular varieties in the Philippines include open pollinated varieties Sta Rita, Makiling and their F_1 hybrids namely Jade Star A and B (Reyes and Rasco 1994).

Sta Rita. It is an open pollinated variety and most popular in Philippines. First harvest starts from 70 days after planting. Its fruits are green, thin straight, shiny, 20–35 cm long weighs about 200 g and resistant to downy mildew.

Japan

Japan Long, Japan Green Spindle, Nikko and Peacock.

Taiwan

Taiwan Large, Taiwan White, Hybrid White Pearl, Hybrid Taiwan White.

Thailand

Small Baby, Hybrid Bangkok Large, Hybrid White Pearl, Hybrid Jumbo Choice.

Sri Lanka

Palee, Matale Green and Thinnaweli White.

Pakistan

Ambika, Rama Krishna and Phauja.

Bangladesh

Hybrid White, Hybrid Green.

USA

CBM 9, CBM 10, CBM 12, CBM 18.

Spine Gourd

(1) *Arka Neelachal Sree*. Developed through clonal selection at Central Horticultural Experiment Station, Bhubaneswar, India. It has good appearance, high yield (4–5 kg/plant) and high market preference (Fig. 8.3a). Its vines are thin and spreading which grows well on 3-line wire-trellis system. The variety is moderately resistant to anthracnose and downy mildew in fields, and is moderately susceptible to angular leaf blight and pumpkin caterpillar.

(2) *Indira Kankad (RMF 37)*. It is the first variety of spine gourd released for commercial cultivation by Indira Gandhi Agricultural University, Ambikapur, Chattisgarh, India. Its fruits are dark green coloured. Single fruit weighs around 14 g

Fig. 8.3 Improved varieties of dioecious *Momordica* species. **a** Arka Neelachal Sree (*M. dioica*), **b** Arka Neelachal Gaurav (*M. subangulata* subsp. *renigera*)

and the average yield is 0.8–1 t/ha in the first year and 1.0–1.5 t/ha in the second year and 1.5–2.0 t/ha in third year after planting.

(3) *Visal*. It is popular among the farmers of Sri Lanka.

(4) *Small Baby Doll*. It is popular among the farmers of Thailand.

Teasel Gourd

(1) *Arka Neelachal Gaurav*. Developed through clonal selection at Central Horticultural Experiment Station, Bhubaneswar, India. It is characterised by dark-green and oval fruits along with small spines (Fig. 8.3b). Its fruits are 6.0 cm long and 3.8 cm thick with an average weight of 50 g. The plant produces 230–250 fruits in full cropping season with assured pollination. The variety needs hand pollination for assured yield which varies between 12 and 15 kg per plant per season. The selected variety is vigorous with dark-green foliage, strong vine and fairly long growing period (15 June–15 October). It produces large numbers of female flowers and shows moderate resistance to pumpkin caterpillar infestation, and moderate susceptibility to anthracnose and downy mildew diseases in the field.

Barring Indian taxa, the South East Asian and African taxa needs to be studied for their ecology, biology and breeding behaviour. Except for enumeration and morphological description, in-depth botanical studies are absent and hence a botanical treatise on biology and breeding behaviour of the taxa leading to their agronomic utilisation and ex situ conservation is the need of the hour. Only in *M. charantia*, a fairly large number of accessions have been explored and available for improvement while in other species only limited work has been carried out. To a large extent, the success of plant breeding depends upon the genetic diversity of germplasm. The natural genetic diversity available in South–East Asia needs to be exploited and genetic analysis of morphological and yield related traits needs to be studied to provide a rational basis for on-going breeding efforts. Among the different species of Asia, some genetic/cytogenetic information has been accumulated on *M. charantia* and emphasis should be given to other species also. Utilisation of interspecific hybridisation for the improvement of *Momordica* is limited due to limited success of species hybridisation and hybrid sterility. There is a need to find out the barriers in various cross combinations and methods to overcome the barriers. In some cases, for example, between the two botanical varieties of *M. charantia*, though high crossability is there, concerted efforts have not been made to advance the crosses (F_2, F_3, BC_1, BC_2, etc.) to get the desirable trait. Very little attention has been given to improve the quality and productivity in these vegetables and there is a great scope to exploit heterosis to increase the productivity and quality. There is a need to make concerted effort to promote progress in the exploitation of heterosis in these crops.

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