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Bitter Gourd: Botany, Horticulture, Breeding

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I. INTRODUCTION

The vegetable *Momordica charantia* L., Cucurbitaceae, is known variously as bitter gourd, balsam pear, bitter melon, bitter cucumber, and African cucumber (Heiser 1979). Although it has many culinary uses, especially in south, southeast and east Asia, it is also grown as an ornamental and is used extensively in folk medicine (Heiser 1979). The fruits are cooked with other vegetables, stuffed, stir-fried, or added in small quantities to beans and soups to provide a slightly bitter flavor. However, for most food preparation, fruits are blanched, parboiled, or soaked in salt water before cooking to reduce the bitter taste. In addition to frying or cooking (e.g., for curries), the fruits can be dehydrated,

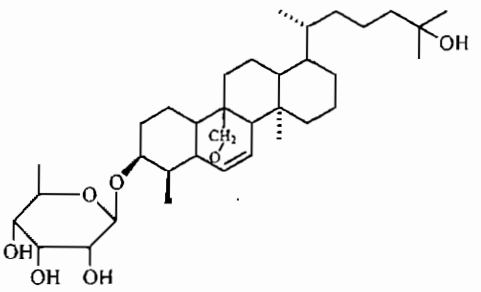

Fig. 2.1. Basic structure of Momordicine, the primary bitter compound of bitter gourd.

pickled, or canned. Fruits, flowers, and young shoots are also used as flavoring agents in various Asian dishes. Young *Momordica* shoots and leaves are also cooked and eaten as leafy vegetables, and leaf and fruit extracts are used in the preparation of tea (Tindall 1983; Reyes et al. 1994). Unlike other cucurbitaceous vegetables, the bitter fruit flavor of *M. charantia* is considered desirable for consumption, and thus bitter flavor has been selected during domestication (Marr et al. 2004).

The bitterness of most cucurbits is mainly due to cucurbitacins (Decker-Walters 1999). The bitterness of bitter gourd is due to the cucurbitacin-like alkaloid momordicine (Fig. 2.1) and triterpene glycosides (momordicoside K and L) (Jeffrey 1980; Okabe et al. 1982). These compounds lack the oxygen function at C-11 that characterizes "true" cucurbitacins (Neuwinger 1994) and are the bitterest compounds in the plant kingdom (Johns 1990).

A. Origin and Domestication

The center of bitter gourd domestication likely lies in eastern Asia, possibly eastern India or southern China (Walters and Decker-Walters 1988; Miniraj et al. 1993). Uncarbonized seed coat fragments have been tentatively identified from Spirit Cave in northern Thailand. However, there have been no archaeological reports of bitter gourd remains in China (Marr et al. 2004). Moreover, a comprehensive compilation of plant remains from 124 Indian archaeological sites does not include bitter gourd (Kajale 1991). Wild or small-fruited cultivated forms, however, are mentioned in Ayurvedic texts written in Indian Sanskrit from 2000 to 200 BCE by members of the Indo-Aryan culture (Decker-Walters 1999), indicating an early cultivation of bitter gourd in India. The lack of a unique set of Indo-Aryan words indicates that the Aryans did not know bitter melon before entering India (Walters and Decker-Walters 1988).

The most modern Hindi (Indian language) term "karela" may ultimately be of Dravidian origin (Turner1966). The earliest written reference to *M. charantia* in China was made in 1370 CE (Yang and Walters 1992).

Both the domesticated and putative wild bitter gourd progenitors of bitter gourd are listed in floras of India, tropical Africa, and Asia as well as the New World tropics, where it first arrived in Brazil via the slave trade from Africa and then spread into Central America (Marr et al. 2004). Based on both historical literature (Chakravarty 1990; Miniraj et al. 1993; Walters and Decker-Walters 1988), and recent random amplified polymorphic DNA (RAPD; Dey et al. 2006a), intersimple sequence repeats (ISSR; Singh et al. 2007) and amplified fragment length polymorphisms (AFLP; Gaikwad et al. 2008) molecular analyses, eastern India (includes the states of Orissa, West Bengal, Assam, Jharkhand, and Bihar) may be considered as a probable primary center of diversity of bitter gourd, where a wild feral form *M. charantia* var. *muricata* (Chakravarty 1990) currently exists. Wild germplasm of bitter gourd has been important to the development of today's crop. For example, a gynoecious line (DBGy 201) was isolated from wild and/or diverse relatively unselected landraces indigenous to eastern India and has been maintained through sib mating. The hybrids produced by using DBGy 201 as one of the parents have shown high percentages of pistillate (female) flowers and remarkable yield potential (Behera et al. 2008b).

B. Nutritional Uses

Bitter gourd fruits are a good source of carbohydrates, proteins, vitamins, and minerals (Table 2.1) and have the highest nutritive value among cucurbits (Miniraj et al. 1993; Desai and Musmade 1998). The vitamin C content of Chinese bitter gourd varies significantly (440–780 $mg \cdot kg^{-1}$ edible portion). Considerable variation in nutrients, including protein, carbohydrates, iron, zinc, calcium, magnesium, phosphorous, and ascorbic acid, has been observed in bitter gourd (Kale et al. 1991; Yuwai et al. 1991). Moreover, the crude protein content (11.4–20.9 $g \cdot kg^{-1}$) of bitter gourd fruits is higher than that of tomato and cucumber (Xiang et al. 2000).

C. Medicinal Properties

Bitter gourd has been used for centuries in the ancient traditional medicine of India, China, Africa, and Latin America. Bitter gourd extracts possess antioxidant, antimicrobial, antiviral, antihepatotoxic, and antiulcerogenic properties while also having the ability to lower blood sugar (Welihinda et al. 1986; Raman and Lau 1996). These medical

Table 2.1. Proximate principles and nutrient composition of bitter gourd (*Momordica charantia* L.) fruit.

Proximate principles	Quantity
Moisture (g/100 g)	83.20
Carbohydrates (g/100 g)	10.60
Proteins (g/100 g)	2.10
Fiber (g/100 g)	1.70
Calcium (mg/100 g)	23.00
Phosphorus (mg/100 g)	38.00
Potassium (mg/100 g)	171.00
Sodium (mg/100 g)	2.40
Iron (mg/100 g)	2.00
Copper (mg/100 g)	0.19
Manganese (mg/100 g)	0.08
Zinc (mg/100 g)	0.46
β Carotene	126.00
Vitamin C	96.00

Source: Gopalan et al. (1993). Nutritive value of Indian foods. National Institute of Nutrition, ICMR, Hyderabad.

activities are attributed to an array of biologically active plant chemicals, including triterpenes, pisteins, and steroids (Grover and Yadav 2004). Ethno-medical reports of *M. charantia* indicate that it is used in folkloric medicine for treatment of various ulcers, diabetes, and infections (Gurbuz et al. 2000; Scartezzini and Speroni 2000; Beloin et al. 2005). While the root decoctions have abortifacient properties, leaf and stem decoctions are used in treatment of dysentery, rheumatism, and gout (Subratty et al. 2005). In addition, juice of *M. charantia* drawn directly from fruit traditionally has been used for medicinal purposes worldwide. Likewise, the extracted juice from leaf, fruit and even whole plant are routinely used for treatment of wounds, infections, parasites (e.g., worms), measles, hepatitis, and fevers (Behera et al. 2008c).

1. Hypoglycemic Activity. Bitter gourd extracts traditionally used as vegetable insulin possess hypoglycemic, antioxidative, and antidiabetic agents (Vikrant et al. 2001; Chen et al. 2003) that are useful in the treatment of diabetes (Baynes 1995). The hypoglycemic effects (i.e., blood sugar lowering) of extracts have been well documented in animal (Raza et al. 1996; Sarkar et al. 1996; Ahmed et al. 1998; Raza et al. 2000; Ahmed et al. 2001; Grover et al. 2001; Miura et al. 2001; Grover et al. 2002; Rathi et al. 2002a,b; Kar et al. 2003; Ahmed et al. 2004; Chaturvedi et al. 2004; Miura et al. 2004; Sathishsekar and Subramanian 2005; Shetty et al. 2005) and human (Baldwa et al. 1977; Leatherdale et al. 1981;

Welihindal et al. 1986; Srivastava et al. 1993) experiments. The beneficial hypoglycemic properties in fruit pulp, seed, and whole plant extracts have also been documented in rat analyses (Jayasooriya et al. 2000; Kar et al. 2003), and the medicinal attributes of such extracts have received broad review (Basch et al. 2003; Subratty et al. 2005; Krawinkel and Keding 2006). One study cites that there was a significant increase in the number of cells in the pancreas of streptozotocin-induced diabetic rats after 8 weeks of bitter gourd fruit juice treatment (Ahmed et al. 1998). In a parallel in vivo clinical human study, oral ingestion of all parts of the bitter gourd plant resulted in low patient toxicity (Rathi et al. 2002b). A mixture of steroidal saponins known as charantin (insulinlike peptides), as well as alkaloids, appears to be responsible for the hypoglycemic actions in bitter gourd extracts.

Some studies have shown that at least three components (steroidal saponins, insulinlike compounds, and alkaloids) were found in bitter gourd plant parts that elicited hypoglycemic potential and/or other benefits for sufferers of diabetes mellitus. The hypoglycemic effect of these chemicals is more pronounced in fruit, where they are present in great abundance. Of the rich mixture of hypoglycemic compounds in bitter gourd fruit, charantin, vicine, and polypeptide-P are thought to provide the major diabetic medical benefits (Yeh et al. 2003; Table 2.2). Polypeptide-P, a previously unidentified insulinlike protein similar to bovine insulin, was identified in bitter gourd fruit and seed and in tissue culture (Khanna and Jain 1981). Although the mechanism of action of these hypoglycemic compounds is still debated, they either regulate insulin release directly or alter glucose metabolism and its insulinlike effect.

2. Antioxidant Activity. The antioxidant properties of carotenoids that protect plants during photosynthesis may also protect humans from carcinogens and mitigate free radical effects associated with heart disease. Natural antioxidants, primarily plant phenolics and polyphenolic compounds (e.g., in fruits and seeds of bitter gourd), are alternatives to synthetic antioxidants for alleviating oxidative deterioration in fruit. For instance, bitter gourd fruit contains as many as 14 carotenoids depending on stage of maturity (5, 6, and 14 in the immature, mature-green, and ripe stage, respectively), where cryptoxanthins becomes the principal chloroplast and chromoplast pigment found in ripe fruit (Rodriguez et al. 1976). Other carotenoids, such as β-carotene, zeaxanthin and lycopene (at ripe stage), and lutein and α-carotene (immature fruit) are also prevalent in the fruits, where they could serve as a model for studying carotenogenesis during ripening (Rodriguez et al. 1976). For instance, carotenogenesis in bitter gourd is not affected by temperatures above 30°C (Tran and Raymundo 1999); in contrast, in

Table 2.2. Major phytochemicals in bitter gourd (*Momordica charantia* L.) fruit, and their health benefits.

Phytochemicals	Plant parts	Usefulness	Reference
β-momorcharin	Seeds	Glycoprotein that acts as midterm abortifacient	Chan et al. 1984
Vicine	Seeds	Hypoglycemic glycoalkaloid	Dutta et al. 1981; Handa et al. 1990
Charantin	Fruits	Nonnitrogenous substance having hypoglycemic principle	Lotlikar and Rao, 1962
Momordicosides A and B	Seeds	Triterpene glycosides that inhibit tumor growth	Okabe et al. 1980
MAP 30	Seeds, fruits	Basic protein that inhibits human immunodeficiency virus (HIV).	Lee et al. 1990, 1995
Polypeptide-p	Seeds, fruits	Hypoglycemic peptide, called plant insulin	Khanna and Jain 1981
Phenols	Seeds,	Antioxidants that reduce blood pressure and lower incidence of cancer and cardiovascular diseases	Horax et al. 2005
Carotenoids	Seeds, fruits	Antioxidants that lower the incidence of cancer and cardiovascular diseases	Rodriguez et al. 1975, 1976

tomato, high temperatures inhibit lycopene but not β-carotene synthesis. Likewise, the total carotenoid concentration of bitter gourd seeds can be a 100-fold higher in the ripe than the immature stage, which is exclusively attributable to lycopene (96% of the carotenoids in ripe seeds; Rodriguez et al. 1975).

Other chemo-preventive antioxidants in plants include vitamin C, vitamin E, phenolic acids, and organosulfur compounds (Simon 1997). Bitter gourd is also a rich source of phenolic compounds, where gallic acid, gentisic acid, catechin, chlorogenic acid, and epicatechin are typically abundant. While the concentration of phenolics varies with plant organ (fruit, leaf, root) and cultivar type, the highest content has been found in the Indian white-fruited (Fig. 2.2E), followed by China white-fruited, China green-fruited, and last India green-fruited (Horax et al. 2005). These plant phenolic compounds are potentially excellent natural sources of food antioxidants, given their abilities to reduce total cholesterol/triglycerides (Jayasooriya et al. 2000; Ahmed et al. 2001), blood pressure, and the incidence of cancer and cardiovascular diseases

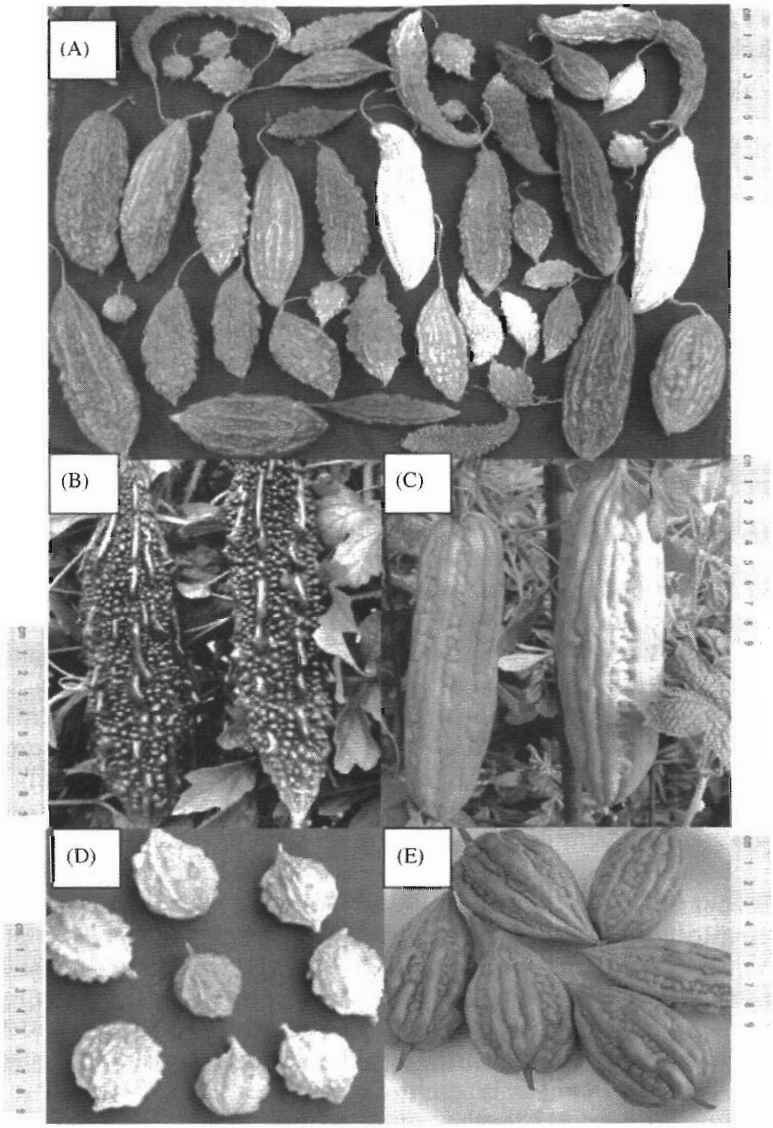

Fig. 2.2. Fruits of bitter gourd (*Momordica charantia*). (A) Fruit diversity (Dey et al. 2006a). (B) Large fusiform fruits, pointed at both ends, numerous triangular tubercles, giving the appearance of a crocodile's back classified as *M. charantia* var. *charantia* (Chakravarty 1990). (C) Chinese long fruit type, 30–60 cm, smooth ridges, light green in colour, and slightly bitter (Yang and Walters 1992). (D) Small fruits (*M. charantia* var. *muricata*; Chakravarty 1990) high in proteins, carbohydrates, iron, calcium, (Desai and Musmade 1998) and Vitamin C (Behera et al. 2008c). (E) Triangular fruit type, cone-shaped, 9–12 cm long, light to dark green with prominent tubercles, moderately to strongly bitter (Yang and Walters 1992).

(Tanaka et al. 1993; Balentine et al. 1997; Bravo 1998; Surh 1999; Gorinstein et al. 2002; Wang and Mazza 2002; Hannum 2004).

3. Antifertility Effects. Excessive consumption of the fruit and leaves of bitter gourd can reduce sperm production (Prakash and Mathur 1976). Bitter gourd ethanol seed extracts have also shown to have potent male antifertility effects (Basch et al. 2003) when administered to dogs (Dixit et al. 1978) and guinea pigs (Udoh et al. 2001).

4. Antiviral Activity. In recent years, a number of chemical components that possess medicinal attributes have been isolated from bitter gourd, such as α-momorcharin, which inactivates ribosome function (Feng et al. 1990; Leung et al. 1997) and stimulates MAP30 (*Momordica* anti-HIV protein) production, which, in turn, simultaneously suppresses HIV (human immunodeficiency virus) activity (Lee et al. 1990, 1995). Interestingly, momordicoside A and B present in bitter gourd inhibit tumor growth (Okabe et al. 1980), and several bitter gourd phytochemicals have in vitro antiviral activity against viruses including Epstein-Barr, herpes, and HIV viruses (Takemoto 1983; Lee et al. 1990; Nerurkar et al. 2006).

5. Antimicrobial Activity. The leaf extracts of bitter gourd possess antimicrobial activity principally against *Escherichia coli*, *Staphylococcus*, *Pseudomonas*, *Salmonella*, *Streptobacillus*, and *Streptococcus* (Omoregbe et al. 1996). Moreover, whole plant extracts have shown antiprotozoal activity against *Entamoeba histolytica*. Generally, fresh fruit extracts have exhibited similar antibacterial properties; more specifically, fruit extracts of *M. charantia* L. have demonstrated activity against tuberculosis and the stomach ulcer–causing bacteria *Helicobacter pylori* (Hussain and Deeni 1991; Omoregbe et al. 1996; Yesilada et al. 1999). Application of bitter gourd fruit powder to wound sites is similarly effective in stimulating tissue regeneration and wound healing in rats (Prasad et al. 2006).

II. BOTANY

A. Taxonomy and Morphology

The genus *Momordica* belongs to subtribe *Thladianthinae*, tribe *Joliffieae*, subfamily *Cucurbitoideae*, of the *Cucurbitaceae* (Jeffrey 1990). The genus *Momordica* has 45 species domesticated in Asia and Africa (Robinson and Decker-Walters 1997). The genus *Momordica* has only

six valid species in India, which can be grouped under two headings: *M. charantia* L. and *M. balsamina* L. representing the monoecious group and *M. dioica* Roxb., *M. sahyadrica* Joseph & Antony, *M. cochinchinensis* (Lour.) Spreng., and *M. subangulata* Blume (ssp. *renigera* (G. Don) W.J.J. deWilde) representing the dioecious group. Although the genus, as circumscribed here, does not include *Momordica cymbalaria* Fenz. [*Luffa cymbalaria* = *M. tuberosa* (Roxb.) Cogn.)], some workers still treat it under *Momordica* (Joseph John 2005).

Indian bitter gourd is classified into two botanical varieties based on fruit size, shape, color, and surface texture (Fig. 2.2A): (1) *M. charantia* var. *charantia* has large fusiform fruits, which do not taper at both ends, and possess numerous triangular tubercles giving the appearance of a "crocodile's back" (Fig. 2.2B); (2) *M. charantia* var. *muricata* [Wild], which develops small and round fruits with tubercles, more or less tapering at each end (Fig. 2.2C) (Chakravarty 1990). Both varieties are widely cultivated throughout tropical and subtropical regions of India. Yang and Walters 1992 classified bitter gourd into three horticultural groups or types:

1. A small-fruited type where fruit are 10 to 20 cm long, 0.1 to 0.3 kg in weight, usually dark green, and very bitter
2. A long-fruited type (most commonly grown commercially in China) where fruit are 30 to 60 cm long, 0.2 to 0.6 kg in weight, light green in color with medium-size protuberances, and are only slightly bitter
3. A triangular-fruited type where cone-shape fruit are 9 to 12 cm long, 0.3 to 0.6 kg in weight, light to dark green with prominent tubercles, and moderately to strongly bitter.

More recently, Reyes et al. (1994) reclassified Indian and southeast Asian *M. charantia* botanical varieties based on fruit diameter [*M. charantia* var. *minima* Williams & Ng < 5 cm and *M. charantia* var. *maxima* Williams & Ng > 5 cm).

The morphological difference among six cultivated species of *Momordica* is described in Table 2.3. Cytogenetic studies confirmed the diploid chromosome number ($2n = 22$) of *M. charantia*. Another species of *Momordica* (*M. dioica*; $2n = 28$), a dioecious cucurbit, has a different karyotype from the other two species (*M. charantia, M. balsamina*; $2n = 22$), but the meiosis in these species is regular (Bhaduri and Bose 1947; Roy et al. 1966; Trivedi and Roy 1972). Crosses of *M. charantia* and *M. balsamina* ($2n = 22$) with *M. dioica* ($2n = 28$) are sexually incompatible (Singh 1990). Likewise, the cross *M. charantia* × *M. dioica* (and reciprocal), failed to set fruit when normal pollen was used (Vahab and Peter 1993).

Table 2.3. Important Indian bitter gourd (*Momordica charantia* L.) cultivars and hybrids and their salient economic and botanic features.

Cultivar	Fruit features
Pusa Do Mausami (OP)[z]	Medium long (15–25 cm), green, club shaped unbroken surface ridges, 80–100 g.
Pusa Vishesh (OP)	Medium long (15–20 cm) medium thick, glossy green, smooth broken surface ridges, 100–115 g.
Arka Harit (OP)	Short to medium long (12–18 cm), medium thick, grayish green with smooth surface broken ridges, 60–70 g.
Coimbatore Long (OP)	White, medium, long (20–25 cm) and thin, broken surface ridges, weight 60–75 g.
VK1 Priya (OP)	Extra long (~40 cm), green-spiny, and the stylar end typically whitish.
MDU 1 (OP)	Greenish white with continuous spine; length varies from 30–40 cm, 120 g.
CO1 (OP)	Dark green, medium long (25–30 cm) and thick (6–8 cm) with characteristics warts, 100–120 g.
Konkan Tara (OP)	Green, prickly, medium long (10–15 cm) and spindle shaped, weight 45 g.
Punjab-14 (OP)	Oblong and green, 35 g.
Pusa Hybrid-1 (Hybrid)	Medium long and small to medium thick, glossy green, smooth broken surface ridges, 100 g.
Pusa Hybrid-2 (Hybrid)	Dark green, medium long with medium thickness (length: 112.5 cm; breadth: 4.5 cm) with irregular smooth ridges, 110 g.
CO (Bgo)H 1 (Hybrid)	Creamy white, light green–tinged stout fruits, 300 g.

[z]OP: Open-pollinated variety

B. Reproductive Biology

Wild-type bitter gourd is monoecious, where staminate and pistillate flowers (Fig. 2.3A, B) are borne on separate nodes. Flowering and fertilization occur between 35 and 55 days after sowing depending on growing conditions (Rasco and Castillo 1990; Reyes et al. 1994), and then continue for about 6 months in the tropics (Reyes et al. 1994). Anthesis typically occurs between 3:30 and 7:30 a.m., when flowers are completely open (Miniraj et al. 1993), and pollen viability is lost relatively rapidly (Desai and Musmade 1998). The stigma is usually receptive for 1 day before or after flower opening, after which it dries and turns brown (Rasco and Castillo 1990).

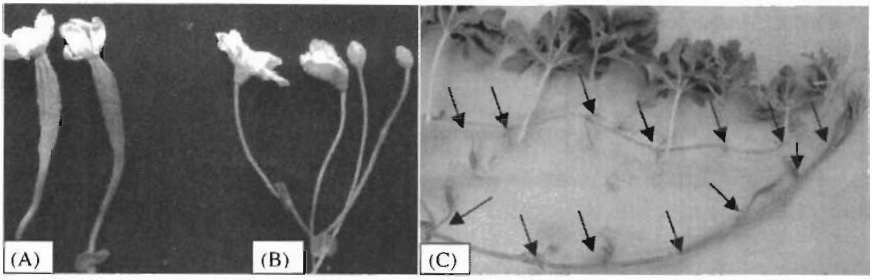

Fig. 2.3. Monoecious flowering habit of bitter gourd; pistillate (A) and staminate (B) flowers are borne at different nodes. (C) A new gynoecious line (DBGy 202) was bred from germplasm collected in the eastern India (Behera et al. 2006). Arrows indicate nodes with pistillate flowers.

Flowering behavior varies with cultivar, climatic conditions, and cultural practices (Deshpande et al. 1979). The average ratio of staminate to pistillate flowers in monoecious lines throughout the flowering period is typically 50 : 1 (Rasco and Castillo 1990), but ratios can vary dramatically (i.e., 9:1 to 48 : 1) (Dey et al. 2005). While long photoperiods cause staminate flowers to bloom up to 2 weeks earlier than pistillate flowers, short days have the reverse effect (Huyskens et al. 1992). Nearly 90% of pistillate flowers borne on the first 40 nodes, and majority of them mature at nodes 21 to 30. Judicious pruning of lower laterals stimulates subsequent lateral branch production, which in turn tends to increase the total number of flowers per plant (Rasco and Castillo 1990). Bees are important pollinators of bitter gourd in India (Behera 2004). The predominant bee species in India is *Apis florae*, followed by *A. cerana* and *A. dorsata*.

The pistillate flower of bitter gourd consists of an inferior ovary and a three-lobed, wet stigma that is attached to a columnar, hollow style (Pillai et al. 1978). The ovary contains three carpels typical of many cucurbits, each with 14 to 18 ovules, surrounded by an ovary wall. Although the number of ovules in an ovary can be up to 60, the average is 40. Anatropous ovules are attached to parietal placenta in two irregularly aligned rows in each carpel. Unlike other cucurbits, however, no more than four ovules can be seen in ovary cross-section. Typically, pollen tubes penetrate papillae tissue within 1 hour of pollination, arriving at the ovary cavities about 6 hours after pollination, and thus fertilization is accomplished within 18 to 24 hours postpollination (Chang et al. 1999).

III. HORTICULTURE

A. Climate and Soil

Most of the cultivated *Momordica* species are similar in their cultural needs, except for the space requirement per plant, which is based on the type and extent of vine growth. Some of the cultural practices described herein reflect empirical knowledge collected by many generations of farmers. Reports of cultural practices based on research by agricultural scientists are meager except for bitter gourd.

Momordica species grow well in hot, humid areas but also grow abundantly in subtropical climates and are day neutral. They are tolerant to a range of environments (Lim 1998) and can be grown in tropical and subtropical climates (Reyes et al. 1994). Bitter gourd is mainly cultivated during the spring, summer, and rainy seasons, with some winter production in subtropical climates. In contrast, it is cultivated through out the year in tropical climates. The optimum temperature for good plant growth is 25° to 30°C. Frost can kill the plants, and cool temperatures will retard development. The bitter gourd crop can grow above 18°C (Larkcom 1991), with 24° to 27°C being optimum (Desai and Musmade 1998).

Bitter gourd performs well in full sun and is adaptable to a wide range of soil types but grows best in a well-drained sandy loam soil that is rich in organic matter. It grows well in soils of shallow to medium depth (50–150 cm), and like most cucurbits, bitter gourd prefers well-drained soils. For bitter gourd, the optimum soil pH is 6.0 to 6.7, but plants tolerate alkaline soils up to pH 8.0, whereas spine gourd prefers a pH of 6.0 to 7.0. Sweet gourd, in contrast, can tolerate soil salinity up to < 4 dS/m.

B. Culture

In bitter gourd, direct seeding is the usual production practice. Sometimes seedlings are transplanted directly to the field. The seed has a hard seed coat and germinates slowly due to slow absorption of water. For rapid germination, the optimum temperature is between 25 and 28°C. Presowing treatments, such as soaking of seeds in slightly warm water for 30 minutes followed by retention of seeds in a wet gunny bag or cloth bag in a warm place for 3 to 4 days, can increase the speed of germination. Poor germination percentage is common at suboptimal temperatures (Peter et al. 1998). Presowing treatments such as priming (mixing seeds with moist vermiculite for 36 hours at 20°C) and hot water (soaking seeds

for 4 hours in water at 40°C) are therefore recommended for successful seedling establishment under suboptimal temperature (Lin and Sung 2001; Hsu et al. 2003).

The field should be well prepared, plowed, and harrowed twice to remove weeds and other plant debris. Bitter gourd seeds are sown in raised mounds (beds) for the rainy season crop and in shallow pits for the summer crop in north India. The planting layout used by most farmers is 1 to 3 m between furrows and 0.5 m between hills with 3 seeds per entry at 10 cm apart within the row. Plant densities vary considerably over locations depending on the species and cultivars. Optimum plant density varies with cultivar, from 6,500 to 11,000 plants/ha (Reyes et al. 1994) or as many as 20,000 plants/ha (Huyskens et al. 1992). Bitter gourd requires a trellis to support the climbing vine. There are several methods of trellising.

During the initial period of plant growth, effective weed control is important to the productivity of bitter gourd. Most weeds can be removed effectively manually or mechanically. Cultivation is also an effective method of controlling weeds. Organic or plastic mulching is used frequently for controlling the weeds. In plastic mulch, planting holes are bored in the plastic sheet at the appropriate planting distance, stretched over the planting beds, with edges held down by thin bamboo slats, and the plastic is stapled into the soil every 20 cm. Organic mulch, such as paddy straw or dry grass, is usually less expensive than plastic mulch and thus is used often. For trellis systems, the pits are cleaned manually and covered with organic mulch, then the interspaces are sprayed with postemergence herbicides. Bitter gourd will not tolerate drought and water stress, which can severely reduce the yield. Thus, appropriate soil moisture should be maintained in the upper 50 cm of soil where the majority of roots are located. Irrigation typically is applied weekly, beginning from the day of sowing (Desai and Musmade 1998).

Fertilizer application rates depend on soil type, fertility level, and soil organic matter. Compost manure or farmyard manure is added to each planting hole before sowing and at 10 to 12 t/ha. Typically, application of 100:50:50 kg ($N:P_2O_5:K_2O$)/ha is recommended (Robinson and Decker-Walters 1997). Recommended fertilizer rates and application schedule in sandy soils at the Asian Vegetable Research and Development Centre (AVRDC) are 184, 112, and 124 kg of N, P_2O_5, and K_2O applied as one-time basal dose with four side dressings as appropriate (Palada and Chang 2003). Bitter gourd is sensitive to lack of micronutrients (e.g., boron), and the micronutrients are often incorporated to improve growth (Njoroge and van Luijk 2004).

C. Sex Expression and Modification

There is a wide range of sex expression in cucurbits (Behera et al. 2006). Cucurbits are predominantly monoecious, but dioecism occurs in pointed gourd (*Trichosanthes dioica*), kakrol (*Momordica dioica*), ivy gourd (*Coccinia indica*), and some feral forms. In *M. charantia*, Wang et al. (1997) found that initially plants bear hermaphroditic bud primordia that can produce either staminate or pistillate flowers. This process is correlated with RNA and protein synthesis, where soluble protein profiles of hermaphrodite flower buds, and staminate and pistillate flowers differ at three early developmental stages (7, 10, and 13 days after initial bud formation) (Wang and Zeng 1998). Predominant 11 and 30 kD proteins are present in pistillate and staminate flowers, respectively, and it is speculated that these proteins may be associated directly with sex expression (Wang and Zeng 1998).

Sex expression is affected by environmental conditions under which *M. charantia* seedlings grow (Wang et al. 1997). Short-day cultivars, when grown under short photoperiods, exhibit rapid development and comparatively high gynoecy. To encourage a high frequency of pistillate flowers, short-day treatments should begin at seedling emergence and proceed to sixth-leaf stage (~20 days postemergence under growing optimal conditions). Pistillate flower production under short photoperiods is increased by low temperatures (20°C) and nighttime chilling (25°C day/15°C night) (Yonemori and Fujieda 1985). Consequently, optimal conditions for gynoecious *M. charantia* seedling growth are short days and low temperatures (Wang et al. 1997a).

The concentration of endogenous growth regulators and polyamines (e.g., spermine, spermidine, cadaverine, and putrescine) in shoot meristems of bitter gourd changes during plant development (Wang and Zeng 1997a). For instance, pistillate flower number increases as indoleacetic acid (IAA) and zeatin concentration decreases after anthesis (Wang and Zeng 1997b). Cadaverine content is also higher in staminate and pistillate flowers when compared to vegetative tissues (e.g., leaf and stem), suggesting a possible role in sex determination (Wang and Zeng 1997a). It has been hypothesized that the variation in spermidine content is related to the initiation and development of pistillate flowers while increases in endogenous putrescine concentrations are related to staminate flower initiation (Wang and Zeng 1997a).

Foliar application of growth regulators can also modify sex expression (Ghosh and Basu 1982). For example, foliar application of gibberellic acid (GA_3) treatment (25–100 mg·L^{-1}) can dramatically increase gynoecy in bitter gourd, while cycocel (CCC; chlormequat) at concentrations of

50 to 200 mg·L^{-1} promotes staminate flower development (Wang and Zeng 1996). Moreover, the appearance of the first staminate flower is delayed and pistillate flower initiation is promoted by relatively low concentrations of GA_3 (0.04 to 4 mg·L^{-1}) (Wang and Zeng 1997c). Likewise, foliar application of CCC promotes staminate flower development at 50 to 200 mg·L^{-1}, and gynoecy at 500 mg·L^{-1}. Foliar application of (2-chloroethyl) phosphonic acid (ethephon), malic hydrazide (MH), GA_3, naphthaleneacetic acid (NAA), kinetin, 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). Foliar application of silver nitrate (i.e., 250 mg·L^{-1} at the 5-leaf stage or 400 mg·L^{-1} at the 3-leaf stage) induces bisexual flower formation, where ovaries and petals are larger than typical pistillate flowers (Iwamoto and Ishida 2005). Likewise, dramatic increases in early pistillate flower appearance can result from foliar application of MH (250 ppm) and ethephon (200 ppm), and staminate flower development can be promoted by application of GA_3 (i.e., 50–75 ppm) (Damodhar et al. 2004). Interestingly, foliar treatment of bitter gourd plants with IAA or HMO at 35 mg·L^{-1} increases total flower formation, which may be due in part to increased ethylene evolution (Damodhar et al. 2004). Regarding such ethylene-dependent sex determination processes, foliar application of ethephon at relatively low concentrations (255 mg·L^{-1}) enhances pistillate flowering while application of moderately high concentrations (100 mg·L^{-1}) depresses pistillate flower development. Likewise, although exogenous application of GA_3 (20–40 mg·L^{-1}) increases pistillate and staminate flower number, comparatively high concentrations of GA_3 (60 mg·L^{-1}) increases only pistillate flower number (Ghosh and Basu 1983). Finally, foliar sprays containing 50 ppm NAA stimulate early and abundant pistillate flower development (Shantappa et al. 2005); boron at 4 ppm enhances pistillate flowers production and fruit number and weight (Verma et al. 1984).

D. Harvest

Optimal timing of bitter gourd fruit harvest is often difficult to ascertain since bitter gourds are consumed before fruits are at physiological maturity (i.e., mature fruits are unmarketable). Optimal harvest is indicated by slight changes in fruit color and increased exocarp development (i.e., fullness of ridges and bumps), which are difficult to evaluate. Seed coat color is a good indicator of optimal harvest maturity (i.e., creamy or pale green-brown, with overmaturity indicated by pink coloration), but obviously it is not useful for easy determination of marketable fruit.

Since fruit continues to mature after harvest, fruit for immediate sale in local markets should be harvested just prior to harvest maturity (i.e., physiologically immature), whereas fruit for long-distance transport must be harvested several days/weeks earlier than this (color maturity indicators given in Vujovic et al. 2000).

Physical appearance and nutritional quality varies with cultivars and the stage of fruit development for harvest (Pal et al. 2005). Optimal bitter gourd fruit harvest typically occurs between 15 to 20 days after fruit set (i.e., ~90 days after planting; Reyes et al. 1994). Nevertheless, due to wide culinary preferences, broad variation in harvest date is common. Harvestable fruits are, in general light green, thick and turgid (Lim 1998), where seeds are typically soft and range from white (Huyskens et al. 1992) to creamy with hues of pale green-brown depending on fruit maturity and variety (Vujovic et al. 2000). Harvests typically are made every 2 to 3 days since fruit ripen quickly (Desai and Musmade 1998). Fruits increase in bitterness during maturation due to an accumulation of the alkaloid momordicine, but they subsequently lose bitterness during the ripening process (Cantwell et al. 1996).

E. Seed Production

Long photoperiods cause staminate flowers to bloom up to 2 weeks before the pistillate flowers while short days have the reverse effect (Huyskens et al. 1992). Flowers open early in the morning, except for spine gourd, which opens late in the evening. Hand pollination can be avoided in bitter gourd by introducing beehives or by blowing pollen with a mister.

Roguing of "off-type" plants is essential for the production of high-quality bitter gourd seed (Behera 2004). This requires considerable expertise since distinct cultivar preferences exist among different consumers. Since bitter gourd is a cross-pollinated species, it is critical to maintain an isolation distance of between 0.5 to 1.0 km between cultivars or inbred lines during seed production (Sirohi 1997). Honeybees typically act as the chief insect pollinator for this crop and should be in abundance at flowering time.

Commercial hybrid seed production of bitter gourd is accomplished by hand pollination. Experienced labors can pollinate 11 to 12 flowers per hour to each produce 15 seeds per fruit in an average commercial operation (Devadas and Ramadas 1993). Thus, the labor requirement for production of 1 kg of seed is ~ 29 hours. Shantappa et al. (2005) indicated that seed yield can be optimized (~840 kg/ha) if 50 ppm NAA or 250 ppm ethephon is applied at the 2- to 4-leaf stage.

Since bitter gourd is, with rare exception, a monoecious plant, landrace seed is produced by hand pollination without emasculation. In controlled pollination, pistillate flowers of the maternal parent and staminate flowers of the paternal parent typically are isolated by bagging with paper envelopes about 24 hours before flowers open. Buds of staminate flowers of the paternal parent also can be covered with nonabsorbent cotton. The next day as flowers open, pollen is collected from the paternal parent and dusted directly onto the stigmata of flowers of maternal plants (Sirohi 2000). After hand pollination (preferably before 9:30 a.m.), the pistillate flowers are tagged and covered again for 4 to 5 days. Hybrid seeds are then extracted from the ripe fruits collected from maternal parents.

F. Insects and Diseases

Foliage pests and diseases tend to be of little consequence in bitter gourd, likely due to toxic compounds in the plant (Robinson and Decker-Walters 1997). However, pests are a serious problem in case of other *Momordica* species. The common pests and diseases of bitter gourd are described next.

1. Fruit Fly (*Dacus cucurbitae*). Maggots of fruit fly cause damage to young developing fruits. The adult fly lays eggs below the epidermis of the young ovaries. The eggs hatch into maggots, which feed inside the fruits and cause rotting. In homestead gardens, the fruits typically are covered with polythene, cloth, or paper bags to provide mechanical protection, and infested fruits are destroyed. Use of "cue lure" traps (10 traps per h) has been found effective. Insects that parasitize the fruit fly and sterilized male fruit flies are used for biological control.

2. Red Pumpkin Beetle (*Aulacophora foveicollis*). Adult beetles eat the leaves, resulting in holes in the foliage, and they also damage roots and leaves. The insect attacks at seedling stage as adults feed on cotyledonary leaves. This insect typically is controlled with insecticides.

3. Aphids (*Aphis gossypii*). This small insect damages the plants by sucking the leaf sap. In the young plant stage, cotyledonary leaf margins "crinkle" and in severe cases, plants wilt. More serious losses are caused by aphids transmitting viral diseases. Some aphidicides are applied

systemically to the foliage for insect control. Contact insecticides often are applied to the underside of the leaves.

4. *Fusarium* Wilt. The causal organism of *Fusarium* wilt has been identified as *Fusarium oxysporum* f. *niveum*. Leaves wilt suddenly, and vascular bundles in the collar region become yellow or brown. It is difficult to control the disease since the fungus persists in the soil. The use of disease-free planting materials during sowing is recommended as a disease control. The fungus can also be controlled by nonchemical methods, namely by cleft grafting bitter gourd shoot (scion) onto *Luffa* (rootstock). *Luffa* provides an excellent rootstock for bitter gourd, and grafting can increase yields substantially (e.g., in Taiwan), mainly by controlling Fusarium wilt infestation (Lin et al. 1998).

5. Anthracnose. Anthracnose is caused by *Colletotrichum* spp. Small yellowish spots appear on leaves as water-soaked areas, which enlarge in size, coalesce, and turn brown to black in color. Seed treatment, proper crop rotation, and clean cultivation minimize initial inoculums. The disease is also effectively controlled by systemic fungicides.

6. Powdery Mildew. Powdery mildew is caused by *Sphaerotheca fuliginea*. Initially white or fluffy growth appears in circular patches or spots on the undersurface of the leaves. Severely infected leaves become brown and shriveled, and defoliation may occur. Fruits of affected plants do not fully develop. Seed treatment and soil drenching with systemic fungicides provides protection at early stages of crop development.

7. Downy Mildew. Downy mildew is caused by *Pseudoperonospora cubensis*. Symptoms appear as irregularly shape yellow to brown angular spots appears on upper sides of the leaves, usually at the center of the plant. Under moist conditions, a purplish mildew typically develops on the underside of the leaf spots. Leaves die as neurotic spots increase in size and cause severe defoliation. Spread is often rapid from the crown toward new growth. Moist conditions favor the development of this disease, but the application of an array of different fungicides can prevent the spread of the fungus.

8. Virus. Bitter gourd is a host of watermelon potyvirus, cucumber green mottle virus (both transmitted by white fly), and bitter gourd mosaic virus (transmitted by aphid). Uprooting and destruction of affected plants and collateral hosts is a common means of control.

IV. BREEDING

A. Genetic Variation and Germplasm Development

The morphological documentation (e.g., passport data) and characterization (assessment of genetic diversity) of bitter gourd germplasm (both cultivated and wild types) was undertaken between 1965 to 1972 by a consortium of workers from Germany, the United States, Japan, China, Thailand, the Philippines, and India. This consortium was funded through the National Bureau of Plant Genetic Resources, Indian Agricultural Research Institute, Kerala Agricultural University, and the Indian Institute of Horticultural Research. More recently, molecular markers (RAPD: Dey et al. 2006a; ISSR: Singh et al. 2007; and AFLP: Gaikwad et al. 2008) have been used to assess the genetic diversity of Indian bitter gourd genotypes including two promising gynoecious lines, DBGy-201 and DBGy-202 (Fig. 2.3C). A wide range in genetic diversity was detected, indicating that a standard accession reference array for future analyses might include 'Pusa Do Mausami-green', 'Pusa Do Mausami-white', DBTG-2, Mohanpur Sel-215, and Jaynagar Sel-1. Regardless of marker analyses type, however, several accessions from West Bengal (Eastern Indian province) are genetically distinct from other common landrace accessions in north Indian provinces [genetic similarity [GS] = 0.57 to 0.72]. Genetic differences between *M. charantia* var. *charantia* and *M. charantia* var. *muricata* accessions are indicative of their use as potential parents for the establishment of narrow- and wide-based mapping populations (Behera et al. 2008b). Such exotic populations have been informative for the characterization of qualitative and quantitative traits in other cucurbit species (Serquen et al. 1997; Zalapa et al. 2007).

In bitter gourd, gynoecy is particularly interesting for hybrid development (e.g., gynoecious × monoecious lines) and their commercial production. The commercial deployment of gynoecy in hybrid technology avoids the tedious step of manual removal of staminate flowers during the hand-production of monoecious × monoecious hybrids. The utilization of such gynoecious lines allows for the production of gynoecious or predominantly gynoecious lines that provide early, uniform, high-yield potential (Ram et al. 2002a). The hybrid 'Cuilli No.1' (China), for instance, was developed by utilizing a gynoecious line as a maternal parent (Zhou et al. 1998). Likewise, gynoecious lines originating in India were identified by Behera et al. (2006; lines DBGy-201 and DBGy-202) and Ram et al. (2002b; line Gy263B) for use in hybrid development programs.

Commercial bitter gourd cultivars and a few accessions/lines with potentially important horticultural traits have been deposited and

registered in national germplasm collections. For example, the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India, possesses unique accessions, such as IC 256185, IC 248256, IC 213311, IC 248282, IC 256110, and IC 248281 (Dhillon et al. 2005; resistant to fruit fly); NIC-12285 and VRBT-39 (Pandey and Singh 2001; resistant to downy mildew); IC 202195 (high yield and long-fruited type); TCR 404 (high yield and white-fruited type); EC 399808 (high yield and greater number of fruits); and INGR 03037 (gynoecious sex with high yield) that can be used directly by plant breeders. Wild bitter gourd ecotypes and botanical varieties (e.g., *M. charantia* var. *muricata*) are also important sources of economically important traits (e.g., resistance against *Dacus cucurbitae*; Dhillon et al. 2005). In the case of resistance to *D. cucurbitae*, host response varies dramatically among the cultivars (Yadav et al. 2003), where fruit fly infestation has been shown to be lowest in 'PBIG-123' (12.08%) and 'Pusa Do Mausami' (13.39%), and highest in 'JMC-4' (41.49%).

Breeding for nutritional/medicinal quality typically emphasizes accessions with relatively high vitamin C content (Dey et al. 2006b). For example, bitter gourd lines DBTG-3, DBTG-8, DBTG-6, and DBTG-9 contain $> 1000\,mg \cdot kg^{-1}$ vitamin C in edible plant parts as compared to $\sim 500\,mg \cdot kg^{-1}$ in standard cultivated types (Dey et al. 2006b). These high-vitamin-C lines are aggressively used in breeding programs whose focus is on the development of cultivars with high nutritional values. High quality is also found in Indian bitter gourd cultivars possessing high total soluble solid content (>3.1°Brix; 'MC-84', 'Preethi', 'RHRBG-5', and 'PBIG-1') and elevated vitamin C ($>950\,mg \cdot kg^{-1}$; 'Konkan Tara', and 'Hirkani') and fruit protein (>1.5%; 'DVBTG-1', 'Preethi', 'Hirkani', and 'Konkan Tara') content (Kore et al. 2003).

B. Inheritance

1. Seed and Fruit Characters. Light brown seed (*lbs*) coat color is recessive to dark brown (Srivastava and Nath 1972). Large seed (*ls*) size is recessive to small seed size (Srivastava and Nath 1972); white epicarp (*w*) is recessive to green (Suribabu et al. 1986; Vahab 1989); and spiny fruit (triangular tubercles) is dominant over smooth (Vahab 1989). Since immature bitter gourd fruits are sliced during the preparation of various Asian meals, exceptional internal fruit quality and uniform green peel color are desirable. Liu et al. (2005) reported high heritability of fruit color (green vs. white) controlled by two genes where green is dominant to white (Miniraj et al. 1993; Hu et al. 2002; Liou et al. 2002). In addition to appropriate internal color, fruit must be firm, without excessive seed

development, and free of internal defects, such as decay and splitting. Fruit color also governs its marketability, although color preference differs among regions. For example, green-fruited types are in demand in southern China while white-fruited types are preferred in central China. Similarly, dark green to glossy green fruits are favored in northern India whereas white fruits are preferred in southern India.

2. Sex Expression. In contrast to recent findings of Ram et al. (2006) and Behara et al. (2009), gynoecy (*gy1*) is recessive to monoecy in India germplasm. Iwamoto and Ishida (2006) reported that gynoecious sex expression was partially dominant in bitter gourd. Their observations, however, were made using Japanese germplasms (i.e., line LCJ 980120; predominantly female). Regardless of genetic control, both studies suggest that such gynoecious or predominantly female lines hold promise for the development of gynoecious F_1 hybrids.

3. Bitterness. Bitterness (higher amount of glycosides) is particularly important to cultivar development. It displays monogenic inheritance with more bitterness dominant to less (Suribabu et al. 1986).

4. Yield. Singh and Ram (2005) determined that complementary epistasis and dominance × dominance interactions were important genetic determinates of yield. Given these facts, Devadas and Ramadas (1994) recommended that selection and hybridization (i.e., reciprocal recurrent selection) would be an appropriate breeding strategy for improvement of fruit triterpinoid content. The genetic analysis of a large-fruited (*M. charantia* var. *charantia/maxima*) × small-fruited (*M. charantia* var. *muricata/minima*) population has indicated that small fruit was partially dominant over large fruit (Kim et al. 1990). In contrast, fruit length was incompletely dominant and is controlled by a minimum of five genes (Zhang et al. 2006). Likewise, the dramatic role of epistatsis in the development of fruits suggests that breeding for this trait will be challenging (Sirohi and Choudhury 1983; Chaudhari and Kale 1991).

C. Character Association

Genotypic correlation coefficients in bitter gourd are greater than phenotypic coefficients (Dey et al. 2005). Nevertheless, phenotypic evaluation of yield and quality characteristics used in path coefficient analysis revealed that fruit weight had the greatest direct effect on yield, followed by number of fruits per plant and fruit length. Ascorbic acid content and

total carotenoid content had a strong negative but indirect effect on marketable yield based primarily on fruit weight, and fruit length and diameter. Thus, selection for small-fruited cultivars could improve ascorbic acid and total carotenoid content.

Fruit length, average fruit weight, and number of fruits per vine are controlled by additive factors, and thus have direct positive effects on fruit yield (Sharma and Bhutani 2001; Dey et al. 2005). Consequently, simple selection strategies (e.g., backcrossing) focusing on flowering duration, harvesting span, fruit length and diameter, fruit rind thickness, average fruit weight, number of fruits per vine, dry fruit weight, dry matter per vine, and harvest index could be used to improve bitter gourd yield. In contrast, 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 this crop species (Celine and Sirohi 1998; Mishra et al. 1998).

In bitter gourd, several genetic studies have determined 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. 2005). For instance, percentage of fruit infestation by gourd fly is positively correlated with rib depth, flesh thickness, fruit diameter and length and negatively associated with fruit toughness (Dhillon et al. 2005). Thus, relative fruit toughness might be used as a selection criterion during the development of fruit fly–resistant cultivars. In this regard, Tewatia and Dhankhar (1996) reported resistance to fruit fly is dominant, and that additive and dominance gene effects, as well as duplicate epistasis, are important components of resistance. Thus, reciprocal recurrent selection was suggested as an appropriate breeding strategy for improvement of this trait. Dhillon et al. (2005) observed a significant and positive correlation ($r = 0.96$) between percentage fruit fly infestation and several fruit characters. In fact, genetic analysis has indicated that total variation for fruit fly infestation and variation for larval density/fruit is associated with variation in flesh thickness and fruit diameter ($r = 0.93$), and flesh thickness and fruit length ($r = 0.76$), respectively. Thus, it appears that phenotypic selection during backcrossing could be practiced directly on these traits for population improvement.

Fruit composition components including ascorbic acid, nitrogen, phosphorus, potassium, protein, reducing sugars, nonreducing sugars, and total sugars are negatively correlated with fruit fly resistance while the moisture content is positively associated with these components. The negative correlation between fruit quality and fruit fly resistance is,

in fact, a challenge for breeding programs focused on combining both these traits in improved germplasm.

D. Goals and Cultivar Development

A wide range of quantitatively and qualitatively inherited phenotypic variation is present in Asian bitter gourd (Behera 2004). The manipulation of these traits forms the basis for plant breeding program goals. The seven most important points of consideration in this regard are:

1. Cultivars must meet international export standards (fruits must be green, 20–25 cm long, and possess a short neck.
2. Cultivars should possess characteristics that enhance nutrition, such as high vitamin (carotenoids and ascorbic acid) and mineral (iron and calcium) content.
3. Gemrplasm with improved abiotic stresses resistance (high temperature, water deficiency, salt tolerance) could be beneficial.
4. Nonbitter cultivars with medicinal benefits such as proteins (charantin), polypeptides (polypeptide-K), glycoalkoloids, phenolics and other antioxidants have better utility.
5. Gynoecious with high yield potential would increase profitability.
6. Germplasm with pest resistance (virus, powdery and downy mildew, and red pumpkin beetle) could broaden bitter gourd's planting range.
7. Cultivars with high fruit quality with late seed maturity, minimized ridges, with uniform green color in a range of fruit sizes are desirable.

Several hybrid and open-pollinated (i.e., usually landraces) cultivars have been released for bitter gourd cultivation (Sirohi 1997), and about 80% of the crop is from established F_1 hybrids. Hybrids usually provide higher yields than open-pollinated cultivars, but hybrid seed is relatively expensive and must be purchased each planting season. In India, the choice of cultivar depends on regional consumer preference for fruit shape, internal and external color, ridging, and degree of bitterness. The most popular Indian bitter gourd cultivars are listed in Table 2.4.

Several bitter gourd cultivars also have been released in China. Prominent among the hybrids grown is the *Fusarium* wilt and powdery mildew resistant 'Cuiyu', which produces dark green, warty-skinned fruit that are 30 to 35 cm long having an average fruit weight of between 500 and 700 g (Chang et al. 2005). Similar in fruit size (30–50 cm) and

Table 2.4. Morphological variation among 8 species of *Momordica* (De Wilde and Duyfjes 2002) including *M. sahyadrica*.

M. charantia L.

Plant: Annual, slender climber, 2–4 m high, scarcely to densely pubescent (tender parts wooly), monoecious.

Stem: Round, internodes 5–6 cm; tendrils delicate, 12–15 cm long.

Leaf: Deeply and palmately 5–9 lobed, reniform to orbicular or suborbicular in outline, 2.5–8 × 4–10 cm, cordate at base, acute or acuminate at apex, lobes ovate or obovate, narrowed at base, margins sinuate to undulate, mucronate; petioles 1.5–5 cm long.

Flower: Male flower stalks slender with bract midway or toward base; peduncle 2–5 cm long; bract reniform, 5–11 mm diam., green, pedicel 2–6 cm long; receptacle-tube cup shape, 2–4 mm long and 2–3 mm wide; sepals ovate-elliptic, 4–6 × 2–3 mm, pale green; petals obovate, 10–20 × 7–15 mm, mucronate at apex, scales 2; filaments 1.5–2 mm long, inserted in the throat of the receptacle tube; anthers coherent. Female flower peduncle 1–6 cm long; bract 1–9 mm diameter; pedicel 1–8 cm long; sepals narrow, oblong-lanceolate, 2–5 mm long; petals smaller than or equal to that in male, 7–10 mm long; ovary fusiform, narrowly rostrate, 5–11 × 2–3 mm, muricate, tuberculate or longitudinally ridged; style 2 mm long.

Fruit: Pendulous, stalk 2–8 cm long; fruit discoid, ovoid, ellipsoid to oblong or blocky, often narrowed at ends, sometimes finely rostrate, 3–20 × 2–5 cm, white or green turning orange on maturity, soft tuberculate with 8–10 broken or continuous ridges, splitting from base in to 3 irregular valves.

Seed: 5–30, squarish rectangular, ends subtridentate, faces compressed, sculptured, 5–9 × 3–6 mm, margins grooved; testa brown or black.

M. balsamina L..

Plant: Annual, slender, trailing herb, 1.5–3.0 m high, subglabrous, monoecious.

Stem: Round, internodes 5.5–6 cm; tendrils delicate, 11–13 cm long, basal 1–1.5 cm uncoiled.

Leaf: Lobed (5–7), subcircular in outline, 4–6 cm diam., base cordate with a cuneate petiole-blade juncture, apex mucronate, lobes rhomboid, margins acutely 3–7 lobulate; petiole 1–4 cm long, slender, puberulous.

Flower: Staminate flowers larger than pistillate; peduncles slender 3–5 cm long; bract subapical, suborbicular, up to 0.6 × 0.5 cm, pale green, cordate at base, margins finely dentate; pedicel 0.3–0.4 cm long, receptacle tube cup-shaped, up to 0.2 mm long; sepals ovate, up to 0.7 × 0.3 mm, obtuse, pubescent; petals obovate, 1–1.3 × 0.7–0.9 cm, pale yellow to creamish-yellow, undulate margins, scales in 2 petals only; filaments up to 0.2 mm long, inserted on the rim of the receptacle tube, anthers up to 1.2–1.8 mm long. Pistillate flowers 1.7–1.8 cm across; peduncles 0.2–0.3 cm long; pedicels 0.4–0.6 cm long; bract small; calyx minute, thread like, thin; petals 0.8 × 0.8 cm, pale yellow to creamish-yellow undulate margins; ovary ovoid to fusiform, 5–7 mm long, style short, slender, whitish yellow.

Fruit: Ovoid to ellipsoid, bulged at middle, 2.5–3.5 (4.0) cm long, 1.8–2.0 cm in circumference and stalk 1–2 cm long, shortly rostrate, ashy-olive green with 2–3 white tubercles in lines across the whole length of fruits; fruits turning orange and later scarlet red on ripening; pericarp thin.

Seed: 3–5, covered by deep red sarcotesta, ovate oblong, compressed, 8.5–9.5 × 5.9–6.2 mm, and margins finely grooved, crenulate; testa grey or light brown.

(*continued*)

Table 2.4 (*Continued*)

M. dioica Willd

Plant: Vine climbing up to 3–10 m high, tuberous roots, dioecious.

Stem: Slender, the internodes 3–8 cm long. Tendrils axillary, 4–12 cm long, the basal 2–4 cm straight and the rest spiral.

Leaf: Thin, light green to green, ovate-cordate, nearly triangular in outline, lobed and sublobed to various degrees or cordate and cuneate at base, the margins entire, undulate, irregularly or coarsely; the upper surface and margins with scattered short hairs, the lower surface densely short hairy; petiole slender to medium thick, 3–7 cm long, 1–1.5 mm in diameter, longitudinally grooved.

Flower: Staminate flowers solitary; peduncles 3–7.5 cm long (usually 5–6 cm), light green, thin; pedicels sub sessile, 2–3 mm long, whitish yellow, subtended by and protected inside a reniform clasping swollen bract, 4–5 × 8–10 mm, light green; calyx funnel-shaped, lobes 5, light green, narrow acute, up to 6 × 1 mm; petals 5, free, pale yellow, glandular, oblong-lanceolate, 12–22 × 5–8 mm. Stamens 5, two of them with a pair of anthers and the other with a single anther, filaments 2–3 mm long, anthers subtriangular, 2–3 mm long, yellowish brown on inner side. Pistillate flowers solitary in leaf axils; peduncles thin, very short 0.5–2.0 cm long; pedicels thin, 2–4 cm long, subtended by a small bract of 3–4 × 2–6 mm; bracts reniform with acute tip just like in male but of small size; sepals 5, semipersistent, green, narrow, 3–6 × 0.8 mm, acute at apex; petals 5; ovary oblong-ovoid, 6–9 × 2–3 mm, rounded at base; styles short, up to 4 mm long, glandular hairy.

Fruit: Oblong, rounded at base, abruptly conical with rostrate tip at apex, 3–4 × 2–3 cm, the entire surface covered with soft short spines (except the beak), light green or dark green, turning uniformly orange on ripening, splitting from base into three irregular pieces and rolling back exposing scarlet red arils (seeds).

Seed: 2–3 mm across, black lustrous and golden-lined (when fresh), sculptured on surfaces, small round to slightly oval or shortly stellate (round-ovate and smooth in Central Indian specimens), seed coat brittle, shell hard, membrane thin, whitish, endosperm oily with characteristic aromatic odor when crushed.

M. sahyadrica

Plant: Robust climber, vines up to 5–6 m high, tuberous roots with outer skin brownish and inner flesh whitish yellow, dioecious.

Stem: Stout, the internodes 5–10 cm long, nodes quadrangular, blackish green, distinctly long hairy. Tendrils medium thick, unbranched, 8–15 cm long, 4–5 cm of base uncoiled, remaining coiled..

Leaf: 3–5 lobed or entire, 10–16 × 8–18 cm, deeply cordate at base with a subangulate juncture with petiole, petiole 3–8 cm long, 1–1.5 mm. in diameter; blades medium thick, ovate, broadly triangular in outline, sometimes hastate, acute, or acuminate at apex, margins highly variable, entire, undulate or coarsely crenulate, lateral veins 5–7 pairs, the lower pair running close to the margin of the subangulate petiole juncture, hairs short, scattered without, snowy white within.

Flower: Staminate flowers axillary, solitary; peduncles 2–5 cm. long; dark green, pedicels short, 0.8–1 cm. long, whitish green subtended, and covered by an inflated bract, up to 1 × 1.5 cm, reniform; calyx base funnel shape, up to 8 mm long and 1 cm across; petals 5, free, fleshy, obovate, up to 4 × 1.5 cm, bright yellow with a greenish yellow narrow base; stamens 3, two of them with a pair of anthers, the other with a single anther, filaments up to 3 mm. Pistillate flowers solitary in leaf axils; peduncles 0.5–2.0 cm, pedicel short, up to 0.5 cm long, subtended by a small rudimentary bract, 1–3 × 0.5–5 mm; sepals 5, green, persistent, 0.8–1.3 × 1–3 mm, equal, lanceolate, acuminate at apex densely glandular

Table 2.4 (*Continued*)

hairy within and without; petals 5, free, fleshy, up to 4 × 2 cm., narrow, greenish yellow, widening toward middle, bright yellow; ovary inferior, oblong-ovoid, 1–1.5 × 0.2–0.4 cm; style up to 6 mm long, whitish yellow, stigma up to 4.0 × 9.0 mm, cushiony, trifid.

Fruit: Broadly ellipsoid, ovoid to fusiform with round blossom end and rostrate distal end, 5–7.5 × 3–4.2 cm in size, 9–12 cm in circumference, 35–50 gm in weight, dark green turning bright orange on ripening, densely clothed with soft short spines; spines 2–4 mm long; arils sweet taste, ripe fruits aromatic and slightly bitter.

Seed: Black, shining, losing its luster on drying, round stellate to slightly cog wheel shape, warty-dentate on margins sculptured on faces with irregular furrows and ridges, 0.2–0.3 × 0.2–0.3 cm, seed coat brittle, hard shell–like, the membrane very thin, smooth, blackish green, conspicuously veined, endosperm oily, distinctly aromatic when crushed.

M. subangulata Blume

Plant: Vine climbing up to 8–10 m high, tuberous roots, dioecious.

Stem: Stout, the internodes 7–11 cm, Tendrils simple, axillary, 15–17 cm long, the basal 5–7 cm erect, the rest when uncoiled.

Leaf: Light green, ovate cordate, unlobed, 8–12 × 7–11 cm., acuminate at apex, cuneate at base, the basal flaps almost touching the petiole, the margins undulate; veins 3–5, ascending and many pinnate from midrib ending up in fine network of areoles, 4–5 mm across, glabrous above, glandular hairy below; petioles 7–10 cm long, thick, channeled longitudinally, margins finely ridged.

Flower: Staminate flowers large, solitary, axillary, showy, creamish yellow, up to 9 cm across; peduncles 4–6 cm long, pedicel 0.5–1 cm long, subtended and covered inside a reniform bract, 2 × 2.5 cm, light green, sepals 5, greenish crimson, united at the base; petals 5, 5–6 × 3–4 cm, free, fleshy, 3 inner petals with blackish purple blotch of 7 × 6 mm size and long glandular hairs; nectary, orange yellow, enclosed in calyx cup; stamens 3, two of them with a pair of anthers, the other with a single anther, filaments up to 4 mm long, black on sides. Pistillate flowers with peduncles short, 1–1.3 cm long, pedicels 10–17 cm long; bracts minute, rudimentary, near axil, often a scar of 2 × 1 mm size; sepals 5, 5–9 × 1–1.5 mm persistent, acute at apex; corolla and scales as in male; ovary oblong ovoid, dark green, 1.5–2 × 0.6 cm., rounded at base, finely echinulate on surface; style 5 to 7 mm long, pale yellow, stigma cushiony, up to 4 × 6 mm, trilobed.

Fruit: Broadly ellipsoid, with dome-shape ends, 7–8 × 13–14 cm, each weighing 50–80 g; densely softly echinate, rarely with remnant ridges at base, spines 2–3 mm long, light green turning yellow and finally bright orange on ripening, exposing the seeds (35–50 per fruit) by basal splitting of the fruit and rolling back of the split lobes; flesh thick (5–6 mm), aril deep red.

Seed: Flat, suborbicular to subtridentate, rectangularly stellate–cog wheel shape, 6 × 3 mm and up to 4 mm thick, sculptured on faces with grooves and dented edges, margins with a double row of wart- like small protuberances.

M. cochinchinensis (Lour.) Spreng

Plant: Stout perennial climber up to 20 m high, roots tuberous, woody, all parts glabrous, dioecious.

Stem: Round, internodes 5–6 cm; tendrils delicate, 11–13 cm long, basal 2–2.5 cm uncoiled.

Leaf: Entire or 3–5, palmately lobed, or 3 foliolate (leaflets ± elliptic with minute petiole), broadly ovate or suborbicular in outline, up to 10 × 16 cm, base cordate (sometimes with 2–4 glandular beadlike projections toward cordate margin), acute or acuminate at apex or acuminate, margins entire, undulate or remotely dentate; petiole 5–12 cm long.

(*continued*)

Table 2.4 (*Continued*)

Flower: Solitary, axillary, staminate sometimes in a loose fascicle of 5–7, with a separate basal one. Staminate flowers with subapical bract; peduncles 8–12 cm long, bract cucullate, suborbicular or reniform, 20–40 mm wide, rounded at base, acute at apex, margins undulate; pedicels 5–8 mm long, receptacle tube saucer shape, 4–5 × 8–12 mm, blackish outside; sepals 0–12 × 4–8 mm, ovate– oblong or triangular, acute at apex, blackish; petals subelliptic, 2.5–4 × purple bull's-eye mark at base, filaments short, fleshy, 5–6 mm long, inserted at the base of the receptacle tube, anthers variable in size, 'S' shape, connective swollen. Female flower with small or rudimentary bract; sepals linear oblong, 4–10 mm long; petals as in male; ovary ellipsoid oblong, 12–15 mm long, densely soft muricate; style 8–9 mm long.

Fruit: Ovoid or oblongoid, bulged at middle, 10–15 × 6–10 cm, rostrate at base and stalk 5–12 cm long; pericarp densely tuberculate with uniformly short round conical structures or interspersed with larger tubercles; single fruit weighing between 350–500 g or more, green turning orange on ripening and bursting irregularly.

Seed: Many, variable in size, 1–1.5 × 0.8–1.2 cm, broadly ovate hexa-octagonal with flat sculptured surfaces, subtridentate at ends and margins, testa black.

Momordica foetida Schumach

Plant: Dioecious, perennial herb, trailing or climbing with simple or bifid tendrils.

Stem: Grows up to 4.5 m long, with dark green flecks when young, woody when old, rooting at the nodes.

Leaf: Alternate, simple; stipules absent; petiole 1.5–17 cm long; blade broadly ovate–cordate to triangular–cordate, 1.5–16 cm × 1.5–17 cm, base deeply cordate.

Flower: Unisexual, regular, 5-merous; calyx with obconic tube and lobes up to 11 mm long; petals free, obovate-lingulate, up to 3.5 cm long, white, pale yellow to orange-yellow, 3 with scales inside at base; staminate flowers 1–9 together in fascicles on peduncle 2–23 cm long, with 3 stamens, anthers coherent in center of flower; female flowers solitary in leaf axils, with inferior, ovoid ovary, stigma 3-lobed.

Fruit: Ellipsoid berry up to 7 cm × 5 cm with a long-stalked, orange when ripe, densely and softly spiny, dehiscing with 3 valves and exposing the many seeds embedded in scarlet pulp.

Seed: Oblong, flattened, c. 1 cm long, brown, testa sculptured, margins 2-grooved.

Momordica rostrata Zimm.

Plant: Dioecious, perennial herb with tuberous roots, trailing or climbing with simple tendrils.

Stem: Grows up to 7 m long, becoming woody with gray bark.

Leaf: Alternate, pedately 9-foliolate; stipules absent; petiole up to 2.5 cm long; central leaflet elliptical to almost circular, 1–4.5 cm × 1–3 cm, lateral leaflets smaller.

Flower: Regular, 5-merous; male flowers in axillary, 1–14–flowered, umbel-like clusters with peduncle up to 10 cm long, sepals triangular, 2–4 mm long, petals oblong, 7–13 mm long, rounded, pale orange-yellow, stamens 3, free; female flowers solitary, subsessile, sepals triangular-lanceolate, 1.5–2 mm long, petals c. 8 × 4 mm, ovary inferior, narrowly ovoid, 12–14 mm long and 2.5–3 mm across.

Fruit: Ovoid berry 3–7 cm × 1.5–3 cm, beaked, rounded or slightly 8-angled, bright red, with many seeds embedded in yellow pulp.

Seed: Broadly ovate, ca. 14 mm long, blackish brown, testa sculptured and margins grooved.

Source: Joseph and Antony (2007).

weight (500 g) is the virus-resistant hybrid 'Hengza No. 2' (Xiao et al. 2005). It differs from 'Cuiyu' in that fruits are straight, cylinderical, and glossy green. Another commonly grown bitter gourd is the powdery mildew resistant hybrid 'Chunyu', which bears green fruit with spines that are on average 26 to 28 cm in length and 326 g in weight (Hu et al. 2002). In Australia, open-pollinated cultivars (typically Vietnamese types) are preferred by growers. However, more recently growers are adopting hybrid cultivars, which provide comparatively greater yields (Morgan and Midmore 2002). Australian vegetable seed companies sell both hybrid and open-pollinated cultivars. The cultivars 'Kiew Yoke 59', 'Known You Green', 'Verdure', 'Moonrise', 'Moonlight', and 'Moon Beauty' are widely grown. In southern Taiwan, three major bitter gourd cultivars, 'Pintong Black Seed', 'Moonshine' (F_1), and 'Highmoon' (F_1), constitute 70%, 20%, and 10% of the commercial production area, respectively (Liou et al. 2002). In addition, the popular open-pollinated heat-tolerant variety 'Pintong Black Seed' is also suitable for tropical regions (Liou et al. 2002).

E. Methods

Several methods usually are employed in tandem to accomplish breeding objectives. Single plant selection, mass selection, pedigree selection, and bulk population improvement are common methods used for bitter gourd enhancement (Sirohi 1997). Pedigree selection typically is used after crossing two parents for the development of inbred lines with high, early yield borne on a unique plant habit, and/or with high-quality fruit [i.e., processing quality, high vitamin C and A (carotenes), and disease resistance]. However, strategies that incorporate selection for disease resistance and improved yield require judicious implementation, since selection for disease resistance can be negatively correlated with yield, as is found in cucumber (Staub and Grumet 1993). Marker-assisted selection could prove beneficial in this species if technologies (map construction and quantitative trait loci (QTL) analysis) were appropriately advanced (Staub et al. 2004; Fan et al. 2006).

1. Heterosis. As bitter gourd is a cross-pollinated crop, exploitation of heterosis (hybrid vigor) is an important aspect of its improvement. Heterosis in bitter gourd was investigated at the Indian Agricultural Research Institute, New Delhi, as early as 1943 (Pal and Singh 1946). Evidence of heterotic effects is supported by genetic analyses that have defined the presence of dominance and complementary gene action for yield in bitter gourd (Mishra et al. 1998). Heterosis for yield per vine

ranges from 27% to 86% depending on genotype (Behera 2004). This heterosic effect is likely attributable to earliness, first node to bare fruit (first pistillate flowering node), and total increased fruit number (Celine and Sirohi 1998). Several hybrids developed by private and public sectors breeding efforts are cultivated in Asia, including China and India.

Techniques used for hybrid development in bitter gourd are similar to those of melons and cucumber (Behera 2004). Even though it is essential to employ inbred lines to achieve hybrid uniformity, the degree of inbreeding required depends on the extent of uniformity that is desired in the resulting hybrid. In bitter gourd, vigorous parental inbreds routinely are maintained by selfing without inbreeding depression (Behera 2004). However, since selfing in later stages of plant development often results in poor fruit set, only the first 1 or 2 pistillate flowers are customarily self-pollinated. In some instances, it may be deemed unnecessary to produce highly inbred lines since "homozygous" genoptypes can be obtained from relatively homogeneous populations (i.e., uniform for morphological characters) and used directly as parents, as is the case for some self-pollinated crops such as tomato, eggplant, and sweet pepper (Swarup 1991). Under circumstances where highly inbred lines are needed for hybrid production, rigorous selection is applied over several selfing generations. These inbred lines then typically are tested for their combining ability through structured single crosses (e.g., North Carolina I or II mating design) and/or diallel analyses. Based on their general and specific combining ability, the most promising lines are chosen for F_1 hybrid production.

2. Mutation Breeding. Bitter gourd progeny (M_1) derived from radiation mutagenesis can possess economically important unique characters that are controlled by single recessive genes (Miniraj et al. 1993). One such bitter gourd cultivar, MDU 1, developed as a result of gamma radiation (seed treatment) of the landrace cultivar MC 103, was found to possess improved yield (Rajasekharan and Shanmugavelu 1984). Likewise, the white bitter gourd mutant 'Pusa Do Mausami' (white-fruited type) was developed through spontaneous mutation from the natural population 'Pusa Do Mausmi' (green-fruited type) at the Indian Agriculture Research Institute.

3. Testing. Testing of experimental bitter gourd cultivars and hybrids varies dramatically from country to country. In India, potentially important bitter gourd germplasm (e.g., improved landraces) and hybrids are evaluated in multi-location trials by cooperating public and private

sector breeders [e.g., All India Coordinated Research Project (AICRP)]. This is typically performed in 3-year, large-scale yield and quality evaluations where entries are evaluated for economically important characters. In the first year, germplasms are tested in eight diverse geographical locations for initial evaluation in replicated (three to four) trials. The best varieties and hybrids are evaluated a second year at the same locations under the same experimental conditions. Then, in the third year, the best cultivars and hybrids are reexamined, and comprehensive information (three years) leads to recommendations for release of exceptional germplasm in the fourth year.

F. Biotechnology

The diverse morphological characters such as sex expression, growth habit, maturity, and fruit shape, size, color, and surface texture (Robinson and Decker-Walters, 1997] of *M. charantia* in India provide for relatively broad phenotypic species variation. Although DNA marker analysis can assist in diversity analyses (Behera et al. 2008a,c), only a few polymorphic markers have been identified in bitter gourd (Dey et al. 2006a; Singh et al. 2007; Gaikwad et al. 2008).

The genome size of *M. charantia* is 2.05 pg per haploid nucleus, which is similar to tomato but 10 times that of *Arabidopsis* (Ingle et al. 1975). The few genes of *Momordica* that have been isolated include MAP 30, trypsin inhibitor, chitinase, and napin, and a seed storage protein (Lee et al. 1995; Vashishta et al. 2006; Xiao et al. 2007). MAP30 (30 kDa *Momordica* protein) was isolated and cloned to evaluate its antitumor property (Sun et al. 2001) and inhibition HIV-1 infection and replication (Lee et al. 1995). More recently, napin and chitinase, which impart fungal resistance, were cloned from bitter gourd plants (Vashishta et al. 2006; Xiao et al. 2007).

In vitro regeneration of *M. dioica* and *M. grosvenori* has met with only a modicum of success. Nevertheless, regeneration from nodal explants of *M. charantia* has been achieved (Agarwal and Kamal 2004). Regeneration from cotyledons is unpredictable but is more practical than regeneration from either internodes or shoot tip explants. In vitro shoot multiplication of bitter gourd has been achieved and is now suggested for in vitro production of secondary metabolites (Agarwal and Kamal 2004).

V. CONCLUSIONS

Bitter gourd is an important vegetable crop of several countries in the tropics. Bitter gourd fruit contain bioactive components with many

important medicinal properties (Horax et al. 2005). Due to unavailability of improved cultivars, most of the species' genetic development and cultivation has been the result of selection within landraces by farmers in local habitats. However, over the last two decades, increasing emphasis has been placed on more systematic bitter gourd improvement strategies in India and China. In India, this has resulted in the release of a number of improved open-pollinated cultivars and hybrids by state agricultural universities, the Indian Council of Agricultural Research, and private seed companies. A few cultivars and hybrids have also been released in China that are resistant to biotic stresses.

Future breeding and genetic emphases in bitter gourd improvement should be placed on the development of nutritious, high-yielding cultivars with superior resistance to major diseases and exceptional fruit quality for both domestic and foreign markets. These efforts should focus on breeding for season and regional adaptation.

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