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Momordica Genus in Asia: An Overview

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Dedicated
to
the loving memory of
Late Dr. Shanthi Chandrashekar
Professor of Genetics,
Indian Agricultural Research Institute, Pusa, New Delhi-12
whose understanding, encouragement and professional help made this humble endeavour possible.

AUTHORS

Foreword

Asia is home to an extremely rich repository of biodiversity, including many *endemic species* adapted to harsh, fragile and extreme environments and naturally considered to encompass centres of origin for many *domesticated plant species*. This rich agro-ecological diversity in Asia enabled greater species diversity which is manifested in *Momordica* as well, with about ten species in Asia of which seven are in India. Diversification and value addition is one of the major thrust of Indian Horticulture in the twenty-first century and among tropical vegetables, *Momordica* can be a prime candidate for working along these lines.

Presently available books on cucurbits are heavily biased towards more popular gourds like cucumber, melon, pumpkin, squash and watermelon and underutilised cucurbits like *Momordica* do not find a place in major treatments on botany, cultivation and utilisation of cucurbits. From the published literature, it is discernible that the number of researchers working in *Momordica* is rather few and work on crop improvement and management, with the probable exception of bitter gourd, is still in its infancy.

Evidently, a strong need was felt for a comprehensive monograph on Asian *Momordica*, and this book hopefully fills the void. The book covers a whole gamut of aspects like biosystematics, ethno-botany and origin, crop improvement, crop management and utilisation aspects, and will be immensely valuable to researchers, the student community and professional horticulturists alike.

I congratulate the authors, Drs. L. K. Bharathi and K. Joseph John, for bringing out this book collating the present status of Asian *Momordica*s with respect to research and utilisation, hopefully catalysing the efforts on further promotion and utilisation of these versatile crops, undoubtedly the bounties from nature graciously bestowed on us.

New Delhi, November 2012

N. K. Krishnakumar
Deputy Director General
(Horticulture)

Preface

Momordica is a genus of under-utilized and wild-gathered vegetables of importance as food, medicine and ecosystem functions. With the probable exception of bitter gourd, other *Momordica* species are little known outside Asian and African consumers. Rich in minerals and vitamins, bitter gourd (*M. charantia*), teasel gourd (*M. subangulata* subsp., *renigera*) and spine gourds (*M. dioica* and *M. sahyadrica*) are reported nutritionally the best among cucurbits. Sweet gourd (*M. cochinchinensis*) is known as 'the fruit from heaven' in South–East Asia, due to its acclaimed properties in enhancing longevity, vigour and vitality. Of course, it is the richest source of β-carotene, the precursor of vitamin A. There is an incredible wealth of traditional knowledge, especially medicinal uses, though not scientifically validated in most cases, among the forest dwelling tribal and native populations. All are extensively used in indigenous systems of medicine including Siddha, Unani, Ayurveda and even Homeopathy.

The biodiversity rich Asia is home to most tropical vegetables and vegetables are the primary source of vitamins and minerals, utilisation of native biodiversity for combating this 'silent hunger' afflicting a sizable population in these countries is still a major challenge for agricultural researchers and administrators alike. Sagacious bio-prospection and judicious utilisation of the natural resources can indeed offer simple and cost-effective solutions to many of our long-standing problems. An exemplary case study is the nutritional supplementation trials in Vietnam by Dr. Voung using the traditionally cultivated gac fruit (*M. cochinchinensis*), which was demonstrated to be an ideal tool for managing chronic cases of vitamin A deficiency in children. This is an example of a highly successful long-term and sustainable strategy by using the indigenously available food resources.

Although bitter gourd is vulnerable to pest problems demanding chemical control and consequent pesticide residues, other *Momordica*s are largely grown in an organic way and hence deserve promotion in the context of the present market demand for green organic foods. Evidently, given the limited information available on their nutritional and nutraceutical value, these crops are not given the due importance they richly deserve. Most of these semi-domesticated crops are endowed with resistance/tolerance to some of the common diseases and pests of

cucurbits. Species like *Momordica balsamina* is least demanding and adapted to suboptimal conditions like dry arid climate and *M. sahyadrica* can be cultivated as a high-value component of cardamom-coffee plantations in the Western Ghats. *M. dioica* and *M. subangulata* subsp. *renigera* are equally prospecting candidates for domestication. At least one of these species can be profitably grown as an ideal homestead vegetable in every home, across extreme environments and diverse ecosystems of the region present interesting opportunities for diversified and nutrition-rich diet.

However, there is a long way to go as most of the species except bitter gourd are in the domestication interphase. Incidentally, Van Rheed's *Hortus Malabaricus*, the first ever printed account of the flora of Malabar or Indian plants for that matter, describe four entities of *Momordica*, which formed the basis for Linnaeus and subsequent botanists to describe the genus and some of the species. However, the irony is that all the four entities (*paval*, *pandipaval*, *erumapaval* and *bempaval*) described and illustrated by him still remain in the wild-undomesticated stage even after 450 years.

Problems like non-availability of adequate high quality planting materials and a comprehensive package of agro-management techniques need greater research attention. If the research gaps are addressed, they can be promoted as major vegetables, thus serving the nutritional and nutraceutical needs of Asian population.

We have endeavoured to give an insight into the present state of knowledge on bitter gourd and other *Momordica*s of South and South–East Asia. Available information on biosystematics, origin and domestication, genetics and crop improvement efforts, ethnobotany and nutritional profile and crop management have been collated thematically under eight chapters. Admittedly, professional and personal experience of the authors spanning over more than a decade forms the bulwark of this book. The authors owe full responsibility for the viewpoints and statements made in the book and in no case the same to be construed as that of the Indian Council of Agricultural Research (ICAR).

We earnestly hope that this will serve as a reference book for all *Momordica* lovers in the world over, especially students in tropical horticulture, crop botany and vegetable breeding. It is our ardent desire that this book will trigger an insatiable quest in the minds of user community to explore deeper into various research gaps in this group of plants.

October 2012

L. K. Bharathi
K. Joseph John

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We would like to express our appreciation and gratitude to our colleagues and authorities in Indian Institute of Horticultural Research (IIHR) and National Bureau of Plant Genetic Resources (NBPGR). We are indeed indebted to Dr. A. S. Sidhu, Director, IIHR, Bangalore, Dr. K. C. Bansal, Director, NBPG, New Delhi, and Dr. N. K. Dwivedi, Principal Scientist and Officer in charge, NBPGR Regional Station, Thrissur, for encouraging us in this pursuit. Thanks are also due to Dr. I. S. Bisht, Principal Scientist, NBPGR, New Delhi, and Dr. S. Anbu, Former Dean, Horticultural College and Research Institute, Periyakulam for critically reviewing the concept and offering suggestions thereof. Curators of various herbaria (CAL, BSI, BSISH, MH and CALI) were gracious enough to open their doors and our esteemed friends in BSI, Dr. V. P. Prasad and Dr. Lakshmi Narasimhan, Formerly Liaison officers at KEW, always lend us a helping hand. Sh. P. C. Majhi, Technical Assistant at CHES, Bhubaneswar, helped us in recording some of the field data.

It was Dr. K. C. Velayudhan, Principal Scientist and former colleague at NBPGR who has introduced us to the fascinating world of the wild *Momordica*, for which we are greatly indebted to him. Since then, we were so enamoured of these 'wild beauties' that we chose it as the subject of our doctoral research.

The south Asian species are comparatively better studied, though problems of misidentification, taxonomic confusion and nomenclatural ambiguities are widespread. Whereas the entities exclusive to South–East Asia are poorly collected and inadequately studied and consequently still remains in the realms of botanical interest. It was largely through the efforts of W. J. J. O. de Wilde and B. E. E. Duyfes, who revised the genus for Malesian region that we know of the species diversity and their distribution in SE Asia.

We salute the memories of several colonial administrators and amateur botanists from Europe like van Rheede, Roxburgh, Hooker, Gamble, and C. B. Clarke to name a few, who painstakingly surveyed the most inhospitable tracts and documented the rich diversity of the Old World tropics and their able successors like Professor H. L. Chakravarty who pioneered botanical research in independent India.

Finally, we owe a great deal of appreciation to our family members for their patient support throughout this period and apologies for compromising attention due to them.

Contents

About the Authors

Dr. L. K. Bharathi was born on 20/03/1974 and is presently working as a Scientist at Central Horticultural Experiment Station a regional research station of Indian Institute of Horticultural Research, Bengaluru. He did his B.Sc. and M.Sc. Degrees from Tamil Nadu Agricultural University, Coimbatore and Ph.D. from Indian Agricultural Research Institute, New Delhi. He joined in Agricultural Research Service as a Scientist at Central Agricultural Research Institute, Port Blair, in 1999 and has more than 13 years of experience in vegetable crop improvement especially in *Momordica* species. He has published more than 20 Research Papers in Indian and International Journals of Repute. Presently, he is engaged in the improvement of *Momordica* species through interspecific hybridization.

Dr. K. Joseph John was born on 20/03/1960 and is presently working as a Senior Scientist at the Thrissur Regional Station of the National Bureau of Plant Genetic Resources (NBPGR) New Delhi, the nodal agency for PGR management in India. He did his B.Sc. and M.Sc. degrees from the University of Kerala and Ph.D. from Mahatma Gandhi University, Kottayam. He joined ICAR service as ARS Scientist at VPKAS, Almora in 1986 and has over 26 years of experience in plant genetic resources management of tropical vegetables and tree fruits. He did his Ph.D. on "Ecogeography and Genetic Diversity of the Genus *Momordica* L in India". Under this work, the genus *Momordica* was revised for India; a new species endemic to the Western Ghats was described and validly published; status of Assam kakrol was elucidated and ethnobotany of the genus in Western Ghats was documented, besides devising of descriptors and taxonomic key for dioecious and monoecius taxa and preparing ecogeographic conspectus for *Momordica*. He has carried out over 25 plant exploration and collection missions in Western Ghats, Andaman and Nicobar Islands, Lakshadweep and in the north-eastern states of India for cucurbits and other vegetables. He has published over 30 research papers in National/International Journals. Presently, he is engaged in the Biosystematics of Indian entities of *Cucumis* and *Abelmoschus*.

Introduction

1

Abstract

The genus *Momordica*, native to the paleotropics, comprises about 59 species, of which 10 occur in Asia and 7 in India. Bitter gourd is cultivated extensively in the warmer regions of the world, while teasel gourd is cultivated to a small extent in Bangladesh and eastern and north eastern parts of India. The Asiatic *Momordica* are unique in the sense that most of them are edible with multiple medicinal properties as expounded by the rich ethno botanical literature, though not validated through clinical trials in most cases. Taxonomy and identification of Asiatic *Momordica* are often confusing and the problem is compounded by the prevalence of identical vernacular names and wrong or interchangeable usage of common names for these entities. All available information are reviewed, collated and synthesised in this book, which hopefully give an overall picture of the current understanding on the taxonomic status, distribution, genetics, cytology, reproductive biology, crossability relationships, genetic resources, crop improvement, husbandry and ethnobotany of this important group of under-utilised vegetables.

Keywords

Momordica · Bitter gourd · Teasel gourd · Sweet gourd · Spine gourd · Under-utilised vegetables

The genus *Momordica* (Cucurbitaceae) is a native of the Paleotropics (Robinson and Decker-Walters 1997) and the name *Momordica* derives from the Latin word 'mordeo' (means to bite) probably in allusion either to the bitten appearance of the grooved margins of the seeds (Durry 1864) or for the biting taste of the ripe fruits of *M. balsamina,* the type species (Genaust 1996). The genus *Momordica* comprises 59 species (Schaefer and Renner 2010) distributed in the warm tropics, chiefly in Africa and with about 10 species in Southeast Asia (de Wilde and Duyfjes 2002). In the flora of Tropical Africa, 14 species viz. *M. cardiospermoides* Klotzsch, *M. cissoides* Benth. (syn. *M. guttata*, *M. maculata*), *M. pterocarpa* A. Rich, *M. angiosantha* Hook. f.,

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M. trifoliata L., *M. balsamina* L., *M. charantia* L., *M. welwitschii* Hook. f, *M. cucullata* Hook. f., *M. morkorra* A. Rich, *M. mannii* Hook. f., *M. corymbifera* Hook. f., *M. multiflora* Hook. f. and *M. cymbalaria* Fenzl ex Naud (syn. *Luffa cymbalaria*) are described (Oliver 1979). Of these, only *M. charantia*, *M. balsamina* and *M. cymbalaria* occur in Asia. Including a newly described entity, presently 12 species of *Momordica* occur in Asia out of which nine are dioecious and 3 are monoecious. The dioecious taxa are *M. dioica* Roxb., *M. sahyadrica* Joseph and Antony, *M. cochinchinensis* (Lour.) Spreng. and *M. subangulata* Blume (subsp. *subangulata* (G. Don) W. J. de Wilde, subsp. *renigera* (G. Don) W. J. de Wilde), *M. rumphii* W. J. de Wilde, *M. clarkeana* King, *M. denticulata* Miq. and *M. denudata* (Thwaites) C. B. Clarke. The monoecious taxa are *M. charantia* L. (var. *muricata* (Willd.) Chakrav. and var. *charantia* L.), *M. cymbalaria* Fenzl ex Naud and *M. balsamina* L. Among these species, six each occur in Malaysia (de Wilde and Duyfjes 2002) and India, where *M. charantia*, *M. subangulata* Blume and *M. cochinchinensis* (Lour.) Spreng. are common; Sri Lanka has three species, of which *M. charantia* and *M. dioica* Roxb. are also represented in India.

The genus includes a major commercial vegetable crop bitter melon/bitter gourd/balsam pear (*Momordica charantia* L.) which is grown in India, Sri Lanka, Philippines, Thailand, Malaysia, China, Japan, Australia, tropical Africa, South America and the Caribbean, a semi domesticated vegetable crop teasel gourd [*Momordica subangulata* Blume subsp. *renigera* (G. Don) de Wilde] which is grown commercially in India (West Bengal, Odisha, Assam, Tripura, Mizoram, Andaman and Nicobar islands) and neighbouring Bangladesh. Bitter gourd is consumed regularly as part of several Asian cuisines and has been used for centuries in ancient traditional Indian, Chinese and African pharmacopoeia. It is a common cucurbit in the wild flora of Africa, occurring almost throughout tropical Africa and occasionally collected from the wild as a vegetable or medicinal plant.

Apart from bitter gourd and teasel gourd the genus *Momordica* comprises a number of small and often poorly known species that bear edible fruits esteemed for their medicinal, nutritional properties and taste. Local people in India are reported to gather and consume teasel gourd, sweet gourd, spine gourd, mountain spine gourd (*M. sahyadrica*) and balsam apple. Their cultivation is restricted to specialised geographical pockets in different agro-geographical regions, mainly by tribal and poor farming communities (Behera et al. 2011). *Momordica* species are also common elements in home gardens (Joseph 2005) of India. Wild food plants can make the diet more balanced and hence can play an important role in combating the silent hunger (deficiency of vitamins and minerals in the diet). These *Momordica* species could also help in poverty alleviation by providing income generating opportunities to tribals/farmers by linking the development of these crops to market opportunities. Although these species, like other minor plant species, do not contribute much as basic foods, yet they do contribute significantly to diversify the human diet. They provide important chemical compounds for the nutraceutical industry and most importantly have the potential to act as sources of additional income for farmers. While all are nutritious fruit vegetables, they are still wild gathered or underutilised except bitter gourd, though teasel gourd (*M. subangulata* subsp. *renigera*) is cultivated to a limited extent in east and northeast India and Andaman Islands. SE Asian *Momordica* are in general highly adapted to high rainfall, humid tropics with low sunshine hours. Similarly, African taxa are better adapted to arid-dry climate. In the event of unforeseen climatic extremes, these species will offer scope for utilisation as direct crops for domestication or as genetic resources for trait incorporation.

Dioecious species of *Momordica* L. are noteworthy for the diverse vernacular names ascribed to it in various Indian languages and dialects. However, more interesting is the ambiguity in taxonomic identity, i.e. the same species being identified under different botanical

names and different species known by the same scientific name. *Bhat karela* of Assam or 'teasel gourd' is known as *Momordica dioica* Roxb. in the botanical parlance (Mishra and Sahu 1983; Ali et al. 1991; Jeffrey 2001; Roy et al. 1966; Sen and Dutta 1975; Hossain et al. 1996) whereas in most of agricultural literature, it is referred to as *Momordica cochinchinensis* Spreng. (Shadeque and Baruah 1984; Handique 1988; Vijay and Jallikop 1980; Mohanty et al. 1994; Ram et al. 2002; Rasul et al. 2004; Sanwal et al. 2011). But in reality it is none of these two but *M. subangulata* subsp. *renigera*. It was even described as a new taxonomic entity, *M. hybrida* (Mondal et al. 2006). Common names such as 'sweet gourd' and 'spine gourd' are used interchangeably as also the vernacular names *kaksa* and *kakrol*. Between *M. charantia* and *M. balsamina* also there is ambiguity in taxonomical identity. The wild bitter gourd (*M. charantia* var. *muricata*) is often misidentified and reported as *M. balsamina* (Maurya et al. 2007).

This publication sets out to provide an insight into current taxonomic delineation facilitating correct botanical identification, reliable distribution data for further enhancing the germplasm collections, to unravel the species relationships enabling the breeders in introgression of genes from wild to cultivated plants, along with an overview of current status and prospects for further exploitation of these underutilised species. In furtherance of these objectives, the relevant information on taxonomy, morphology, cytology, crossability, reproductive biology, diversity, distribution, genetic resources and breeding is reviewed, distilled and synthesised in the overall thematic framework. Of course, the personal experience of the authors, spanning over two decades of working in this genus, forms the bulwark. Admittedly, this publication is skewed in favour of Indian species which is holding >50 % of the Asian *Momordica* species diversity, as information on entities exclusive to Southeast Asia, being rather truly wild, are rather limited and is one step in the long process leading to total understanding of the genus *Momordica* for its exploitation for human health and well-being.

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Description and Crop Production

2

Abstract

Twelve species of *Momordica* have been botanically described from Asia. All the species grow well in hot, humid areas and seems to be almost day-neutral and like most cucurbits prefer a well-drained soil with a pH of 6.0–6.5. In annual species, direct seeding is the usual production practices while all the dioecious taxa exhibit varying degrees of gradual release of seed dormancy. Low temperature and hard-seededness are reported to be the main reason for slow and poor germination in *M. dioica* and saponins are reported to inhibit seed germination in *M. cochinchinensis.* Tuber pieces are commercially used as planting material in teasel gourd while in sweet gourd, a better and reliable method is to use rooted vine cuttings/wedge grafting. Though many workers proposed rooted vine cuttings as an alternative propagation tool for *M. dioica*, there are no reports on ratooning behaviour of such propagules. Tissue culture propagation would be of immense importance for production of *M. dioica* and *M. sahyadrica* where propagation through stem cuttings, root tubers and seeds are difficult. Protocols have been established for direct shoot regeneration from nodal segments, cotyledons and plantlet regeneration from the cell suspension cultures. In monoecious species, male and female flowers are borne separately on the same plant while for dioecious species, provision of 10 % male plant in the field is considered imperative for good fruit set. In case of teasel gourd, artificial pollination gave 95–100 % fruit setting, but natural pollination contributed only about 25–50 % fruit set. Experimental data on nutrient management of *Momordica* species are not very extensive. However, generous amounts of organic matter in the soil, from animal source are beneficial for the growth. Harvesting starts about 50–60 days after sowing and is done twice or thrice a week and fruit responds quickly to the presence of ethylene and should be isolated from fruits that produce large amounts of ethylene to prevent post-harvest ripening. Fruit borer, fruit fly, powdery mildew, downy mildew are the major pests of *Momordica* species.

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Keywords
Seed germination · Breaking dormancy · Tissue culture · Pollination management · Insect pests

Description

Momordica L.

Climbers, annual or perennial; glabrous or pubescent. Leaves simple, entire or lobed or (sub) pedately 3–5 (12–15 in African) foliate. Tendrils simple, unbranched. Flowers medium to large, monoecious or dioecious, sometimes ± zygomorphic, petals imbricate off white, cream or yellow. Inflorescence of male flowers solitary or in short loose pseudo-racemes, each flower stalk with a persistent hooded bract; female flowers solitary, in axils, also with a conspicuous or rudimentary bract. Male flower pedicels minute or long, receptacle tube short, cupular or saucer shaped, calyx lobes entire or scarious, adnate at base. Petals 5, free, entire, 1–3 with an incurved scale inside at the base-receptacle juncture. Stamens 3, anthers 1-one thecous, 2-two thecous, filaments very short, free, inserted at the mouth of the receptacle tube; thecae usually coherent, connective sometimes swollen, pistillode absent. Female flowers calyx as in the male or distinct, petals as in the male; ovary oblong-fusiform, ribbed, warty or soft papillose, ovules mostly many, horizontal; stigma 3-lobed; staminode absent. Fruit ovoid ellipsoid to fusiform, fleshy, ornamented with soft spines, warts or tubercles and ridges, irregularly or regularly 3 valved, dehiscent, rarely indehiscent. Seeds many, enclosed in orange-red sarcotesta (aril). Small or large, flattened or turgid on faces, smooth or sculptured, margins often undulate and dentate.

1. *M. charantia* L. (*Source* Joseph 2005)

Annual, slender climber, 2–4 m high, scarcely to densely pubescent (tender parts wooly), monoecious. Leaves: blade usually deeply palmately 5–9 lobed, reniform to orbicular or sub orbicular 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. Flowers solitary, pubescent, petals yellow. Male flowers: stalks slender with bract mid way or towards base; peduncle 2–5 cm long; bract reniform, 5–11 mm diameter, green, mucronate at apex, margins entire; pedicel 2–6 cm long; receptacle tube cup shaped, 2–4 mm long and 2–3 mm wide; sepals ovate-elliptic, 4–6 × 2–3 mm, pale green touching each other and protecting the corolla tube; 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; disc shortly cup shaped, c. 1.5 mm diameter. Female flowers: 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 c. 2 mm long; nectary 3 at stylar base. Fruit pendulous, stalk 2–15 cm long; discoid, ovoid, ellipsoid to oblong or blocky, often narrowed at ends, sometimes finely rostrate, 3–8 × 2–5 cm, white or green turning orange on maturity, soft tuberculate with 8–10 broken or continuous ridges, splitting from base into 3 valves exposing the arillate seeds; seeds 5–15, squarish rectangular, ends subtridentate, faces compressed, sculptured, 5–9 × 3–6 mm, margins grooved, testa brown or black.

2. *M. balsamina* L. (*Source* Joseph 2005)

Slender trailing herb, 1.5–3 m high, annual, sub glabrous, monoecious; stems round, internodes 5.5–6 cm; tendrils delicate, 11–13 cm long, basal 1–1.5 cm uncoiled. Leaves 3–5(–7) lobed to c. halfway or more, sub circular in outline, 4–6 cm diameter, base cordate with a cuneate petiole-blade juncture, mucronate at

apex, lobes rhomboid, margins acutely 3–7 lobulate; petiole 1–4 cm long, slender, puberulous. Flowers solitary. Male flowers 2–3 cm across, bigger than in female; peduncles slender (2) 3–5 cm long; bract sub apical, sub orbicular, up to 0.6 × 0.5 cm, pale green, filmy, cordate at base, margins finely dentate; pedicel 0.3–0.4 cm long, ±pubescent; receptacle tube cup shaped (obconical), up to 2 mm long; sepals ovate, up to 0.7 × 0.3 mm, obtuse, faint green or pale cream, pubescent; petals obovate, 1–1.3 × 0.7–0.9 cm, pale yellow to creamish yellow with green sub parallel veins and undulate margins, scales in 2 petals only; filaments up to 2 mm long, inserted on the rim of the receptacle tube, anthers up to 1.2–1.8 mm long, ±coherent at base only; thecae bright orange, disc inconspicuous by deep orange coloured nectary, open from above. Female flowers 1.7–1.8 cm across; peduncles 0.2–0.3 cm long; pedicels 0.4–0.6 cm long; bracts small; calyx minute, thread like, thin, recurved; petals 0.8 × 0.8 cm, pale yellow to creamish yellow with green sub parallel veins and undulate margins; ovary ovoid to fusiform, shortly rostrate, 5–7 mm long, ±pubescent, finely remotedly warty in rows, style short, slender, whitish yellow. Fruit stalk 1–2 cm long, fruits broadly ovoid-ellipsoid, bulged at middle, 2.5–3.5 (4.0) cm long, 1.8–2 cm circumference, shortly rostrate, ashy olive green with 2–3 white tubercles in lines across the whole length of fruits, bumps (murication in interspace between ridges) absent. Fruits turning orange and later scarlet red on ripening, pericarp thin, seeds 3–5, covered by deep red sarcotesta, ovate oblong compressed, 8.5–9.5 × 5.9–6.2 mm, margins finely grooved, crenulate, testa grey or light brown, delicately verrucose.

3. *M. cymbalaria* Fenzl ex Naudin (*Source*: Cooke 1901–1908)

Monoecious, roots woody, tuberous, perennial; stems very slender, scandant, branched, striate, pubescent or sub-glabrous. Tendrils filiform, slightly pubescent, simple. Leaves orbicular-reniform in outline, 1.90–4.50 × 2.50–5.00 cm, glabrous or with a few scattered hairs, punctuate on both surfaces, deeply cordate at the base, obtusely but not deeply 5–7 lobed, the lobes short, acute or obtuse; petioles 1.25–3.80 cm long, striate, pubescent. Male flowers in 2–5 flowered racemes; peduncle 0.60–2.50 cm long, filiform, pubescent, ebracteate; pedicels 0.30–1.00 cm long. Calyx hairy; tube short, broadly campanulate, narrowed at the base, lobes 0.60 cm long, lanceolate, acute. Corolla pale yellowish white, segments obovate, obtuse, 0.30–1.25 cm long. Stamens 2; filaments very short, thick, flattened; anther 10.20 cm long, the connective broad. Female flowers: peduncle 1.90–3.80 cm long, slender, ebracteate. Ovary fusiform, beaked; Fruit 1.90–2.50 cm long, up to 3 g, pyriform or broadly fusiform, narrowed into a curved peduncle, fleshy, dark green, 8-ribbed, sparsely hairy, placenta spongy to fibrous, white. Seeds 2–3, 0.40–0.60 cm long, broadly ovoid, slightly compressed, strophiole, not margined; testa polished and shining, dark brown.

4. *M. dioica* Roxb. (*Source*: Joseph 2005)

A dioecious vine, climbing up to 3–10 m high; the tap root perennial, tuberous, fusiform in the first year, subsequently getting elongated and bulged, rarely branched or forked below, 9–18 × 6–11 cm, weighing between 180 and 350 g, occasionally up to 800 g. Stems slender, the internodes 3–8 cm long, cylindrical, nodes in the mature basal region quadragonal. Tendrils axillary, 4–12 cm long, the basal 2–4 cm straight and the rest in a coiled position. Leaf blades thin, light green to green, ovate to cordate, nearly triangular in outline, lobed and sub lobed to various degrees or unlobed; cordate and cuneate at base, acute or acuminate at apex, the margins entire, undulate, irregularly or coarsely crenulate or regularly dentate; venation ending up in spathulate hydathodes which is sometimes like broad short bristles at margins and dent tips, lateral veins 4–5 pairs on each side of the midrib, the lower most pair running parallely closer to the margin of the cordate sinus, but soon branching out into 3–4 veinlets; the upper surface and margins with scattered short hairs (10×), the lower surface densely short hairy; petiole slender to medium thick, 3–7 cm long, 1–1.5 mm in diameter, longitudinally grooved. Staminate flowers solitary in axils or often a

loose fascicle with a separate lower one; 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 × 8–20 mm, light green, cucullate with 8–12 longitudinal veins, attached to the pedicel by base at one side; calyx (cup) 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; acute at apex with 3–5 sub parallel veins branching sideways. Stamens 3, two of them with a pair of anthers and the other with a single anther, filaments 2–3 mm long, anthers sub triangular, 2–3 mm long, extrose, yellowish brown on inner side, each anther with a single 'S' shaped pollen locule, filaments at base extended to petal base covering the nectary; disc inconspicuous. Pistillate flowers solitary in leaf axils; peduncles thin, very short 0.5–2 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, semi-persistent, green, narrow, 3–6 × 0.8 mm, acute at apex; petals 5, same as in male flower; ovary oblong-ovoid to urn shaped, 6–9 × 2–3 mm, rounded at base; nectary 5, small, white, butt-like cylindrical structures between petals at stylar base on the disc; styles short, up to 4 mm long, glandular hairy, stigmatic lobes 3, each lobe 'V' shaped, up to 3 × 5 mm, lemon yellow, cushiony, glandular. Fruits broadly ovoid-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 to dark green, turning uniformly orange on ripening, splitting from base into three pieces and rolling back exposing scarlet red arils (seeds); seeds 2–3 mm across, black lustrous and golden lined (when fresh), sculptured on surfaces, small round to slightly oval or shortly stellate (Central Indian specimens had round ovate and smooth seeds), seed coat brittle, shell hard, membrane thin whitish, endosperm oily with characteristic aromatic odour (common to *Momordica* spp.) when crushed.

5. *M. sahyadrica* Joseph and Antony (*Source*: Joseph 2005)

A dioecious robust tendrillar climber, vines up to 5–6 m high, the tap root perennial, tuberous, fusiform when young, sub globose or bulged irregularly when matures, 10–18 cm long, 5–10 cm across, outer skin brownish and inner flesh whitish yellow. Stems stout, cylindrical turning quadrangular as it matures, 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, the rest coiled. Leaves heterophyllous. Petiole 3–8 cm long, 1–1.5 mm in diameter, medium thick, longitudinally grooved above. Leaf blades medium thick, ovate, broadly triangular in outline, 3–5 lobed or entire, 10–16 × 8–18 cm, deeply cordate at base with a subangulate juncture with petiole, 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. Male flowers axillary, solitary or a loose fascicle of 5–7 (up to 15) flowers and in such case the lowermost flower produced separately and early; 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, margins cucullate; calyx base funnel shaped, up to 8 mm long and 1 cm across, purplish black, lobes free, up to 1 × 0.6 cm, yellowish white at center and blackish purple at base and margins, elliptic oblong, recurved at apex, margins and apex scarious, densely hairy within and sparsely hairy without; petals 5, free, fleshy, obovate, up to 4 × 1.5 cm, bright yellow with a greenish yellow narrow base, veins prominent (embossed), each petal bearing a small tongue-like ciliate appendage near the base; stamens 3, 2 of them with a pair of anthers, the third one with a single anther, filaments up to 3 mm long, anther 2–3 × 1–2 mm, extrose, thecae dull black, 'S' shaped with abundant orange pollen, pollen grains tricolpate. Pistillate flowers solitary in leaf axils; peduncles

0.5–2 cm, often less than 1 cm; pedicels short, up to 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 hairy within and without; petals 5, free, fleshy, up to 4 × 2 cm, narrow, greenish yellow and ciliate at base, widening towards middle, bright yellow, veins 5–7, sub parallel; nectary 5, white, short cylindrical, alternating with petals, protected by a spur at the base of petals; ovary inferior, oblong-ovoid, 1–1.5 × 0.2–0.4 cm, more or less densely clothed with soft papillae of 1 mm length; style up to 6 mm long, whitish yellow, stigma up to 4 × 9 mm, cushiony, trifid, each lobe again sub lobed dichotomously. Fruits broadly ellipsoid, ovoid to fusiform or top shaped with round blossom end and rostrate distal end, 5–7.5 × 3–4.2 cm in size, 9–12 cm in circumference, 35–50 g in weight, dark green turning bright orange on ripening, densely clothed with soft short spines; spines 2–4 mm long; arils sweet to taste, ripe fruits aromatic and slightly bitter. Seeds black, shining, losing its luster on drying, round to slightly cogwheel shaped, 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.

6. *M. cochinchinensis* (Lour.) Spreng. (*Source*: Joseph 2005)

Stout perennial climber up to 20 m high, primary roots woody, all parts glabrous, dioecious. Leaves: blade entire or 3–5 palmately lobed, or 3 foliate (leaflets ± elliptic with minute petiolule), broadly ovate or sub orbicular in outline, up to 10 × 16 cm, base cordate (sometimes with 2–4 glandular bead-like projections towards cordate margin), acute or acuminate at apex, margins entire, undulate or remotely dentate; petiole 5–12 cm long, usually with 2–6 glandular bead-like crateriform glands (Assam and Andaman specimen). Flower solitary, axillary, male sometimes in a loose fascicle of 5–7, with a separate basal one. Male flowers with sub apical bract; peduncles 8–12 cm long, bract cucullate, sub orbicular or reniform, 20–40 mm wide, ±scabrous, rounded at base, acute at apex, margins undulate, veins sub parallel, very prominent outside; pedicels 5–8 mm long, receptacle tube saucer shaped, 4–5 × 8–12 mm, blackish outside; sepals coriaceous, 10–12 × 4–8 mm, ovate-oblong or triangular, acute at apex, blackish, finely scabrid; petals sub elliptic 2.5 × 6–7 cm, conspicuously sub parallel veined, scales 3, at the base of the blotched petals, protecting the nectary; inner 3 petals with 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' shaped, connective swollen. Female flower: bract small or just as in male; sepals: linear oblong, 4–10 mm long or just as in male; petals as in male; ovary ellipsoid oblong, 12–15 mm long, densely soft muricate; style 8–9 mm long. Fruit stalk 5–12 cm long, fruit ovoid or oblong-ovoid, bulged at middle, 10–15 × 6–10 cm, shortly rostrate at base; pericarp densely tuberculate with uniformly short round conical structures or interspersed with larger tubercles; single fruit weighing between 350 and 500 g or more, green turning orange on ripening and non bursting as epicarp is leathery; seeds many, variable in size, 1.5–2 × 0.8–1.2 cm, broadly ovate penta-hexangular with flat sculptured surfaces, subtridentate ends and dentate margins, testa black.

7. *M. subangulata* Blume subsp. *renigera* (G. Don) W. J. de Wilde (*Source*: Joseph 2005)

A dioecious vine, climbing up to 8–10 m high, the roots (tap root, secondary and tertiary roots) tuberous, tubers both sessile and non sessile, fusiform to globoid or sub globoid to irregularly bulged, often branched, bulging 3–7 × 2–5 cm. Stems stout, the internodes 7–11 cm long, quadrangular, grooved, nodes slightly bulged, often twisted. Tendrils simple, axillary, 15–17 cm long, the basal 5–7 cm straight, the rest when uncoiled measuring up to 10–12 cm long. Leaf blade medium thick, light green, ovate cordate, unlobed, 8–12 × 7–11 cm, acuminate at apex, cunctate at base, the basal flaps almost touching the petiole or overlapping giving rise to two sinus or cavities, the margins

undulate and coarsely denticulate with fine bristles projecting as continuation of veinlets; veins 3–5, ascending and many pinnate from midrib ending up in fine network of areolas, 4–5 mm across, glabrous above, glandular hairy below; petioles 7–10 cm long, thick, channeled longitudinally, margins finely ridged. Flowers large, showy, creamish yellow, up to 9 cm across, opening early in the morning, withering by afternoon and falling (petals) by evening. Male and female flowers solitary, axillary. Staminate flowers: peduncles 4–6 cm long, pedicel 0.5–1 cm long, subtended and covered by a reniform bract, 2 × 2.5 cm, light green, plicate with about 15 ribs, shining, glabrescent inside, pubescent outside; calyx cup saucer shaped, sepals 5, greenish crimson, united at the base, 10 × 7 mm, ovate, acuminate at apex; petals 5, 5–6 × 3–4 cm, free, fleshy, prominently networked with 5–7 sub parallel veins and intricate cross veins, creamish yellow with intense colouration towards base, obovate, acuminate at apex, narrow at base, highly imbricate, 3 inner petals with blackish purple blotch of 7 × 6 mm size and long glandular hairs; nectary orange yellow, enclosed in calyx cup, scales 3, very prominent, flap like; 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, thecae yellowish white and dull brown bearing abundant orange yellow pollen. Pistillate flower: peduncles short, 1–1.3 cm long, pedicels 10–17 cm long (Mizoram, Gangtok, Kahikuchi Tripura specimens); 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; nectary 5, white butt-like cylindrical structures protected inside the petal base, touching the style; style 5–7 mm long, pale yellow, stigma cushiony up to 4 × 6 mm, trilobed. Fruits broadly ovoid-ellipsoid, with doom shaped ends and a prominent rostration (3–5 mm) at base, 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/fruit) by basal splitting of the fruit and rolling back of the split lobes. Flesh thick, (5–6 mm), aril deep red; seeds flat, sub orbicular to sub tridentate, rectangularly stellate-cogwheel shaped, 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.

8. *M. denudata* (Thwaites) C. B. Clarke (*Source*: Trimen 1893–1900)

Perennial, stems compressed, two-edged, furrowed, glabrous. Leaves 3–10 cm, cordate, ovate in out line, very acute, more or less deeply 3–5 lobed at base, distantly denticulate, glabrous, punctuate beneath, petiole channeled above, slightly pubescent. Flowers dioecious, male in a small raceme of 4–8 and a separate basal one, pedicel about 1.5 cm, puberulous, bracts minute or inconspicuous. Female flower solitary. Calyx segments linear-lanceolate or linear, acuminate, longer in female. Petiole 0.5–2.5 cm, lanceolate, acute, pubescent, narrower in female. Ovary densely covered with long acute papillae. Fruit about 3.8 cm, ovoid, usually lopsided, suddenly narrowed into a strong blunt beak, covered with short pointed processes. Seeds large, over 0.6 cm, ovoid, not compressed, tuberculate. A photograph of the herbarium specimen is provided in Fig. 2.1.

It is endemic to Sri Lanka and is said to be rather common in moist and lower montane zone at 1500–4000 ft. The leaves are very variable; the central lobe is, however, always large and is often elongate and very acuminate. A perusal of the type specimen (CP 1615) indicates its distinctness from other *Momordica* species in its branched male inflorescence, scar-like inconspicuous male bracts and small round buds. Reported occurrence of it in Kerala part of India is based on wrong identification of *M. dioica* specimens (Joseph 2005). Rheede's plate in *Hortus Malabaricus* with the vernacular name "bempaval" is a male specimen of *M. dioica* with flowers in pseudoracemes, which is equated by many botanists as *M. denudata*. According to Clarke (1879), it is altogether remote from *M. dioica* and evidently closely allied to

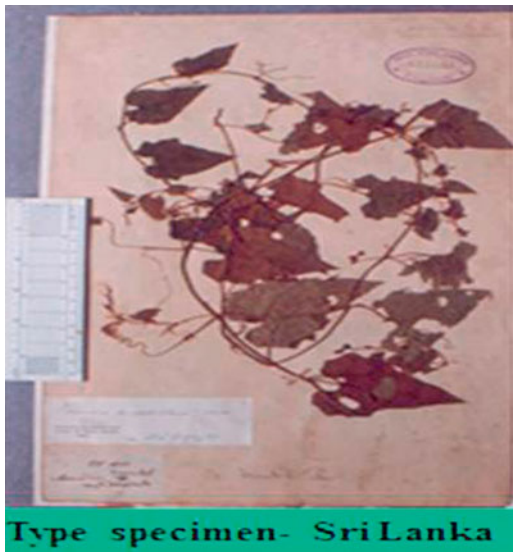

Fig. 2.1 *M. denudata* type specimen

M. cymbalaria which should be shifted to *Luffa* by virtue of its exert anthers, long pedicellate flowers and distinct flower shape. Characters like absence of prominent male bracts and branched male inflorescence indicates the remoteness of *M. denudata* from other species of *Momordica.*

9. *M. subangulata* Blume subsp. *subangulata* (*Source*: de Wilde and Duyfjes 2002)

Dioecious, perennial climber, with annual aerial stem. Stem angular. Tendrils unbranched, short. Leaves simple, 3–5-palmately lobed, thin, 3–5-veined; petiole up to 5 cm long; leaf-blade ovate-reniform, 6–13 × 4–9 cm, base cordate, margins denticulate. Flowers solitary in leaf axils, yellow, up to 5 cm in diameter. Male flowers with long peduncle up to 12 cm long, subtended with an apical, reniform bract, c. 2 cm long; pedicel short, c. 2.5 mm long; calyx tubular, 5-lobed, lobe ovate, apex emarginate; corolla 5, free petals; stamens 3. Female flower solitary, peduncle 6–7 cm long, bearing a small bract at base, perianth the same as in male flower; ovary superior, 3-carpellate, stigma 3-lobed. Fruit a pepo, ovoid, 6–7 by 3–4 cm, longitudinal wings (Fig. 2.2). Seed 1 × 1 × 0.5 cm, grey. A photograph of the herbarium specimen is provided in Fig. 2.3.

10. *M. rumphii* W. J. de Wilde (*Source*: de Wilde and Duyfjes 2002)

Slender perennial climber; glabrous; dioecious. Leaves: blade 3-foliate, sub circular in outline, 8–11 cm diameter, apex acuminate, leaflets ovate-oblong, the two outer unequal-sided, 5–7 × 2–3.5 cm, margin sparsely dentate, petiolule 0.6–0.8 cm long; petiole 2–4 cm, glands absent. Flowers solitary, or male occasionally up to 3 per node, (sub) glabrous; petals are yellowish (?). Male flowers: stalk with bract sub apical; peduncle 1.5–2 cm long; bract rather closely subtending the flower, sub orbicular, 10–15 mm diameter, base ± cordate, apex rounded with minute acuminate tip, margin puberulous; pedicel 7–10 mm; receptacle-tube cup shaped, tapered, 2.5–3 × 3–4 mm, somewhat blackish; sepals oblong, c. 5 × 2 mm, narrowly obtuse, pale (green-) brown, puberulous, petals ± elliptic oblong, 13–15 × 5–6 mm, base ± clawed, apex obtuse or sub acute, puberulous. Female flowers unknown. Fruit: solitary, stalk slender, c. 2 cm long (fide Rumphius, t. 152, f.2); fruit broadly ovoid-ellipsoid or sub globose, 1–2 mm beaked at apex, c. 4.5 × 4 cm, sparsely muricate, orange. Seeds: few, c. 5 per fruit, thick but flat, circular in outline, c. 15 mm diameter, c. 8 mm thick; margin with a double row of 8–9 coarse warts or undulations; testa brown–black, finely corrugated.

11. *M. clarkeana* king (*Source*: de Wilde and Duyfjes 2002)

Climber 6–8 m, perennial; (sub) glabrous; dioecious. Leaves: blade unlobed, ovate in outline, 4–14 × 3–12 cm, base cordate, apex acute-acuminate, short-mucronate, margin remotedly dentate, teeth minutely mucronate; petiole 2–8 cm long, without glands. Flowers: male (solitary or) (1–) 2–4 fascicled, the fascicles sub axillary to reduced leaves, usually arranged on loose raceme like lateral shoots to 10 cm long; petals pale yellow. Male flowers: peduncle (almost) absent; bract basal, spathulate, minute, 1–2 mm, ±dentate, glandular; pedicel slender, 15–30 mm long; receptacle-tube cup shaped, c. 2 × 2.5 mm, brownish; sepals broadly ovate, c. 4 × (2–3) mm, obtuse, brown, paler to the

Fig. 2.2 Fruits of *M. subangulata* subsp. *subangulata* (*Source* JIRCAS, Japan)

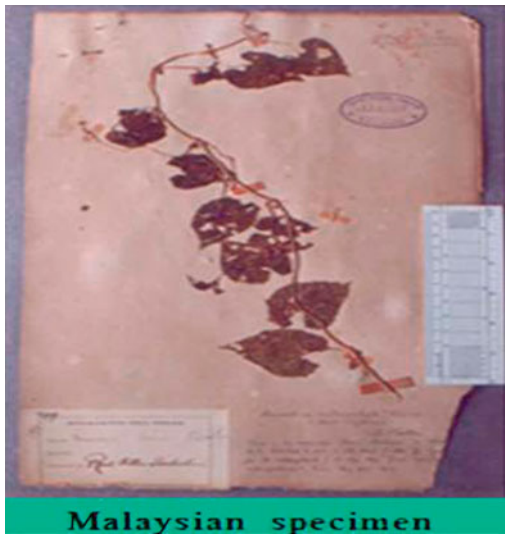

Fig. 2.3 *M. subangulata* subsp. *subangulata* type specimen

margin, glabrous, margin short-fimbriate; petals obovate-elliptic, c. 10 × 6 mm, apex obtuse (or sub acute), papillose-pubescent. Female flowers unknown. Fruit solitary (or rarely 2/node); peduncle absent; bract not seen (absent?); fruiting pedicel (fruit stalk) slender, 3–5 cm long; fruit (broadly) ovoid, base and apex broadly rounded, apex 2–3 mm beaked, 4.5–7 × 3.5–5 cm, smooth, glabrous; pericarp thin, hard-leathery, orange or red. Seeds few (c.6), elliptic or sub circular, compressed, large, 15–18 mm diameter; margin with c. 8 conspicuous undulations (cogwheel shaped, resembling seeds of *M. cochinchinensis*); testa (black–) brown, faces sometimes sculptured.

12. *M. denticulata* Miq. (*Source*: de Wilde and Duyfjes 2002)

Perennial climber to 8 m; most parts (excl. inflorescences) glabrous; older bark whitish grey, fissured, not tuberculate; dioecious. Leaves: blade entire, sometimes coriaceous, ovate-oblong or oblong, (7–) 9–15 (–20) × 4–9 (–12) cm, base truncate or cordate, apex sub obtuse or acute-acuminate, hardly fetid when crushed, greenish on drying, ±shiny on both sides, margin entire or variously (sparsely) sharply dentate, sometimes only a sharp tooth on each basal lobe; veins 3(–5) palmate from base, ascending and few pinnate from midrib, ultimate nervation sharp, forming areolas c.1 mm diameter; glands on blade surface absent; petiole 2–4 cm long, without or with few glands in the upper half and/or on the basal blade margin. Flowers like those of *M. cochinchinensis*, scabridulous or pubescent, solitary or male solitary or up to 30 grouped in bracteate racemes to 5(–15) cm long; petals creamy-white, the inner three with or without a black blotch at base, pubescent or bearded towards the base. Male flowers: stalk with bract sub apical; peduncle 2–8 cm long, glabrous or puberulous, bract circular or broadly ovate, (0–15)20–35(–50) mm diameter, scabrid on both surfaces, base cordate, apex obtuse or acute, with or without glands, margin finely puberulous; pedicel 5(–15) mm long; receptacle-tube saucer shaped, 2–3 × 8–12(–15) mm, ±blackish or not; sepals sub coriaceous, (±ovate-oblong or) triangular, 10–15 × 5–8 mm, acute (-acuminate), (blackish) green or yellow brown, scabridulous; petals ± elliptic or oblong, 30–50 mm long, apex rounded or acute (-acuminate), distinctly veined, scales as in *M. cochinchinensis*; androecium as in *M. cochinchinensis*, 6–10 mm long; each

stamen (or lobe) with or without a conspicuous appendage. Female flowers: stalk (peduncle and pedicel) 4–6 cm long; bract acute, 2–3 mm long, at 5–12 mm from the base; ovary fusiform, narrowed in the apical bract, 18–25 × 4–5 mm, densely minutely hairy (hairs 0.1 mm or less; receptacle-tube, c. 3 mm wide; sepals linear, 7–8(–10) mm long, acute; style slender, 5–7 mm long. Fruit: stalk 5–10 cm long, with bract scar near base; fruit (ovoid-) ellipsoid-oblong, apex narrowed into 10(–15) mm long beak, 8–14 × 5–10 cm, pericarp ± leathery, without ornamentation, sometimes minutely scabrid, like fine sandpaper, green–yellow or red; pulp orange–red. Seeds: numerous, flat, sub orbicular, cogwheel shaped (as in *M. cochinchinensis*), 20–30 mm diameter, 6–7 mm thick; margin with a double row of c. 10 blunt wart like bulges; testa brown blackish, faces finely sculptured in a blotchy pattern.

Pollen Morphology

Morphology of the pollen has been studied only in three species and their typical description is given below (Awasthi 1961).

M. charantia: 3-zonicolporate (Fig. 2.4), prolate (76 × 55 μ; range 70–84 × 49–59 μ). Apocolpium diameter 14 μ. Ectocolpium ends acute, tenuimarginate. Endocolpium very faint. Exine 2.8 μ thick. Ectine is thicker than endine (endine very thin). Columella very clear.

M. balsamina: 3-zonicolporate, prolate spheroidal (40 × 34 μ; range 35–43 × 28–36 μ). Apocolpium diameter 10.5 μ. Ectocolpium ends slightly rounded (acute), tenuimarginate. Endocolpium very faintly demarcated, slightly lalongate, ends rounded. Exine 2.8 μ thick. Ectine thicker than endine, reticulate ± areolate, areolas irregularly shaped. Columella clear.

M. dioica: 3-zonicolporate (few grains syncolpate), spheroidal (diameter 58 μ; range 53–70 μ). Apocolpium diameter 21 μ. Colpi ends acute tenuimarginate. Endocolpium very faintly defined, slightly lalongate (17 × 7 μ). Exine 5.6 μ thick. Ectine thicker than endine (ectine 4.2 μ thick), areolate, areolas irregularly shaped. Columella clear.

Crop Production

Climatic Requirements

Asiatic *Momordica* species are thought to be native to warm, humid and arid regions in different parts of Africa and Asia and they have many ecological requirements in common. They grow well in hot, humid areas but also grow well in subtropical climate. All the species seems to be almost day neutral and grow from the plains to an altitude of 1500 m. The annual species and the stems of perennial species are killed by frost and water stress. But in case of perennial species, new shoots sprout from surviving underground stem tissue (tuberous roots) after cessation of winter. *Momordica* species are mainly cultivated during the spring, summer and more often rainy seasons where winter is severe, while it is cultivated throughout the year in tropical climates.

Bitter gourd requires a minimum temperature of 18 °C during early growth (Larkcom 1991);

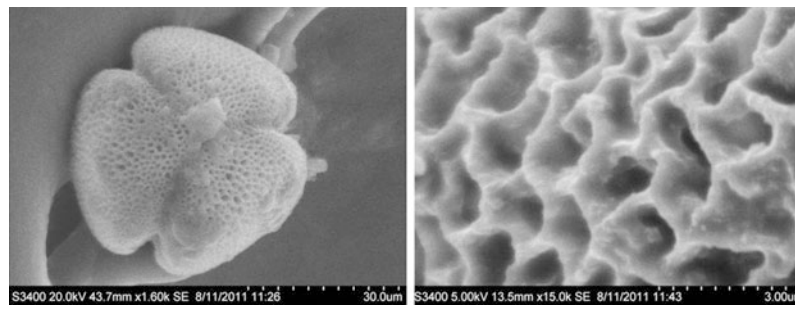

Fig. 2.4 SEM polar view showing 3 colpi (*M. charantia*) and reticulate exine surface

with 24–27 °C being optimum (Desai and Musmade 1998). But when temperature becomes too high (>37 °C) fruit set often becomes problem, depending on the genotype (Njoroge and van Luijk 2004). Seed germinates in a temperature range of 15–45 °C, with large differences among cultivars (Singh 1991). Sex expression in bitter gourd is affected by environmental conditions (Wang et al. 1997). Short day conditions will help in improving female flower production (Yonemori and Fujida 1985) while long days cause male flowers to bloom up to 2 weeks before female flowers (Palada and Chang 2003). A temperature range of 25–30 °C and 1500–2500 mm rainfall are ideal for the growth and expression of teasel gourd and spine gourd (Ram et al. 2002a; Joseph 2008). In South Andaman Islands, characterised by a temperature range of 22–30 °C with an average rainfall of 3000–3500 mm received from May to December and very high relative humidity of 82–85 % throughout the year, a good population of sweet gourd was found to thrive in the wild (Joseph and Bharathi 2008). *M. sahyadrica* prefers a temperature range of 20–25 °C and 2500–3000 mm rainfall prevailing in the high ranges of Western Ghats of India (Joseph 2005).

Soil Requirements

Momordica spp. prefers a well-drained sandy loam soil of shallow to medium depth (50–150 cm) that is rich in humus or organic matter with a pH of 6.0–6.5. *M. charantia* grows best in a well drained sandy loam, rich in organic matter, but will tolerate many type of soils (Cantwell et al. 1996; Reyes et al. 1994) and the optimum soil pH is found to be 6.0–6.7 (Desai and Musmade 1998). Though most of the cucurbits do not perform well in acidic soil, *M. balsamina* thrives well in acidic soil with a pH range of 5.0–6.5 (Mishra et al. 1986; Joseph and Antony 2008). Sweet gourd can tolerate soil salinity up to <4 dS/m (Joseph and Bharathi 2008). Sandy loams, well-drained alluvial soils and worked out laterite soils of pH 6–8 are ideal for the growth of teasel gourd (Joseph 2008).

Production Technology

Standard production technology have not been developed for *Momordica* species except for bitter gourd, as teasel gourd and spine gourd are still in domestication inter-phase and other species are wild gathered. *M. cochinchinensis* is reported to be grown in most households in Vietnam as a homestead crop usually without much attention (Voung 2001); in contrast, production of bitter gourd is more structured in terms of field preparations and maintenance. Few tips for cultivation of *M. balsamina, M. cochinchinensis* and *M. dioica* have been published in the Indian context (Shadeque and Baruah 1984; Maharana and Tripathy 1996; Ram et al. 2002a; Bharathi et al. 2005; Joseph and Antony 2008; Mishra et al. 1986).

Propagation

Seed Propagation

Freshly collected, depulped seeds show varying degrees of germination. *M. charantia* and *M. balsamina* do not show any dormancy and germinate fast. Direct seeding is the usual production practice in these species; sometimes, seedlings (raised in polybags especially hybrids) are also transplanted in the field. The seed has a hard seed coat and germinates slowly due to slow absorption of water. Poor germination percentage is common at sub optimal temperature (Peter et al. 1998). For rapid germination, the optimum temperature is between 25 and 28 °C. In bitter gourd, pre-sowing treatments such as soaking of seeds in slightly warm water for 30 min, overnight soaking of seeds, soaking of seeds in butter milk (Singh and Singh 1969) and keeping seeds in wet gunny bag or cloth bag in a warm place for 3–4 days speed up germination (Katyal and Chadha 1985). Pre-sowing treatments such as priming (mixing seeds with moist vermiculite for 36 h at 20 °C) and hot water soaking of seeds (for 4 h in water at 40 °C) are recommended for successful seedling

establishment under sub optimal temperature (Lin and Sung 2001; Hsu et al. 2003). Nath et al. (1972) obtained high seed germination of 79.5 % in Cv. Long Green by soaking in 50 ppm GA_3 for 12 h and the germination percent was further improved by exposing the seeds to red light.

The seeds of perennial taxa remain viable in soil for more than a year and occasionally one or two plants germinate before and after the peak germination. All the dioecious taxa exhibit varying degrees of gradual release of seed dormancy. *M. dioica* and *M. sahyadrica* shows strong dormancy while *M. subangulata* subsp. *renigera* shows intermediate behavior with staggered germination, having differential dormancy in different seeds of the same fruit. Cent percent viability was noticed through tetrazolium staining test and the poor germination percentage of fresh seeds indicated presence of strong dormancy factors (Joseph 2005).

On the contrary for crop plants, hard seededness is disadvantageous, the lack of simultaneous germination preventing the establishment of uniform stand of seedlings. Treatments applied to break this dormancy are highly species specific and no single method is universally accepted because even within a genus, distinct difference in the seed coat dormancy have been observed for several species of crop plants (Bhattacharya and Saha 1990). Application of GA_3 (100–200 ppm) and thio urea (100 ppm) caused early germination in *M. dioica* (Bhuyar et al. 2000; Patro and Reddy 2009). Traditionally, farmers of Odisha (India) sow the fresh seeds along the sides of irrigation channels or in beds which germinate 6–8 months after sowing and the seedlings are used for planting. Under experimental condition at Central Horticultural Experiment Station (CHES), Bhubaneswar also, 90 % germination was observed in the above method. Sowing of 6-month-old seeds after deshelling showed quick germination within 4–7 days (LKB Pers. Obs.). The seeds on deshelling show better germination indicating quiniscence, a condition where seeds fail to germinate due to unfavourable environment. Higher germination in soil seed banks and ant hives may be attributed to leeching out or breakage of inhibiting metabolites due to natural weathering.

Forest fire by increasing soil temperature breaks physical dormancy. Smoke also has a stimulating effect on germination (Baskin and Baskin 1998). Though many workers (Ram et al. 2001, 2002a; Mishra et al. 1988; Mishra and Sahoo 1983) has mentioned dormancy of the seeds as the main factor preventing cultivation of spine gourd, not much effort has been initiated to find out the reasons for dormancy and methods to break it. Ali et al. (1991) have reported low temperature and hard seededness as the reason for slow and poor germination in *M. dioica*. Saponins are reported to inhibit seed germination in *M. cochinchinensis* (Watanabe et al. 1988a, b) and deshelling is effective in breaking dormancy.

Ethno-botanical studies give hints of involvement of birds and ants in seed dispersal and careful observation revealed predation of fresh seeds by specific species of birds. Again, the tribal people expressed the opinion that there is a preponderance of higher population density of *M. dioica* in forests subjected to summer fire. This gave indications of the role of temperature and gut enzyme scarification in breaking the dormancy of seeds. Good germination was obtained in one accession of *M. sahyadrica* collected from Kurichiya hamlet, which upon enquiry was found to have been after ripened for 8 months over smoke from kitchen. Similarly, seeds of *M. dioica* after ripened for 6 months upon deshelling and maintenance in germination media at 25–30 °C were reported to give very high germination (Ali et al. 1991).

Vegetative Propagation

In the absence of an easy method of seed propagation, various vegetative propagation options need to be adopted on a species to species basis to ensure maximum production of viable propagules.

Root tubers. Tuber pieces are commercially used as planting material in *M. subangulata* subsp. *renigera*. An average plant produces 20–25 adventitious tubers of 60–80 g. Large tubers can be cut into pieces and used as propagule. Cut surface should be treated with fungicide solution (2 %) and shade dried for wound healing before planting. Tubers have a short dormancy of 2–3 months, which can be broken by exposure to air, light and room temperature. In spine gourd tuberous roots of 150–200 g size are usually planted and dipping in 1 % thio urea increased sprouting percentage (Panda et al. 1994). Use of tubers has been advocated for commercial cultivation of *M. dioica* (Mishra and Sahoo 1983; Mishra et al. 1988; Shadeque and Baruah 1984; Ram et al. 2002a) and *M. cymbalaria* (Reddy et al. 2007). In *M. cymbalaria*, tuber weight of 60 g and above recorded significantly higher fruit yield per plant (120 g) over rest of the tubers (Reddy et al. 2007).

M. subangulata subsp. *renigera* has the highest reproductive efficiency through root tubers whereas in *M. dioica*, *M. sahyadrica* and *M. cymbalaria* one tuber (tap root) gives rise to one plant only or the maximum of 2–4 plants (Fig. 2.5). In the former tubers are reproductive units whereas in the later three species, they are perennating organs. In *M. cochinchinensis*, the tap root becomes gigantic and woody which is not amenable to uprooting or transplant. Anatomical study of seedling taproot tubers and secondaries of teasel gourd confirmed their root nature. Exarch steele, radial arrangement of xylem and phloem and presence of lenticels indicate their root nature. The study also suggest that mid-February to mid-March is the best time for planting of *M. dioica* and *M. sahyadrica* tubers under Kerala condition, whereas *M. subangulata* subsp. *renigera* can be planted throughout the year under tropical humid (Kerala) conditions.

Dormancy of the tubers was observed in all species and *M. subangulata* subsp. *renigera* has the shortest tuber dormancy (Table 2.1). In situ tillage of the tuber base was very effective in initiating sprouting across the species. Allowing moisture loss from the tuber and aeration of the tubers were found effective in breaking dormancy. *M. subangulata* subsp. *renigera* and its hybrid has the shortest dormancy of 1 month, whereas *M. dioica* has 5 months dormancy and *M. sahyadrica* has about 4–4.5 months dormancy.

Vine cutting. All the species are amenable to rooting from vine cuttings. However, there is difference between species, *M. subangulata* subsp. *renigera* being most efficient and *M. charantia* var. *muricata* showing the least efficiency. Young midlevel cuttings are the best to root and establish across species while vine tips are unable to withstand stress induced by detaching from mother plants. Vine cuttings of *M. dioica* and *M. sahyadrica* developed few sessile root tubers, whereas *M. subangulata* subsp. *renigera* develops many root tubers, both sessile and non sessile. Such adventitious root tubers in *M. dioica* and *M. sahyadrica* did not germinate and remain intact in soil over the years, whereas in *M. subangulata* subsp. *renigera*, it sprouted vigorously (Joseph 2005).

In sweet gourd, a better and reliable method is to use rooted vine cuttings as propagules. Mid and top level cuttings root well with rooting hormone treatment. Closed Media Sachet technique may be adopted for home gardens (Joseph and Bharathi 2008). Rooted vine cuttings can also be used in *M. subangulata* subsp. *renigera*, but yield will be higher in tuber raised plants. In case of *M. dioica* and *M. subangulata* subsp. *renigera* 2–3 node cuttings from the basal portion of vine gives better rooting, plant growth and yield (Tripathy et al. 1994; Ram et al. 2002a). However, the cuttings should be taken from vigorously growing mother plants at early flowering stage and before axillary flower buds emerge. Though many workers have mentioned seed dormancy as the main factor limiting cultivation of spine gourds (Mishra et al. 1988; Ram et al. 2001, 2002a) and proposed rooted vine cuttings as an alternative propagation tool, there are no reports on ratooning behaviour of such propagules. Joseph et al. (2009) found that tubers formed at the base of the vine cuttings in the case of *M. dioica* and *M. sahyadrica* are purely storage organs and do not sprout in

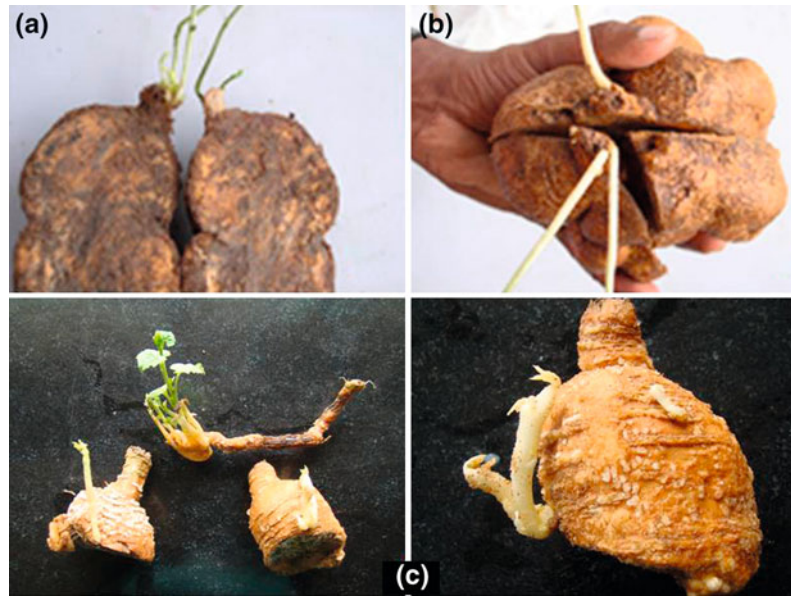

Fig. 2.5 Tubers of dioecious *Momordica* species used as planting material. **a** *M. dioica* longitudinally split tap root **b** *M. sahyadrica*-split tap root tubers with apical meristem **c** Split tubers of *M. subangulata* subsp. *renigera*

Table 2.1 Effect of physical treatments on sprouting of dormant tubers in various *Momordica* spp.

Treatment	No. of tubers sprouted/days to sprout emergence		
	M. dioica	*M. sahyadrica*	*M. subangulata* subsp. *renigera*
T_1	12 (90)	13 (110)	15 (20)
T_2	14 (75)	12 (90)	15 (22)
T_3	10 (32)	12 (60)	28[a] (15)
T_4 (control)	15 (120)	15 (148)	36[a] (90)

Source Joseph (2005)
Values in parenthesis denote days to sprout emergence
[a] including subterranean sprouting of underground tubers
T_1— unearthed tubers, potted, mulched and without irrigation
T_2— unearthed tubers, potted, mulched irrigated after 60 days
T_3—in situ tillage at tuber base, mulch removed
T_4— control-undisturbed plot

subsequent seasons as they lack shoot primordial. On the contrary, teasel gourd produces roots and shoots from any tuber or tuber piece irrespective of their tuber morphology.

Leaf rooting. Rooting of leaves is found useful as an alternative germplasm collection strategy for teasel gourd. *Momordica subangulata* subsp. *renigera,* having got very short tuber dormancy, was the most efficient species amenable to this type of reproduction. Unlike the other dioecious species, *M. subangulata* ssp. *renigera* exhibit totipotency where any part of the tuber, irrespective of whether tap root or adventitious root tuber, gives rise to shoot sprouts. This unique trait of adventitious sprouting in *M. subangulata* ssp. *renigera* enables the use of leaf tubers as planting materials. Choice of propagating plants of desired sex is an added advantage in this method. Adoption of this technique is expected to boost *M. subangulata* subsp. *renigera* cultivation in non traditional areas due to the increased availability of planting materials. Although, it takes two growth seasons to reach reproductive maturity, this technique can be used effectively as an alternate germplasm collection strategy. Also,

from the conservation point of view this technique will help in rehabilitating the species in natural habitats and popularizing them as ornamental and kitchen garden vegetables. The technique developed (Joseph 2005) for leaf rooting is described in the following paragraph.

Detach fully developed, healthy leaves of 30 days age (in early flowering stage) of known sex from the stem at petiole base with a sharp blade and treat the basal 1 cm portion of petiole and cut surface with rooting hormone (IBA at 3000 ppm). Spread the treated cuttings in shaded condition for 15 min for the hormones to get absorbed. Insert the treated petiole bases in a medium of river sand for induction of callusing and root initiation using the Closed Media Sachet Technique (Srivastava 1996) and sprinkle water periodically for 2 weeks for a mist effect. To avoid overcrowding and subsequent rotting of leaves, remove the dead and rotten leaves periodically. In *M. subangulata* subsp. *renigera,* callus formation is observed between seventh and 9th day and rooting between 12 and 15 days. Transplant the rooted leaves (21 days after planting in sand bed) to a secondary nursery. The leaves come to senescence within 60–90 days and on excavation, micro tubers of 1–2 cm size weighing 5–8 grams are formed from the base of these senescent leaves. After a period of short dormancy (4–6 weeks), these micro tubers start germinating giving rise to tiny plantlets. However, the initial growth of these plants is slow and they come to flowering only after 120 days.

Grafting. Although bitter gourd is basically seed propagated, wedge grafting on *Luffa* had been in vogue in China and Taiwan for control of *Fusarium* wilt (Chung Ta and Chin Ho 1996). It also increases the yield of bitter gourd (Palada and Chang 2003). Compatibility with 81.1 % success and 38.4 % yield increase over non grafted control was reported due to freedom from nematode and *Fusarium* wilt infection (Xiangbo et al. 1998). Similarly grafting of *M. dioica* on pumpkin has also been reported successful (Mian and Morokuna 1992, 1993).

In sweet gourd, wedge grafting of growing tips on vigorous sprouts can also be attempted. Such grafted plants are compact and require less space (4–5 m^2) compared to uncontrolled vine growth of seedling plants and rooted cuttings (Joseph et al. 2011). Through grafting unproductive surplus male plants can be converted to bearing female plants. They also perenniate over the years as in sweet gourd, the areal stem do not wither completely during unfavourable growth season.

In vitro propagation. Tissue culture propagation would be of immense importance for production of *M. dioica* and *M. sahyadrica* where propagation through stem cuttings, root tubers and seeds are difficult. As most of the Asian species are dioecious nature, micro propagation could be useful for rapid multiplication of genetically uniform planting material of known sex for commercial cultivation. Tissue culture methods from various plant parts like shoot tip, nodal segments, cotyledon, root segment, etc., have been used for regeneration in *M. charantia*, *M. balsamina*, *M. dioica*, *M. subangulata* subsp. *renigera* and *M. cymbalaria*.

Several investigations have been reported on the plant regeneration of *M. charantia* from different explants such as, micro propagation from nodal and shoot tips (Wang et al. 2001; Sultana and Miah 2003; Huda and Sikdar 2006; Malik et al. 2007; Ma et al. 2012; Thiruvengadam et al. 2012a); organogenesis from stem segments (Tang et al. 2011a, b), from leaf segments (Thiruvengadam et al. 2010, 2012b), from cotyledon segments (Halder and Gadgil 1982; Islam et al. 1994; Hoque et al. 2000) and from nodal and root segments (Munsur et al. 2009); and somatic embryogenesis from leaf explants (Thiruvengadam et al. 2006; Paul et al. 2009). Both the micro propagation and organogenesis of shoot have been established using shoot apices, nodal and internodal explants (Agarwal and Kamal 2004). Malik et al. (2007) reported that various explants of leaf, stem and cotyledon induced different types of callus in *M. charantia* but that none of these produced any shoots. In balsam apple micropropagation through anther culture (Tang et al. 2009) and from nodal explants (Thakur et al. 2011) has been established. In case of *M. cymbalaria* multiple shoot regeneration was achieved using nodal segments

and leaf explants (Nikam et al. 2009; Ailinea et al. 2009; Jeyadevi et al. 2012).

Because of ambiguity in taxonomic identity most of the studies on tissue culture pertaining to *M. subangulata* subsp. *renigera* has been reported under the name of *M. dioica*. However, through the description of crop, cultivation status, collection locality and published photographs we have identified and reported here with the correct species name. Among the different explants of *M. subangulata* subsp. *renigera* studied, cotyledon showed high performance in callus induction than shoot tip, leaf and nodal segments (Nabi et al. 2002). The concentration of 1.0 mg/l BAP and 0.1 mg/l NAA gave best response on callus formation (Karim and Ahmad 2010). The best response of shoot proliferation was obtained in medium supplemented with 2.0 mg/l BA + 0.2 mg/l NAA (Hoque and Rahman 2003). The concentrations of different hormones used for callus induction and shoot regeneration in various studies are presented in Table 2.2. Recenlty, Hoque et al. (2007) reported in vitro adventitious shoot regeneration from embryo axes of seeds from a homosexual hybrid.

Higher success rate was obtained for callus induction with auxillary bud explants (Deokar et al. 2003; Ghive et al. 2006) of *M. dioica* in MS medium containing 1.5 mg/l BAP + 1.0 mg/l NAA and multiple shoot development in MS medium supplemented with 70–80 mg/l $AdSO_4$ + 1.0 mg/l BAP + 1.0 mg/l NAA (Ghive et al. 2006). Apart from auxillary bud, multiple shoots were induced from nodal segments (Meemaduma and Ramanayake 2002; Rai et al. 2012) and leaf segments (Hoque and Rahman 2003) of *M. dioica*. Protocols for direct shoot regeneration from cotyledons of *M. dioica* (Nabi et al. 2002) and plantlet regeneration from the cell suspension cultures of spine gourd through somatic embryogenesis has also been established (Thiruvengadam et al. 2007). Rajashekaran et al. (2011) attempted in vitro culture of *M. sahyadrica* using nodal and shoot tip explants and a maximum of 8–10 shoots along with slight callusing was obtained in MS medium supplemented with BAP (3 mg/l).

Plant Establishment and Densities

The *Momordica* spp. may be planted in several ways: (i) by direct field-seeding in hills; (ii) by transplanting of polybag raised seedlings in polyhouse in severe winter; (iii) planting of tuberous roots/rooted cuttings in field. First and second methods are commonly practiced in annual species while the third method is followed in perennial species.

The field should be well ploughed and harrowed twice to remove weeds and other plant debris in the field. Raised beds of 20–30 cm height are prepared using a plough or mechanical bed shaper. Bitter gourd seeds are sown in raised mounds for the rainy season crop and in shallow pits for summer crop (Gopalakrishnan et al. 1983). The rate and distance of planting used by most farmers is one to three meters between furrows and 0.5 m between hills with 3 seeds per hill at 4 inches apart. The stand should be thinned to two plants per hill. It may be advantageous to raise the plants in polybags in polyhouses during winter months. Seedlings at 5–6 leaf stage are transplanted to the field when all danger of frost is over. For sowing one hectare field, 2–3 kg of bitter gourd seed will be required.

Plant densities vary considerably from one location to another depending on the species and cultivars. For example sweet gourd produces larger plants and their planting densities must be lower. In bitter gourd optimum plant density varies with cultivar, from 6500 to 11000 plants/ha (Reyes et al. 1994; Palada and Chang 2003) or 20000 plants/ha (Huyskens et al. 1992). Teasel gourd and spine gourd are generally planted 4500–6000 plants/ha (Ram et al. 2002a; Joseph 2008) while for sweet gourd 1500–2000 plants/ha is optimum (Joseph and Bharathi 2008). A spacing of 2 m between rows and 1 m between plants of *M. dioica* produced higher yield per plant (Patro and Reddy 2009). Higher yield of 10.7 t/ha from main crop and 7.3 t/ha from ratoon crop were obtained in spine gourd from the narrowest spacing of 1 m apart (Seshadri and Parthasarathy 2002). Tuberous roots/vine cuttings of perennial species may be

Table 2.2 Concentrations of hormones used for callus formation and shoot regeneration in *Momordica* species

Species	Callus formation	Shoot regeneration	Reference
M. charantia	1.0 mg/l 2, 4-D + 1.0 mg/l BAP	1.0 mg/l 2, 4-D + 1.0 mg/l BAP	Munsur et al. (2009)
	2.0 mg/l NAA + 0.5 mg/l BAP + 2 mg/l 2,4 D	2.0 mg/l NAA + 0.5 mg/l BAP	Agarwal and Kamal (2004)
	1–0 mg/l BAP + 1.5 mg/l NAA + 1.0 mg/l 2,4 D	1.0 mg/l BAP + 0.1 mg/l TDZ	Malik et al. (2007)
	5.0 µM 2,4 D + 2.0 µM TDA	4.0 µM TDZ + 1.5 µM 2,4 D + 0.07 mM L-glutamine	Thiruvengadam et al. (2012b)
M. subangulata subsp. *renigera*		1.5 mg/l BA and 0.1 mg/l NAA	Hoque et al. (1995)
	1.0 mg/l BAP and 0.1 mg/l NAA	1.0 mg/l BAP and 0.1 mg/l NAA	Nabi et al. (2002)
		2.0 mg/l BA + 0.2 mg/l NAA	Hoque and Rahman (2003)
		10.8 mg/l BA + 1.08 mg/l NAA + 0.54 mg/l GA_3 (embryo explants) 16.2 mg/l BA + 2.7 mg/l NAA + 0.54 mg/l GA_3 (Cotyledon)	Hoque et al. (2007)
M. dioica	1.0 mg1-1 BAP + 0.1 mg1-1 NAA		Karim and Ahmad (2010)
	1.0 mg/l 2,4-D + 2.0 mg/l BAP	1.5 mg/l BAP + 1.5 mg/l Kn.	Devendra et al. (2009)
	10 mg/l BA + 5 mg/l IBA	3 mg NAA/litre + 0.2 % activated charcoal	Pawar et al. (2004)
		0.9 µM BA + 200 mg/l CH	Rai et al. (2012)
	1.5 mg/l BAP + 10 mg/l NAA	70 mg/l $AdSO_4$ + 1 mg/l BAP + 1 mg/l NAA	Ghive et al. (2006)
		0.05 mg/l GA_3 + 0.1 mg/l TDZ	Meemaduma and Ramanayake (2002)
M. balsamina		1.0 mg/l BAP + 1.0 mg/l KN	Thakur et al. (2011)
M. cymbalaria	2.5 µM BA	10 µM Kn + 2.5 µM BA NAA	Nikam et al. (2009)
		4.40 mM BA + 4.6 mM Kn	Jeyadevi et al. (2012)

planted with pre-monsoon showers in pits of 60 × 60 × 60 cm size prepared at a spacing of 1.5 × 1.5 m (teasel gourd); 1.0 × 1.0 m (spine gourd) and 3 × 3 m (sweet gourd). For sweet, spine and teasel gourds, provision of 10 % male plant in the field are considered imperative for good fruit set (Bharathi et al. 2006; Joseph 2008; Joseph and Bharathi 2008).

Training

As *Momordica* species are weak stemmed plants they require a trellis to support the climbing vine. Staking and trellising will increase fruit yield and size, reduce fruit rot and make spraying and harvesting easier. Under natural conditions M. *cochinchinensis* spreads on big trees and *M. sahyadrica*, *M. dioica*, *M. subangulata* subsp. *renigera* on bush or grasses in forest. If the vines are allowed to spread on the ground, vines start rotting/decaying (Ram et al. 2002a).

There are several methods of trellising (Fig. 2.6) viz., single line trellis, double line trellis, pandal/bower type, lean-to type, arch-type, single plant staking, etc. For the single row vertical trellis, the trellis should be about 6 feet high, constructed from stakes 2 m apart, with a system of vertical strings between horizontal wires. The bottom horizontal line is fixed at

Fig. 2.6 Various training systems adopted for cultivation of *Momordica* spp. **a** *M. charantia* in single line trellis system. **b** *M. charantia* in double line trellis system. **c** *M. charantia* in single plant staking system

three feet height and the subsequent lines at one feet interval. Train the vines on the vertical trellis regularly by tying the vines to the trellis. Lateral shoot/vine may be pruned every 4–5 days, leaving only the main stem. Initial pruning should be done 1 month after planting or when lateral vines appeared. *M. subangulata* subsp. *renigera* is a dioecious plant pollinated by *Ctenoplectra* bees in its native habitat (Schaefer 2005). But, without hand pollination fruit set is reduced to 15–20 % (Patnaik and Patnaik 1976) and so farmers resort to hand pollination. Hand pollination could be performed perfectly, quickly and easily in vertical net trellis compared to other systems of training (Mian et al. 2001) which compensates with initial cost of training. However, vertical (fence) trellising has been reported to reduce the proportion of marketable fruit of bitter gourd and overhead or T-trellising may increase the proportion of marketable fruit (Huyskens et al. 1992). Higher yields are obtained with 2 m than 1 m high trellises and the crop is more accessible (Abusaleha and Dutta 1994a).

For bower type, a bower of suitable dimension with wooden stakes/iron/concrete pillar is erected at a height of 5 feet followed by criss cross wire netting. Sweet gourd is a robust climber with a high aerial biomass and bower type may be highly suitable for trailing. Usually the plant is trailed to thatched sheds or treetops. In Vietnam sweet gourd is grown as intercrop in orchards and allowed to trail on tree tops.

For the lean-to type, the stakes are joined between two adjoining beds forming an inverted V-shaped structure and at the top horizontal stakes are tied joining all other beds. The stakes support the climbing vines. For the arch type, plants are grown inside an arch-shaped structure made of either PVC or galvanised iron pipe. In homesteads, the farm fencing can be utilised for trailing of plants.

Pruning

Non productive side branches should be removed until the vine reaches the top of the trellis. Leave 4–6 laterals and cut tip of the main vine to induce early cropping. Removal of lateral branches in the first 10 nodes has a positive effect on total yield (Palada and Chang 2003) of bitter gourd. In bitter gourd, most of the female flower occurs between 10 and 40th node or at a height of 0.5–2 m and pruning the lower laterals increases the total number of flowers per plant by increasing the number of flowers on higher

laterals (Rasco and Castillo 1990). In case of *M. cochinchinensis* new sprouts will emerge from the main vine and therefore pruning has to be done carefully. Only side and dead branches are removed when the plant undergoes dormancy, while in *M. dioica*, *M. sahyadrica* and *M. subangulata* subsp. *renigera* the aerial part is completely dried and can be removed during dormant period.

Weed Management

During initial period of plant growth effective weed control is important to get higher yield. Most of the weeds can be effectively removed manually or mechanically. Deep cultivation should be avoided since *Momordica* species have many shallow roots. Organic or plastic mulching can also be used for controlling the weeds. In plastic mulch, planting holes are bored into the plastic sheet base at specified planting distance. To use the plastic mulch, stretch it over the planting beds, with edges held down by thin bamboo slats, staple well into the soil at every 20 cm. Organic mulch such as paddy straw or dry grass is cheaper than plastic mulch. In case of trellis system the pits are cleaned manually and covered with organic mulch. The interspaces are sprayed with post emergence herbicides like glyphosate. The 'Stale seed bed' technique can also be used to prevent weed growth. The field is ploughed and given a light irrigation. This encourages weed seeds to germinate, and then killed with a non-residual herbicide like glyphosate 3 days before planting.

Water Management

Bitter gourd cannot tolerate drought and water stress can severely reduce the yield and good soil moisture should be maintained in the upper 50 cm of soil where the majority of roots are located. Irrigate at least weekly, beginning from the day of sowing (Desai and Musmade 1998). *M. charantia* is intolerant to flooding (Reyes et al. 1994), with 4 days of flooding producing significant changes in morphology (Liao and Lin 1994). The crop can be furrow irrigated every 10 days during cool dry season and weekly during hot dry season. Drip irrigation is an efficient method of supplying water and nutrients where the necessary equipment is available. Irrigation is likely to increase size and weight of individual fruit. Sweet gourd and spine gourds do not require irrigation if regular rainfall is received. In case of uneven rains, light irrigation at 3–5 days interval will be advantageous. They are highly sensitive to water logging.

Flowering and Pollination Management

M. charantia, *M. balsamina* and *M. cymbalaria* are monoecious with male and female flowers borne separately on the same plant while other species are dioecious with male and female flowers borne in different plants. All the species of Indian occurrence produce first flower at 45–60 days except *M. cochinchinensis* which takes about 90–120 days. In plants where unisexual flowers exist, staminate flowers are more frequent than pistillate flowers. In *M. charantia* pistillate flowers may be as low as 12–16 % which is a limiting factor in fruit production (Thomas 2008). Yield in bitter gourd can be enhanced by increasing the number of female flowers or decreasing the number of male flowers which can be achieved by spraying growth hormones to alter the sequence of flowering and sex ratio. Spraying of BA 25 ppm or ethepon 200 ppm or GA 25–100 ppm after six to eight true leaf stage (Yonemori and Fujieda 1985); 500 ppm ethrel at germination or 100 ppm GA_3 in adult plants (Thomas 2008) increases the female flowers. Production of male flowers was significantly reduced with 200–600 ppm of ethrel (Ravindran 1971) and female flower production was increased with B-9 (500–5000 ppm) and CCC (500–2000 ppm) (Bose and Ghosh 1968; Ghosh and Bose 1970). Nearly 2.5 times yield increase in bitter gourd was reported with spraying of 500 ppm CCC in the variety HK-8 (Mangal et al. 1981). Application of Boron @

4 ppm (Verma et al. 1984) and α-NAA @ 100 ppm (Bisaria 1974) also reported to increase the female flower production. In vitro hormone application during seed germination was much more successful than spraying of field grown plants (Thomas 2008). Soaking of seed at 25–100 ppm NAA, kinetin, ethrel for 24 h and keeping at 5 °C for 5–15 days before sowing increased the ratio of pistillate flower to staminate flower (Prakash 1976).

Flowers are pollinated by insects especially bees (Fig. 2.7). Bitter gourd flowers are pollinated by small bees (Sands 1928) while *M. cochinchinensis* and *M. subangulata* subsp. *renigera* are reported to be pollinated by *Ctenoplectra* bees (Schaefer 2005) in its natural distribution range. Hand pollination can be avoided in bitter gourd and spine gourd by introducing bee hives or blowing pollen with an unloaded mister. However, during less favourable environment for insect activity like high temperature and low humidity hand pollination could increase the yield considerably (Abusaleha and Dutta 1994b).

For dioecious species, provision of 10 % male plant in the field is considered imperative for good fruit set. High fruit set was observed in dioecious species under natural condition except *M. subangulata* subsp. *renigera*. In case of *M. subangulata* subsp. *renigera* natural pollination contributed only about 15–50 % fruit set (Patnaik and Patnaik 1976; Hossain et al. 1987; Das 1988) while artificial pollination gave 95–100 % fruit set. Flowers are sufficiently large enough to do hand pollination and 90–100 % success can be obtained if pollination is done at optimum stigma receptivity (Joseph 2008). Male flowers are plucked and stamens touched to receptive stigmas between 6 and 10 am for 100 % fruit set. In case of *M. cochinchinensis*, good fruit set under natural condition (climbing on big forest trees) was observed in its home range, whereas under cultivation less fruit set was observed in Odisha (LKB pers. obs.) and hand pollination is essential to get higher fruit set and yield. However, under Kerala conditions good natural insect pollination and high fruit set was observed (JJK Pers. obs.).

Fig. 2.7 Honey bee pollinating a hybrid plant of *Momordica* spp.

Fruit development can be made independent of fertilisation or seed development by providing artificial stimuli which may be dead pollen, pollen extract, incompatible pollen, auxins or synthetic hormones. Development of parthenocarpic fruits are highly useful especially in case of teasel gourd where regular cumbersome hand pollination increases the cost of production (Rasul et al. 2008) and presence of large number of hard seeds in the fruits decreases its palatability (Handique 1988; Rasul et al. 2008). Vijay and Jalikop (1980) reported that application of 2, 4-D at the rate of 50–100 ppm is effective in inducing parthenocarpic fruit set than NAA and IAA in *M. cochinchinensis* while Handique (1988) found that application of NAA 100 ppm induced 95 % parthenocarpic fruit though the fruits are smaller than normal fruits. In *M. dioica*, 2, 4-D (50 ppm) spray at anthesis showed high parthenocarpic fruit development (Choudhury et al. 2007; Rasul et al. 2008). However, it must be noted that, all these studies were in fact carried out in *M. subangulata* subsp. *renigera* and not in *M. dioica* or *M. cochinchinensis*, as reported, consequent of the taxonomic misidentification of entities prevalent hitherto.

Apart from growth regulator spray, interspecific and intergeneric pollinations also induced higher percent of parthenocarpic fruit set in *M. dioica* i.e., when pollinated with *M. charantia*, *Leucantha leucantha* (Singh 1978; Bharathi et al. 2012). We have developed an interspecific hybrid between *M. dioica* and *M. cochinchinensis* (F_1) which produces parthenocarpic fruits

(90–95 % fruit set) of *M. dioica* size when pollinated with *M. cochinchinensis* (Unpublished).

Nutrient Management

The kind and quantity of fertilizer needed depend on the soil type and amount of nutrients already available in the soil and is difficult to recommend a blanket fertilizer dose. Experimental data on nutrient management of *Momordica* species are not very extensive. However, generous amounts of organic matter in the soil, from animal manure are beneficial for the growth. In general, compost manure or farmyard manure is added to each planting hole before sowing and a dose of 10–12 t/ha is recommended. The various recommendations of nutrient requirement for different species by different authors are given in Table 2.3. Bitter gourd is quite sensitive to lack of micronutrients such as Boron and application of these elements can strongly improve yield (Njoroge and van Luijk 2004). Mishra et al. (1986) recommended 20 g of 15:15:15 NPK per basin for *M. balsamina*.

In case of teasel gourd, a mixture of 25 kg well-rotten FYM and 250 g neem cake is applied to each pit. Although no specific fertilizer recommendations are available, the application of 40–45 kg N 40 kg P_2O_5 and 40 kg K_2O/ha is cost-effective. Half of N and full doze of P and K are applied to the pits at the time of land preparation and the remaining half N top dressed at the time of flowering (Joseph 2008). Application of 150 g Single super phosphate and 50 g Muriate of Potash to the basin and top dressing with Urea @ 15 g twice at 4–5 leaf stage and 30 days age are recommended for good yield in sweet gourd (Mishra et al. 1988).

For spine gourd, basal application of 4–5 kg well-decomposed farmyard manure or compost, 100 g neem or castor cake, 50 g Urea, 225 g Single Super Phosphate and 90 g Muriate of Potash, along with one-fourth sand and remaining quantity of soil has been found to produce optimum growth of the plant. At 25 and 40 days after planting 50 g Urea should be added to each basin. The subsequent nitrogenous fertilizer dose should be applied 15 cm away from the plant and incorporated well to the basin soil. The plant is sensitive to Potassium deficiency. Therefore spraying of Sulphate of Potash @ 2 g/lit is recommended whenever the symptom is noticed.

Harvesting

Bitter gourd. Harvesting starts about 50–60 days after sowing and is done twice or thrice a week. Bitter gourd fruit is often harvested based on visual assessment of marketable stage for which size, length, diameter and weight of the fruit (depending on cultivar) are important criteria. Maturity indications include a slight change in fruit colour and the fullness of ridges and bumps. It takes about 15–20 days after fruit set to reach marketable stage (Reyes et al. 1994). It accumulates bitterness with time, due to a buildup of the alkaloid momordicin, and then loses the bitterness during ripening (Cantwell et al. 1996). Fruit should be light green, thick and juicy (Lim 1998) and the seeds should be soft and white creamy (Huyskens et al. 1992) to pale green–brown (Vujovic et al. 2000) at harvest. Harvest at every 2–3 days interval as the fruit ripens quickly (Desai and Musmade 1998). Bitter gourd fruit responds quickly to the presence of ethylene and should be packed separately from fruits that produce large amounts of ethylene to prevent post-harvest ripening. Regular picking is important as fruits will become bitterer as they mature and it can also hamper the growth of new fruits. Average yields of bitter gourd are 8–10 t/ha, but up to 20 t/ha for open-pollinated cultivars has been reported. F_1 hybrids under good management can give yield up to 40 t/ha.

Bitter melon is prone to chilling injury and may be air-cooled to 10–12 °C (Zong et al. 1995). Lower temperature causes chilling injury such as pitting, decay and discolouration and higher temperature causes ripening. USDA storage recommendations are 12–13 °C at 85–90 % RH, with an approximate storage life of 2–3 weeks.

Table 2.3 Recommended fertilizer rates (kg/ha)

Country/state	N	P_2O_5	K_2O	Reference
M. charantia				
India (Punjab)	100	50	50	Rajan and Markose (2003)
India (Punjab)	56	56	0	Dhesi et al. (1966)
India (Himachal Pradesh)	100	50	50	Rajan and Markose (2003)
India (Karnataka)	62	50	0	Rajan and Markose (2003)
India (Tamil Nadu)	20	50	60	Rajan and Markose (2003)
India (Kerala)	60	30	60	Rajan and Markose (2003)
China	184	112	124	Palada and Chang (2003)
M. dioica				
India (Odisha)	30	30	30	Tripathy et al. (1993)
India (Andhra Pradesh)	240	160	75	Patro and Reddy (2009)
M. subangulata subsp. *renigera*				
India	80	50	50	Shadeque and Baruah (1984)

Spine gourd. The fruits become ready for harvest within 75–80 days in case of seed raised crop and 55–60 days in case of ratoon crop. Ratoon crop gives economic yield up to 5–6 years and fruit yield thereafter declines. Harvesting of fruits twice a week increases the yield. The fruits should be harvested at mature green stage. The fruit attains marketable maturity within 7–10 days of pollination. Under optimum crop management condition fruit yield of 75–100 q/ha can be realised (Bharathi et al. 2006).

Teasel gourd. Fruits reach marketable maturity between 12 and 15 days after flowering. Crop is ready for harvest from 60 to 70 days after planting (DAP). Peak harvest starts from 90 DAP and continues up to 6–7 months. Half yellow half green stage is suitable for harvesting and fruits stored in air tight polythene bag showed better moisture retention and keeping quality (Fakir et al. 1992). Delayed harvest beyond 20 days leads to progressive red colouration of fruits and hardening of seeds which reduce the visual appeal and cooking quality. Yield up to 160–180 q can be realised from one hectare (Ram et al. 2002a).

Sweet gourd. Fruits reach harvestable maturity by 15–20 days after pollination, beyond which the seeds become hard and skin become leathery. A plant produces 30–60 fruits each weighing between 250 and 500 g in one season (Vuong 2001; Shadeque and Baruah 1984; Joseph and Bharathi 2008). Raw fruits have an agreeable taste and are slightly bitter. Flavour is similar to spine gourd, though of less intensity. The fruits can be stored safely for 1 week at room temperature. Elsewhere in Vietnam it is harvested at ripe stage (90–100 days after pollination) for its red ripe aril and pulp. Fruits store well for 2–3 days at room temperature and up to 7 days in air tight polybags under refrigeration.

Pest and Diseases

Although it is considered that foliage pests and diseases tend to be not much of a problem in bitter gourd due to the toxic compounds in the plant (Robinson and Decker-Walters 1997), nowadays there are many insect pests and diseases are observed in bitter gourd and other *Momordica* species of Asia. The most common pests and diseases of *Momordica* species are described hereunder (Figs. 2.8 and 2.9).

Ladybird beetle (*Epilachna septima*). *E. vigintioduopunctata* is reported to cause damage to bitter gourd (Mandal et al. 2012). However, *E. vigintiduopunctata* do not feed on *M. charantia* and *Epilachna septima* is reported to damage bitter gourd (Dharmaretnam 2002) and *E. vigintiduopunctata* was unable to complete its lifecycle on Cucurbitaceous plants (Ueno et al. 2001).

Fig. 2.8 Insect pests of *Momordica* spp. **a** Adult and larvae of ladybird beetle (*Epilachna vigintiopunctata*) feeding on leaf of *M. subangulata* subsp. *renigera*. **b** Fruit fly (*Bactrocera cucurbitiae*) damaged fruit of *M. subangulata* subsp. *renigera*. **c** Fruit borer (*Diaphania indica*) damaged leaf, flower and fruit of *M. subangulata* subsp. *renigera*. **d** Bitter gourd leaf showing the symptom of leaf miner (*Liriomyza trifolii*) damage. **e** Roots of *M. subangulata* subsp. *renigera* heavily infested with root knot nematode

All the dioecious taxa are equally preferred by ladybird beetle, whereas no larval feeding was observed in *M. balsamina* (Joseph 2005). Lace-like skeletonised patches appear on leaves, which turn brown later. The affected leaves dry up and fall down. Collect grubs, adults and egg along with infested leaves during the early stage of attack and destroy them. Spray Deltamethrin 0.028 % or Monocrotophos 0.05 % to keep the insect population under control.

Fruit Borer (*Diaphania indica*). It is a serious pest in Asia and Africa. *M. charantia* is one of the host plants for the larvae of *Diaphania indica* (Yasui 2002). Young bright green larvae, initially scrapes the chlorophyll content. Later it folds and webs the leaves and feeds within. It also feeds on flowers and bores into the developing fruits and is a severe problem in spine gourd (Bharathi et al. 2006; Singh et al. 2009) and teasel gourd (LKB Pers. obs.). Early symptoms of infestation are the development of

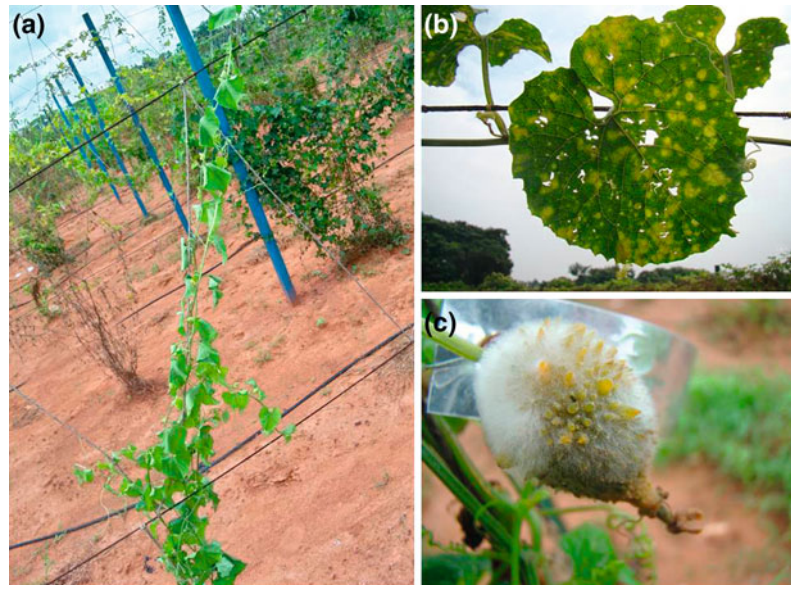

Fig. 2.9 Various disease symptoms of *Momordica* spp. **a** A plant of *M. dioica* showing wilting due to *Fusarium*. **b** Downey mildew symptom in *M. subangulata* subsp. *renigera* leaf. **c** Fruit of *M. dioica*

lace-like patches of networks on intact small leaf veins. Damage is most serious in the early stages of fruit formation, when the pests feed on and puncture the skin of young fruit, particularly where they touch leaves or the soil, but well-developed fruits with hard rinds may escape attack (Patel and Kulkarny 1956). The early stage caterpillars should be collected and destroyed. Several insecticides are recommended including Methomyl, Endosulfan or Carbaryl and Dimethoate are also effective, as is the bacterium *Bacillus thuringiensis* @ 2 ml/litre of water.

Fruit fly (*Bactrocera cucurbitiae*). Fruit fly is severe in *M. charantia* and all cultivars are highly susceptible. Teasel gourd, sweet gourd, balsam apple and spine gourd are equally susceptible but *M. sahyadrica* shows marked resistance. *M. charantia* var. *muricata* germplasm showed varied response with the wild forms showing tolerance. Fruit fly damage is restricted to localised areas in the fruit and seeds often mature. In bitter gourd, the melon fruit fly damage is the major limiting factor in obtaining good quality fruits and high yield (Srinivasan 1959; Lall and Singh 1969; Mote 1975; Rabindranath and Pillai 1986). It prefers young, green and tender fruits for egg laying. The females lay the eggs 2–4 mm deep in the fruit pulp, and the maggots feed inside the developing fruits. A few maggots have also been observed to feed on the stems (Narayanan 1953). The fruits attacked in early stages fail to develop properly, and drop or rot on the plant. Since, the maggots damage the fruits internally; it is difficult to control this pest with insecticides. To manage the pest, remove and destroy all infested fruits and also expose the pupae by ploughing and turning over soil after crop harvest. For trapping the adult, sex pheromone blended plywood blocks may be used. For this purpose a mixture of ethanol, cue lure and Malathion in the ratio of 6:4:1 may be prepared. Plywood blocks of 5 × 5 × 1.2 cm is prepared and soaked in this solution for 48 h. These can be used in bottle traps @ 10 blocks/ha. Under severe infestation, 100 g jaggery may be mixed in 1 litre of water with 2 ml carbaryl and sprayed on foliage. Double layer paper bags are used against melon fly in Taiwan and are applied when fruit measure 2–3 cm in length (Fang and Chang 1987). The braconid larval parasitoid *Opius fletcheri* provided considerable suppression of this pest infesting the small fruits of the balsam apple *M. balsamina* (Singh 2004).

Red pumpkin beetle (*Aulacophora foveicollis*). Among the Cucurbitaceous vegetables studied, *M. charantia* was found to be highly

resistant to red pumpkin beetle (Mehta and Sandhu 1989; Roy and Pandey 1990, 1991; Saljoqi and Khan 2007). Chandravadana (1987) isolated triterpenoids (momordicine II, 23-*O*-*β*-glucopyranoside of 3, 7, 23-trihydroxycucurbita-5, 24-dien-19-al) from the leaves of *M. charantia* Linn (bitter gourd) which was found to elicit feeding deterrent activity against red pumpkin beetles (*Aulacophora foveicollis*).

A study by Joseph (2005) showed that leaf damage due to red pumpkin beetle is severe in *M. dioica* while *M. balsamina* shows high tolerance. Adult beetle eats the leaves, makes holes on foliage and causes damage to roots and leaves. Incorporation of carbaryl 10 % WP in pits before sowing the seeds destroys grubs and pupae. Adults feed on the cotyledonary leaves at seedling stage. Effective control can be achieved by spraying of Sevin 50 WP (2 g/L). Farmers of India practice dusting of ash mixed with kerosene to repel the insect however, heavy dusting arrests growth of seedling. Alternatively, *Parthenium hysterophorus* plant extract have the ability to minimise the population below critical threshold level of red pumpkin beetle in bitter gourd and the extract can be used instead of synthetic pesticides or can be supplemented to avoid excessive use of chemicals for the safe and friendly environment (Ali et al. 2011).

Leaf Miner (*Liriomyza trifolii*). Leaf miner incidence is very rare especially; *M. charantia* was reported to be free from this pest (Patnaik 2000). The main damage caused to the plant is due to the presence of larva mining and if the infestation is severe, the photosynthetic activity is reduced. Observations on the oviposition behaviour by *L. trifolii* demonstrated that among the cucurbitaceous plants, *M. charantia* is rarely attacked by *L. trifolii* (Mekuria et al. 2006). A field survey (Mekuria et al. 2005) has shown that *L. trifolii* fed and laid eggs on Cucurbitaceous vegetables but not on *M. charantia* leaves. The reason is that females are often deterred from ovipositing on *M. charantia* leaves (Mekuria et al. 2005) due to the presence of momordicin I. They form tunnels by burrowing in the leaf between the epidermal layers consuming the green tissue as they go. In case of severe infestation, leaves will dry and drop. To control the insect, collect and destroy the mined leaves and good field sanitation can also greatly reduce the population of this pest.

Root-knot nematode (*Meloidogyne incognita*). Incidence of root-knot nematode is observed in *M. subangulata* subsp. *renigera* (LKB pers. obs.), *M. charantia* (Singh et al. 2012), *M. balsamina* (Kaur and Pathak 2011) whereas *M. dioica* and *M. sahyadrica* are free from nematode attack (Joseph 2005). It is one of the important pests of bitter gourd and is reported to cause 38–48.2 % yield losses (Kaur and Pathak 2011). Root system of the nematode infested plant is heavily knotted and growth of vines is severely arrested. The leaves appear yellow and leaf size is reduced and majority of the veins become dry and wither. Dipping of vine cuttings/root tubers in Monocrotophos 1000 ppm for 6 h before planting and application of neem cake (500 g), and Bionematon (10 g) per pit as basal application with FYM is effective in reducing the severity of the infestation. A second dose of Bionematon @ 10 g/pit at 40 days after planting (DAP) may also be applied to reduce infestation.

Fusarium wilt (*Fusarium oxysporum* f. *niveum*). Fusarium wilt, caused by *Fusarium oxysporum* is probably the most common and damaging soil borne disease of cucurbit crops worldwide. Leaves wilt suddenly and vascular bundles in the collar region become yellow or brown. It is difficult to control the disease as the fungus persists in the soil even when effective chemicals are available. Use of disease free planting material for planting and drenching with Captan (1.5 g/L) and Bavistin (2 g/L) around the root zone, long crop rotation and application of *Trichoderma* at the rate of 100 g/pit are recommended to control the disease. It can also be controlled by cleft grafting of bitter gourd shoot as scion on *Luffa cylindrica* rootstock. *Luffa cylindrica* provides an excellent root stock for bitter gourd and grafting can increase yields substantially as reported from Taiwan, mainly through the control of *Fusarium* wilt (Lin et al. 1998).

Anthracnose (*Colletotrichum lagenarium*). The disease is reported to be severe in *M. dioica* (Sawant et al. 2000). The small yellowish spot appears on leaves as water soaked areas, which enlarges in size, coalesce and turn brown to black in colour. Seed treatment, proper crop rotation and clean cultivation minimise the initial inoculums. The disease can be effectively controlled by repeated spray of Dithane M 45 at 5–7 days interval.

Powdery Mildew (*Sphaerotheca fuliginea*). Initially, white or fluffy growth appear in circular patches or spots on the under surface of the leaves. Severely affected leaves become brown and shrivelled and defoliation may occur. Among the fungicides tested in *M. charantia*, Nimrod (buprimate) was found to be the best in reducing the disease intensity and increasing yield followed by Benlate (Benomyl) and Karathane (Dinocap) (Gupta and Singvi 1980).

Downy Mildew (*Pseudoperonospora cubensis*). It is one of the most important foliar diseases of cucurbits, causing significant yield losses. The symptoms of pale green areas separated by dark green areas appear on upper surface of leaf. Under humid conditions, corresponding lower surface of yellowish areas is covered with faint purplish fungal growth. The affected leaf dries up quickly. Use of beds with wider spacing, good drainage, air movement and exposure to sun, help to check the disease development. An aggressive spray programme is essential, as plants must have a protective barrier of fungicide prior to sporangium deposition to avoid yield losses (Elizabeth et al. 2011). Foliar sprays of Dithane M 45 (0.2 %) have been found to be effective in controlling the disease.

Fruit rot (*Pythium aphanidermatum*). This disease is observed in *M. charantia*, *M. dioica* (LKB pers. obs.) and *M. cochinchinensis* (Verma and Sengupta 1981). The causal organism causes a water-soaked lesion which develops into a watery soft rot. White, cottony mycelium is also generally associated with *Pythium* lesions. Fungus can enter the fruit through old floral parts or directly from the soil. The fungus can infect any portion of the fruit, producing dark-green, water-soaked lesions. The fruit become soft very rapidly and may be completely covered with white, cottony mycelium during wet weather. This fruit rot can occur rapidly when conditions are moist since the fungus spreads by fruit-to-fruit contact. Rotation and deep turning are cultural practices that can reduce the amount of disease inoculum near the soil surface. Practices which ensure good drainage can also reduce losses due to these fungi. Systemic fungicides such as Ridomil may aid in suppression of *Pythium*. Avoid picking fruits from infested areas of the field. Infected fruits will contaminate adjacent fruits in storage containers.

Viral diseases. Bitter gourd Yellow Mosaic Virus (BGYMV) is a Whitefly transmitted gemini virus that can attack at any stage of the crop. The association of Indian cassava mosaic virus (ICMV) with yellow mosaic disease of *M. charantia* has been detected for the first time in Tamil Nadu, South India (Rajinimala and Rabindran 2007). The symptoms that characterise the yellow mosaic disease of bitter gourd are mosaic and mottling starts at the edges of the leaf and advance inwards. Subsequently, chlorotic patches appear on leaves, and in advanced stages of infection, the entire leaf becomes chlorotic with few, small patches of green tissue remaining over the leaf area. Control the vectors by spraying Dimethoate 0.05 % or Phosphamidon 0.05 %. Uprooting and destruction of affected plants and collateral hosts may prevent further spread of the disease. Ali et al. (2010) reported tomato leaf curl Palampur virus also affecting bitter gourd. Symptoms of the disease included chlorosis, leaf crumpling, vein thickening and stunting of plants.

Witches' Broom. Main symptoms of this disease are malformation and proliferation of axillary buds. The diseased plants show many abnormally little leaves, which fail to attain full size but bear many flowers and blossom earlier than healthy plants. Flowers on infected plants show characteristic green, phyllody symptoms. Fruits formed from the infected flowers are very small, cylindrical and deformed. Five to six foliar sprays of Phosphamidon (0.05 %) at 10 days interval control the vector population.

Seed Production

Most cultural practices for successful seed production are not different from those for successful commercial cultivation for fruit production. Therefore the present discussion of cultural practices will emphasise only those factors most important for a seed crop. The field selected for seed production must not have been sown with bitter gourd in the previous season. This is done to avoid volunteer plants that cause admixture. Seed is very sensitive to weather and selecting the right season is necessary to get good seed yield. Though bitter gourd can be grown throughout the year, seed crop should be sown such that the seed matures in cool dry climate. This will facilitate proper ripening of fruits and reduce the fungal infection.

Selection of seed is the first step in production of quality seed. This involves selection of seeds with the right genetic make-up of the variety chosen to be produced. Seeds must be from an approved source. This is possible if the seed is procured from the breeding firm/university research station or from the breeder himself. Nearly 50 % increase in seed yield was obtained in closer spacing 1 × 0.25 m (Catedral and Mamicpic 1976).

Since *Momordica* species are highly cross pollinated, maintaining the proper isolation distance between the two varieties/inbred lines is necessary. The isolation distance of 400 m for C.S, 800 m for F.S. and at least 1000 m for breeder seed production are recommended. An isolation of 0.8–1 km should be given between two varieties/inbred lines (Sirohi 1997). Another important requirement in production of high quality seed is rouging of infected and off type plants before they start flowering.

In bitter gourd, seed extraction is easy. Open the fruits longitudinally and collect the seeds along with pulp. Crush the pulp with hands and wash with excess quantity of water to remove the pulp. The extracted seeds are to be dried properly. Alternatively, the seeds along with arils are mixed with dry soil for easy removal of the arils. Immediately after seed extraction, it has to be properly dried, since seeds were extracted from 100 % moist condition. The extracted seeds should be spread on gunny bags in a thin layer and dried under shade for 8–10 h for 1 or 2 days. Avoid drying the seeds in hot sun (during 12 noon to 3 p.m.) as the rays emitting from sun and the heat may affect the seed viability. A seed yield of 60–120 kg can be obtained from one hectare.

Quality and storability of seed is greatly influenced by the processing measures. Therefore, after proper drying, the seeds have to be processed in a proper way. By removing the ill-filled and small size seeds, vigour and viability are improved. For bitter gourd, seed processing BSS 4 wire mesh sieve has to be used. After sieving, those seeds that are broken, fungal infected and seed coat damaged are removed. Seed moisture is the foremost seed physical attribute that contributes to storage life. Lower the seed moisture, longer the shelf life. Short-term storage can be achieved by drying the seeds to 7–8 % moisture content while long-term storage is possible by reducing the seed moisture even further to 6 %. Prior to storage, seeds are treated with fungicide to ward off fungal pathogens. Seeds are mixed with Carbendazim at the rate of 4 g/kg. The minimum certification standards prescribed for certified and foundation seed is presented in Table 2.4.

Apart from seed treatment, the next most important aspect of seed storage is seed container. Container can be chiefly differentiated as moisture pervious and moisture impervious types. Cloth, paper and gunny bags are moisture pervious as the moisture from outside atmosphere can enter and exit freely. Hence, even if the seed is dried to safe moisture levels, when stored in humid climate, the seeds absorb moisture during storage and loose viability. In low humid areas seeds can be safely stored in moisture pervious bags. In hot and humid regions, after drying the seed to safe moisture limit, seeds can be safely stored in moisture impervious bag-like thick polythene bags of 700 gauges or in tin/plastic containers that are sealed tightly. In case of short-term storage

Table 2.4 Minimum seed certification standards prescribed for foundation and certified seed of bitter gourd

Factor	Foundation	Certified
Pure seeds (minimum limit)	98.0 %	98.0 %
Inert matter (maximum limit)	2.0 %	2.0 %
Other crop seed (maximum limit)	None	None
Total weed seeds (maximum)	None	None
Objectionable weed seeds[a] (maximum)	None	None
Other varietal seeds (maximum)	5/kg	10/kg
Moisture (maximum)	7.0 %	7.0 %
Moisture proof bag	6.0 %	6.0 %

Source Tamil Nadu Seed Certification Department, India

[a] Objectionable weed seed shall be *M. balsamina*, *M. dioica*, *M. cochinchinensis*

(4–6 months) cloth bags will be sufficient. Partial vacuum extended the longevity of primed seeds of bitter gourd up to 12 months by enhancing their antioxidative activities that minimise accumulation of total peroxide during long-term storage (Yeh et al. 2005).

Hybrid Seed Production

Hybrid seeds can be produced by (i) Bagging and hand pollination, (ii) defloration, removal of male flowers from the female parent and insect pollination, and (iii) use of gynoecious lines. However, commercial seed production of bitter gourd is being accomplished by bagging and hand pollination. Production of hybrid seeds in bitter gourd is highly expensive because it is done mainly through hand pollination. But utilisation of a gynoecious line would be more economical and easier method (Ram et al. 2002b).

In the first method, female flowers are covered with butter paper bags on previous day of flower opening and rebagged after hand pollination. Experienced hands can pollinate 11–12 flowers per hour. In the second method, female and male parents are planted alternatively in an isolated field. Male flower buds in female parent are removed before anthesis. Female flowers are left on seed parent for insect pollination from pollen parent or female flowers are hand pollinated with pollen of male parent during morning hours (6–9 am). Honey bees are chief insect pollinators for bitter gourd and honey bees should be in abundance in the field at the time of flowering. Hand pollination can be avoided by introducing bee hives.

A planting density of 30000–35000 plants per ha is recommended by Huang et al. (2010) for higher hybrid seed yield. Seed yield and quality were highest in plants fertilised with 240–120–60 kg NPK/ha. The high yield was due to greater number of filled seeds per fruit which were bigger and heavier than the seeds produced from other treatments. Moreover, the above treatment produced seeds with the highest percentage germination and seed vigour index (Islam 1995).

A perusal of the scanty botanical literature available on SE Asian and African species indicates that many of them are incompletely described. As majority of them are dioecious, either male or female flowers or fruits are unknown. Further, no recent collections are reported in these wild species. Distribution data is scanty as herbarium and gene bank representation is meagre. A complete botanical description based on live specimens is warranted. Seed dormancy in dioecious *Momordica* is the single largest obstacle to establishment of a uniform plant stand which inhibits its domestication progress. Methods to break seed dormancy or development of genotypes with good uniform and quick germinability are important for crop husbandry as well as ex situ regeneration. Standard agronomic practices for sweet gourd, spine gourd, teasel gourd and mountain spine gourd are lacking which needs to be developed.

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Origin, Domestication and Distribution 3

Abstract

Momordica is a monophyletic genus that originated in tropical Africa and the Asian species are considered the result of one long-distance dispersal event that occurred about 19 million years ago. Monoecious species evolved from dioecious species seven times independently, always in Africa and mostly in the Savanna region with low population densities. *M. dioica* is indigenous to India and possibly evolved in Central India. *M. sahyadrica* is more advanced and might have evolved from *M. dioica* in the Western Ghats and may be considered as a neo-endemic (Behera et al. 2011). Morphological and cytological analysis suggests that *M. subangulata* subsp. *renigera* is a segmental allopolyploid of *M. dioica* and *M. cochinchinensis* genomes. Though *Momordica* is one of the large genera in the family Cucurbitaceae, *M. charantia* is the only widely cultivated crop in the genus. *M. dioica, M. cochinchinensis* and *M. subangulata* subsp. *renigera* are under domestication interface while other species are purely wild. The putative areas for domestication of *M. charantia* proposed by various workers include southern China, eastern India and south-western India. The natural geographic distribution of wild edible *Momordica* was investigated and characteristics of distribution in India analysed based on a study of herbarium sheets in major Indian herbaria and passport data of germplasm collections. It is distinct from the earlier reported distribution as a new taxa based on revision of the genus has been incorporated and maps plotted based on corrected herbarium specimens and field spotting. Areas of higher concentration have been marked for individual taxon.

Keywords

Distribution maps · *Momordica* L. · Hotspots · Herbarium survey

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Origin

Momordica is a monophyletic genus that originated in tropical Africa and the Asian species are considered the result of one long-distance dispersal event that occurred about 19 million years ago (Schaefer et al. 2009; Schaefer and Renner 2010). Earlier *M. charantia* and *M. balsamina* were reported to be of Asian origin while a recent study using plastid and mitochondrial DNA-based markers (Schaefer and Renner 2010) reported that these species are most likely of African origin and not Asian. Monoecious species evolved from dioecious species seven times independently, always in Africa and mostly in the Savanna region.

Although *Momordica* is one of the large genera in the family Cucurbitaceae, *M. charantia* is the only cultivated species in the genus which has undergone the most profound study in recent years. It has a long history as a cultivated food and medicinal plant in Africa and Asia (Morton 1967; Walters and Decker-Walters 1988). There are two botanical varieties viz.; *M. charantia* var. *muricata* (syn. var. *abbreviata*) and *M. charantia* var. *charantia,* the former mostly wild and the latter cultivated. The wild variety (*M. charantia* var. *muricata*) is considered as the progenitor of cultivated *M. charantia* var. *charantia* (Degner 1947; Walters and Decker-Walters 1988) which can be found in tropical Asia and Africa. The original place of domestication of *M. charantia* is unknown or unclear (Li 1970; Zeven and de Wet 1982) for want of credible archaeological evidences. The putative areas for domestication of *M. charantia* proposed by various workers include southern China, eastern India (Sands 1928; Degner 1947; Walters and Decker-Walters 1988; Raj et al. 1993; Robinson and Decker-Walters 1997; Marr et al. 2004) and south-western India (Joseph 2005). From Africa, *M. charantia* is believed to have taken to Brazil via slave trade and thence to "Middle America" (Ames 1939). However, there are no reports of *M. charantia* remains from archaeological sites in China or Southeast Asia, apart from tentatively identified uncarbonated seed coat fragments from Spirit Cave in northern Thailand (Yen 1977). The earliest report of bitter gourd in China is from northern China and was reported in Dian nam Pen Tsao (Yang and Walters 1992). The characteristics that were most transformed in the process of domestication of *M. charantia* were mainly those connected with handling and preferred uses, for example, relatively uniform germination and increase in the size of fruits. The different degrees of variation in bitterness suggest a strong association with human interests and humans might have selected bitter types as both domesticate and the wild-type have bitter fruit (Marr et al. 2004).

M. charantia and *M. dioica* were originally described from Peninsular India by Linnaeus (1753) and Roxburgh (1832) based on van Rheede's plates of the taxa in his *Hortus Malabaricus* (Van Rheede 1688). Sanskrit writings reveal that the Vedic-speaking Indo-Aryans of 2000–200 B.C. valued *Momordica* for use as medicine, food, containers, musical instruments, and literary metaphors (Decker-Walters 1999). The most prominent Sanskrit name for bitter gourd is *kdravalff* along with its various permutations and modern derivatives (e.g., *karilff*, *kariyalla*, *kareld*, *karelo*). The Indo-Aryan words for *M. charantia* may have been borrowed from the Dravidian (Turner 1966) before the Indo-Aryans arrived, indicating an even earlier awareness of the plant (Decker-Walters 1999). The Ayurvedic drug *karavllam* is derived from bitter gourd (Sivarajan and Balachandran 1994). Other Sanskrit names for bitter gourd describe its bitter taste (*kat.illa, kdnd.akat.u*), strong stem (*su-kdnd.a*), creeping habit (*toya-valh*), beaked fruits (*nasd-sam. vedana*) and penetrating smell (*ugra-gandhd*). Sanskrit names based on the morphemes *kdn.da* or *kand.a* (e.g., *kand.uras*, *kan.d*, *iras*, *ugra-k* ~ *n.d.a* as well as those listed above) may also be of Dravidian or Munda origins (Kuiper 1948). Whereas the Dravidian languages possess an additional distinct suite of terms for bitter gourd (e.g., *pakal*, *paval*), the lack of a unique set of Indo-Aryan words indicates that the Aryans did not know bitter gourd before entering India.

Apparently missing from the Sanskrit texts are any obvious references to *M. balsamina* and *M. dioica*. The one possible Sanskrit word for *M. dioica* mentioned in Jain and DeFilipps (1991), *vahisi*, was not found elsewhere and does not have modern equivalents. *M. balsamina*, which may be the plant featured on a third millennium tomb at Benihassan in western Asia (Pickering 1879), may have been a latecomer to India. Unlike *M. balsamina*, *M. dioica* has several names in modern Indo-Aryan (e.g., *kaksa*, *kakrol*, *jangli-karela*, etc.) and Dravidian (e.g., *agakral*, *hagal*, *karlikai*, etc.) languages (Decker-Walters 1998), reflecting its importance as a useful plant in recent centuries. There is also a *Munda* (aboriginal tribe from Central India) name for *M. dioica, kanchan-arak* (Chakravarty 1982).

M. dioica is indigenous to India and possibly evolved in Central India (Behera et al. 2011). Based on the evaluation of hybrid progeny between *M. dioica* and *M. sahyadrica* it seems that *M. sahyadrica* is more advanced and might have evolved from *M. dioica* in the Western Ghats and may be considered as a neo-endemic (Behera et al. 2011) and may be of hybrid origin (de Wilde and Duyfjes 2002; Schaefer and Renner 2010). *M. dioica* may be regarded as an aneuploid series but whether this series has arisen only due to fragmentation of chromosomes is highly doubtful (Roy et al. 1966). If fragmentation is the principal cause to raise the chromosome number from 11 (*M. charantia*/*M. balsamina*) to 14 (*M. dioica*), some chromosomes in *M. dioica* will be smaller than those in *M. charantia* and *M. balsamina*, and the absence of such smaller chromosomes in *M. dioica* contradicts the fragmentation hypothesis (Trivedi and Roy 1972). However, they have hypothesised *M. dioica* as having possibly originated from *M. charantia* through non-disjunction or delayed separation of some bivalents during anaphase resulting in inclusion of both chromosomes of a bivalent in one of the daughter nuclei, thereby raising the haploid number in the gametes. Such a gamete after fertilisation will give rise to an organism with a higher chromosome number. In contrast, Beevy and Kuriachan (1996) suggested that the basic number 11 might have evolved from 14 by aneuploid reduction.

An Ayurvedic name for *Momordica cochinchinensis*, *karkot.aka*, is also the name of an ancient northern India tribe presumably of Austroasiatic descent (Levi et al. 1929). The cochinchin gourd might have originally been utilised in India by Munda-speaking inhabitants; it has long been cultivated and naturalised throughout much of southeastern Asia. In India, various plant parts are cooked for food (especially the immature fruit), used medicinally and made into poison (hence the Sanskrit name *karkot.aka-visha). M. cochinchinensis* must have originated in south Asia, probably in the Cochinchina region of Vietnam. Pre- and post-zygotic reproductive barriers suggest an origin independent of *M. dioica* (Mondal et al. 2006). Hypotheses have been made on the origin of polyploid species; *M. subangulata* subsp. *renigera*, whether it is auto- or allopolyploidy. Based on meiotic analysis, *M. subangulata* subsp. *renigera* has been reported to be an autotetraploid derived from *M. dioica* (Roy et al. 1966), but morphological analysis suggests that *M. subangulata* subsp. *renigera* could be an allopolyploid derived from the hybridisation of two diploid species, *M. dioica* and *M. cochinchinensis*, followed by chromosomal doubling (Mondal et al. 2006). Recent evidence based upon the cytological behaviour of the hybrids of *M. dioica* and *M. cochinchinensis* Bharathi et al. (2010) hypothesised that *M. subangulata* subsp. *renigera* arose by natural hybridisation between *M. dioica* and *M. cochinchinensis* followed by spontaneous chromosome doubling. They also proposed that the genome of *M. dioica* be designated as A_1A_1, *M. cochinchinensis* as A_2A_2 and *M. subangulata* subsp. *renigera* as $A_1A_1A_2A_2$.

Distribution

To make the most efficient use of limited resources, germplasm collectors must have a clearly defined set of target taxa and must know

Table 3.1 Species wise distribution of herbarium specimens across states in India

Species	KE	KA	TN	GA	MH	GJ	RJ	AS	NE	AN	OS	Total
M. balsamina	–	–	–	–	–	6	39	–	–	–	2	47
M. charantia	29	5	30	2	11	9	12	5	3	2	20	135
M. dioica	41	10	37	–	122	12	34	–	–	–	64	320
M. sahyadrica	44	23	9	13	14	–	–	–	–	–	–	103
M. sub. ssp. *renigera*	–	–	–	–	–	–	–	20	37	–	1	58
M. cochinchinensis	–	–	–	–	–	–	–	–	1	9	1	11
M. cymbalaria	–	5	6	–	3	–	–	–	–	–	–	14
Total	114	38	76	15	147	27	85	25	41	11	88	681

Abbreviations KE Kerala, *KA* Karnataka, *TN* Tamil Nadu, *GA* Goa, *MH* Maharashtra, *GJ* Gujarat, *RJ* Rajasthan, *AS* Assam, *NE* Other NE states, *AN* Andaman and Nicobar Islands, *OS* Other states and Union Territories

where to find these species within their target region. Passport data provides information regarding specific ecological conditions of collected germplasm. Herbarium specimens are very useful in assessing the range of morphological variability present in the target taxa (Miller and Nyberg 1995). Herbarium labels and passport data together provide many details of the collection site, which can be used to predict where target germplasm can be located and the best time for collection. Thus information regarding distribution of particular species in particular region and ecosystem and pattern of infra specific diversity could be derived, which will help in formulating collecting priorities and conservation strategies (Maxted et al. 1995).

Herbarium Representation

In India, out of 667 herbarium accessions, CAL (Botanical Survey of India, Kolkota) had the highest number of sheets (241), followed by BSI (BSI Western Circle, Pune) (130), BLAT (St. Xavier's College, Bombay) (79), MH (BSI Southern Circle, Coimbatore) (58), CALI (University of Calicut, Calicut) (31), RHT (St. Joseph's College, Tiruchirapalli) (34), BSI Arid Zone Circle, Jodhpur (BSIJO) (26) BSI Eastern Circle, Shillong (BSISH) (25), Tropical Botanical Garden and Research Institute, Trivandrum (TBGT) (12), Agharkar Research Institute, Maharashtra Association for the Cultivation of Science, Pune (AHMA) (11), National Herbarium of Cultivated Plants, NBPGR, New Delhi (NHCP) (10), Kerala Forest Research Institute, Thrissur (KFRI) (5) and Regional herbarium of Kerala, Changanacherry (RHK) (4). A total of 478 sheets were found to be labelled under *M. dioica*, of which 102 sheets should be placed under *M. sahyadrica* and 58 sheets under *M. subangulata* subsp. *renigera* (Joseph 2005; Joseph and Antony 2007). Even after taking out *M. sahyadrica* and *M. subangulata* subsp. *renigera*, *M. dioica* has the highest representation (318 out of 667 records) among the various *Momordica* species. The state of Maharashtra stands unique in its high natural distribution of *M. dioica* and *M. sahyadrica* (Table 3.1).

Species Distribution, Hotspots and Ecological Amplitude

M. dioica and *M. charantia* var. *muricata* had wider distribution scattered over the entire geographical territory except the former in North–East and Northwest Himalayas, whereas *M. subangulata* subsp. *renigera* is restricted to Northeast and adjoining North Bengal hills (Fig. 3.1). *M. cochinchinensis* has localised distribution in Andamans and a few localities in the Eastern and Northeastern states. *M. balsamina* is restricted to the arid belt comprising Rajasthan and Gujarat. *M. sahyadrica* is endemic to the Western Ghats. *M. balsamina*, *M. sahyadrica* and *M. subangulata* subsp. *renigera,*

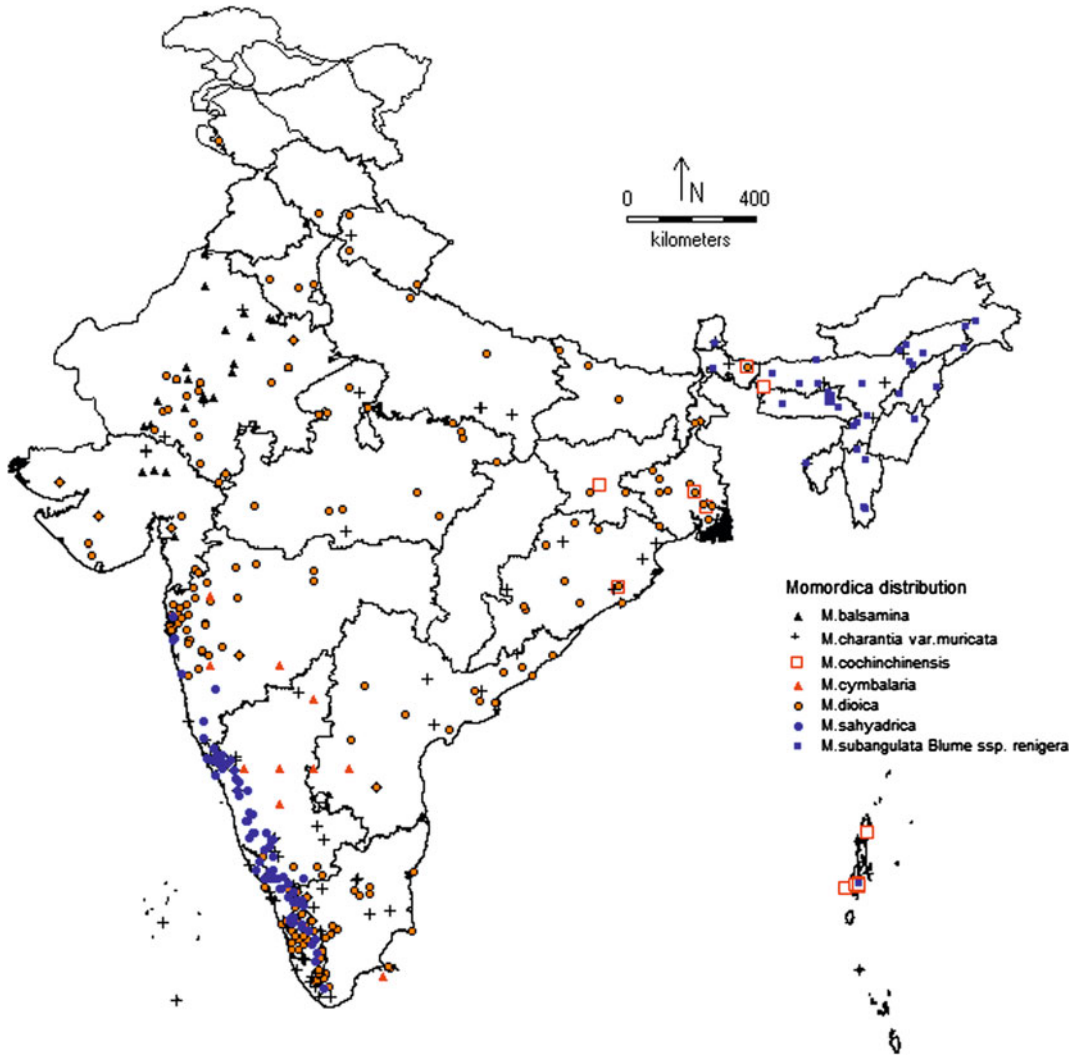

Fig. 3.1 Map showing distribution of *Momordica* species in India

by virtue of their narrow distribution range and habitat specificity, occupy mutually exclusive regions. Sympatric distribution was not observed except for *M. charantia*; otherwise, the species occupy mutually exclusive areas. However, in western Maharashtra, overlapping distribution of *M. dioica* and *M. sahyadrica* was observed to a limited extent with some of the herbarium specimens showing characteristics of interspecific hybrids and their derivatives. Areas of higher concentration based on herbarium and literature survey in each species are given in Table 3.2.

M. charantia is ubiquitous in distribution. *M. dioica* is another species with wide distribution, having many ecotypes adapted to various ecological conditions prevailing in the country, the major distribution areas being Peninsular India (Type locality) extending beyond the Deccan Plateau to Central India. Herbarium labels show its occurrence as common in Rajasthan (Jalore and Pali districts) and Maharashtra (Borivali NP, Mumbai suburbs, Thane and Khandala). Herbarium labels also mention its popularity as a wild gathered vegetable sold in tribal and village markets in Andhra Pradesh, Tamil Nadu,

Table 3.2 Areas of natural distribution

Species	Distribution	
	Continent/Country/Province[a]	India[b]
M. charantia (wild forms)	Tropical and subtropical Africa, S, E and SE Asia, Malesia, Australia and Pacific, India-Andaman and Nicobar Islands, South, North (except NW Himalayas), East and NE, Pakistan, SE Asia: Thailand, Indonesia (Sumatra, Java, Borneo), Malesia, Vietnam, Laos, Cambodia, Myanmar, Sri Lanka, parts of China (Yunan), Nepal	Tamil Nadu, Kerala, Andhra Pradesh, Karnataka, Odisha, Madhya Pradesh, Uttar Pradesh, Chhattisgarh, West Bengal, Assam, Rajasthan, Jharkhand, Mizoram and Andaman Islands
M. balsamina	N, E and S Africa to West Asia, North and East Australia, Western India, Pakistan (Sind), West Asia—Arab countries, Israel, Palestine, Syria, Lebanon, Saudi Arabia	Rajasthan, Gujarat
M. dioica	South Asia: India—Central and South India, East India, Bangladesh (rare), NW Pakistan (rare), Sri Lanka	Tamil Nadu, Kerala, Andhra Pradesh, Karnataka, Maharashtra, Odisha, Madhya Pradesh, Uttar Pradesh, Chattisgarh, West Bengal, Rajasthan
M. sahyadrica	India	Western Ghats of Kerala, Tamil Nadu, Karnataka, Goa and Maharashtra
M. subangulata subsp. *renigera*	S. China (Kwantung, Kwangsi, Yunan), Thailand, Myanmar, Laos, Sumatra, W. Java, Peninsular Malesia	
M. subangulata subsp. *renigera*	S. China, N. East India, N. Bengal, Bangladesh, Myanmar, N&WC Thailand, Nepal, Bhutan	West Bengal, Assam (Kokrajar and Kamrup districts), Meghalaya and Mizoram (Naga-Khasi-Jainthia and Garo hills), Arunachal Pradesh, Nagaland, Tripura and Sikkim
M. cochinchinensis	India, Andaman and Nicobar Islands, West Bengal (rare), Odisha (rare), Jharkhand (rare), Myanmar, S. China and Yunan (China), Malaysia, Philippines, Vietnam, Laos, Cambodia, Cochinchina, Siam, Sulavesi, Sumatra, Borneo, Thailand	NE India, Andaman islands, Odisha (rare), Jharkhand (rare), Andaman and Nicobar islands, West Bengal (rare)
M. cymbalaria	NE and E Africa, Asia: Pakistan, WC India, Deccan (Tamil Nadu, Karnataka and Andhra Pradesh)	Tamil Nadu, Andhra Pradesh, Maharashtra, Karnataka, Madhya Pradesh
M. denudata	Sri Lanka	Not available in India
M. denticulata	N&C Sumatra, Borneo, Peninsular Malesia	Not available in India
M. rumphii	West Seram, & Ambon (Indonesia)	Not available in India
M. clarkeana	Peninsular Malesia	Not available in India

Joseph (2005)
[a] Based on Chakravarty (1959), de Wilde and Duyfjes (2002), USDA (GRIN Taxonomy 2009)
[b] Based on field and herbarium survey (Joseph 2005)

Maharashtra, Odisha, Madhya Pradesh and Uttar Pradesh. As per the herbarium labels, soil types varied from gravelly (Rajasthan), black cotton (Deccan plateau), sandy loam (Uttar Pradesh) to river alluvium and laterite loam (Kerala).

The dioecious taxa (except *M. dioica*) and *M. balsamina* occupy mutually exclusive climatic regimes, the former localised in high rainfall, montane cooler habitats and the latter occupying hot arid plains. *M. balsamina* has a clear-cut

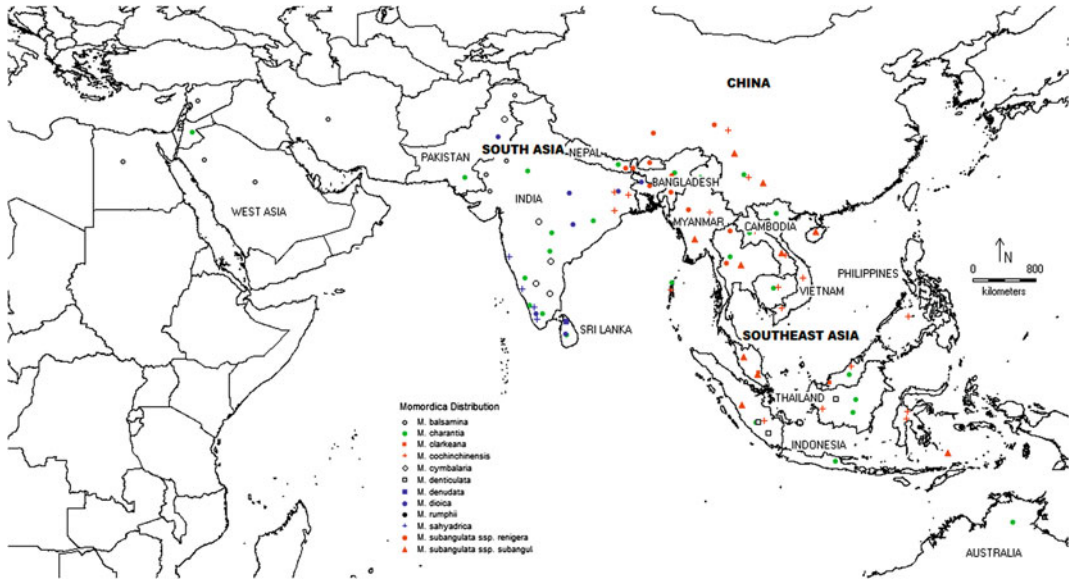

Fig. 3.2 Map showing distribution of *Momordica* species in Southeast Asia

preference for slightly high pH soils with hot days and cool nights. The natural distribution of *M. sahyadrica* is restricted to low and mid-elevation range of Western Ghats from Kerala to Maharashtra through the Nilgiris and Konkan hills.

Herbarium survey indicates prevalence of *M. subangulata* subsp. *renigera* largely in Assam (Kokrajar and Kamrup districts), Meghalaya and Mizoram (Naga-Khasi-Jainthia and Garo hills) and occasionally in Arunachal Pradesh, Nagaland, Tripura and Sikkim. The low frequency of herbarium collections from the states of Arunachal Pradesh, Nagaland, Tripura and Sikkim are rather an indicator of poor botanical exploration conducted in these states, as evidenced from field survey. It has a clear preference for fertile loamy soils in humid high rainfall areas, not tolerating climatic extremes.

M. cochinchinensis also exhibit a clear-cut preference for heavy rainfall-high humidity regions with two divergent regions in India. To a higher extent, it occurs in low elevation coastal jungles in South, Middle and North Andamans, which is in continuation of its distribution in Vietnam, Thailand, Cambodia and Philippines to Australia. To a lesser extent, it occurs in Assam-Tripura-Manipur-Nagaland forests, which is in continuation of its distribution in Myanmar and Chittagong hill tracts to South China (Fig. 3.2).

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Taxonomy and Biosystematics

4

Abstract

Momordica belongs to the subtribe Thalidianthinae Pax, tribe Joliffieae Schrad., subfamily Cucurbitoideae of Cucurbitaceae. Chakravarty (1959) enumerated seven species from India. De Wilde and Duyfjes (Bot Z 87:132–148, 2002) list out ten species from Asia of which six each occur in India and Malaysia. Joseph and Antony (Indian J Plant Genet Resour 23:172–184, 2010) presented a taxonomic revision of the genus for India. They recognized six species: *M. balsamina* L., *M. charantia* L., *M. dioica* Roxb., *M. sahyadrica* Joseph and Antony, *M. subangulata* Blume [subsp. *renigera* (G. Don) W. J. de Wilde] and *M. cochinchinensis* (Lour.) Spreng. *M. dioica* sensu stricto comprises delicate forms with evening anthesis and intensely musky scented flowers, distributed in low elevation areas in the Western Ghats, and in peninsular and Central India. Stout forms with day anthesis and large showy flowers occurring in mid and high elevation Western Ghats are separated as a new species (*M. sahyadrica* Joseph and Antony). North-eastern elements, presently treated under *M. dioica*, are placed under *M. subangulata* ssp. *renigera*. *M. macrophylla* Gage has been placed in synonymy with *M. cochinchinensis*. The presence of *M. denudata* (Thwaites) C. B. Clarke in India is doubtful in the absence of valid herbarium specimens or field collections from the reported localities. Generic and specific descriptions, key to species, and notes on distribution, habitat and ecology are also provided. A biosystematic account of the genus for the Indian taxa comprises morphology, molecular taxonomy, cytology, crossability and conclusions on evolutionary relationship are also presented.

Keywords

Momordica · Systematics · Taxonomic key · Evolutionary relationship · Seed fat

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Taxonomy

Momordica belongs to the subtribe Thalidianthinae Pax, tribe Joliffieae Schrad., subfamily Cucurbitoideae of Cucurbitaceae (Jeffrey 1980; de Wilde and Duyfjes 2002). Generic and species descriptions (along with keys in some cases) are found in various monographic and floristic treatises (Willdenow 1805; Blume 1826; Seringe 1828; Wight and Arnot 1841; Thwaites 1864; Hooker 1871; Clarke 1879; Keraudren 1975; Jeffrey 1980). No comprehensive monographs covering taxonomy and nomenclature of *Momordica* species are known to exist.

The similarity of the common characters, taken as key to distinguish between dioecious taxa of *Momordica* has led to widely conflicting taxonomic treatments of this genus in South and South–East Asia. An understanding of the taxonomy of the target taxa and their distribution is the basic prerequisite for undertaking a viable conservation programme. It is essential to ascertain a taxon's correct scientific name if a specimen is to be linked to the wealth of information that may be known about the taxon to which it belongs. Misidentification of any material will lead to spurious results when the germplasm is studied and used.

History

The taxonomic treatment of the genus *Momordica* is quite extensive. Generic and species descriptions along with keys are found to be varying in degrees in various floras published in India before 1947. Van Rheede's (1688) descriptions and illustrations of paval (=*Momordica charantia*) in the *Hortus Malabaricus* is the first printed record. Linnaeus (1753), de Candole (1828), Roxburgh (1832), Clarke (1879), Cooke (1901), Gamble and Fischer (1919), Blatter (1919) and Kanjilal et al. (1938) have extensively dealt with the systematics of the genus. After 1947, Santapau (1953), Saldhana and Nicholson (1976), Chakravarty (1959, 1982) and Mathew (1981, 1983) have treated the genus in their floristic works. Many of the regional and district floras also mention and give a small description of various *Momordica* species (Srivastava 1976; Oommachan 1977; Bhandari 1978; Naik 1979; Rao 1985; Shetty and Singh 1987; Ramachandran and Nair 1988; Vajravelu 1990; Narasimhan and Sharma 1991; Deshpandey et al. 1993; Kothary and Murthy 1993; Chauhan 1996; Sasidharan and Sivarajan 1996; Sivarajan and Mathew 1997; Pallithanam 2001; Singh et al. 2002; Bhat 2003).

Chakravarty's (1982) treatment of *Momordica* in his *Fascicles of Cucurbitaceae* is the classification that is by far the most relied upon in India. He has enumerated seven species from India including *M. denudata* from Kerala and *M. macrophylla* from the Assam–Manipur belt bordering Myanmar. Gamble and Fischer (1919) mention occurrence of *M. denudata* in Kerala from "low country Quilon", which might have prompted Chakravarty (1982) to mention its distribution in Kerala. He has also described a new variety, i.e. *M. charantia* var. *muricata* based on Rheede's plate in *Hortus Malabaricus* as type. Jeffrey (1980) rules out *M. subangulata* from India for the absence of ridged or longitudinally alate fruits and hence treats this component under *M. dioica*. Kumar and Pandey (2002) also worked on the taxonomy and diversity of the genus in India. However, it does not vary substantially from that of Chakravarty (1982) and reports the same number of species and distribution in India. Joseph and Antony (2010) have recently revised the genus for India.

Trimen (1893–1900) gives a detailed technical description and key to the species of *Momordica* occurring in Sri Lanka. Backer and Brink (1963), Henderson (1974), and Keraudren (1975) give detailed floristic account of *Momordica* species in other South–East Asian countries. De Wilde and Duyfjes (2002) give a detailed taxonomic treatment of the genus in south and South–East Asia. They have thoroughly revised the species concept and according to them *M. cochinchinensis* and *M. subangulata* do not occur in South India. A new subspecific rank in *M. subangulata* has been proposed which partially includes material

treated under *M. dioica* of north-eastern India. A considerable part of the taxa hitherto treated under *M. cochinchinensis* has been taken out and placed under *M. denticulata*. This study is of much interest as it covers all Indian species and the Malaysian taxa, which has affinity with the north-eastern, Andaman and Western Ghats taxa. Oliver (1979) gives keys and detailed descriptions of various African species of *Momordica*.

Delimitation of the Taxon

The species falling under *Thalidiantha*, *Cyclanthera*, *Ecbalium*, *Luffa* and *Diplocyclos* were included by different workers under the genus *Momordica*. Chakravarty (1982) retained separate taxon status for *M. macrophylla*, distinct from *M. cochinchinensis* for the unlobed nature of leaves. Heterophylly is observed in *M. dioica* (Bharathi 2010) and *M. sahyadrica* (Joseph 2005). Primary leaves, fully grown leaves and late growth stage leaves of these taxa vary in shape especially in lobing even in tuber sprouts. Hence, leaf shape may not be a reliable character in distinguishing species in the dioecious group. *M. cymbalaria* Fenzl ex Naud. (syn. *M. tuberosa* (Roxb.) Cogn.) was originally described as *Luffa tuberosa* by Roxburgh (1814, 1832) and renamed as *M. cymbalaria* Fenzl. and the name was adopted (Clarke 1879). Cogniaux (1881) placed it under *M. tuberosa* (Roxb.) Cogn., based on Roxburgh's *Luffa tuberosa.* The fruit was like that of *Luffa amara* Wall., but without stopple and with only eight angles (Roxburgh 1832). Absence of stopple which is one of the generic characters of *Luffa* was the reason to transfer this species to the genus *Momordica*. Chakravarty (1959) stated that *Momordica* is characterised by the presence of true cystoliths of Calcium Carbonate on the lower surface of the leaf which are absent in *M. cymbalaria*. Further, based on evidence from breeding behaviour, pollination biology and comparative morphology, Joseph and Antony (2010) place it under *Luffa* in their biosystematic treatment of *Momordica*. Bharathi et al. (2011, 2012a) highlighted its distinctness from other *Momordica* species of Indian occurrence. On the other hand, *M. cymbalaria* is reported to be closer to African species like *M. humilis*, *M. kirkii*, *M. boivinii* and *M. sessilifoilia* (Schaefer and Renner 2010) and *M. cabraei* (Ali et al. 2010).

Diagnostic Characters

Throughout the taxonomic treatments of *Momordica*, certain characters ('general' representing the genera and 'specific' applicable to individual taxa) have repeatedly been used to define and distinguish the genus. The major diagnostic features of the genera are the presence of conspicuous floral bracts (male), calyx cup, entire petal, scales on corolla, pendulous, echinate or muricate fruits, sculptured seeds and viny habit. Within the genus, three subgeneric groups can be recognised based on sex expression and habit (Table 4.1). Once these major divisions have been made, several other characters are used to distinguish within the subgenera. These minor diagnostic characters are flower colour, petal shape and size, petal markings, pubescence, bract shape, position, calyx cup colour, sepal shape, gland dottedness (petiole), floral scent, anthesis time, seed sculpture, shape, colour, pollinators, fruit surface ornamentation, etc.

Current Taxonomic Status

As different workers have treated it differently, there is no clarity and consensus in the interspecific taxonomy of the genus *Momordica* L. Taxonomic confusion exists because of the widespread use of common names. The botanical names and common names are used incorrectly or interchangeably and are often misleading. For example, *M. subangulata* subsp. *renigera* is referred as *M. cochinchinensis* (Ram et al. 2002; Sanwal et al. 2011) and *M. dioica* (Ali et al. 1991). Similarly, the descriptions of morphological features of many species are incorrect or incomplete, further compounding the problem. A perusal of over 700 sheets lodged

Table 4.1 Subgeneric classification of Indian *Momordica*

SN	Character	Subgenus A	Subgenus B	Subgenus C
1	Basic chromosome number (*n*)	11	14	9
2	Breeding behaviour	Monoecious	Dioecious	Monoecious
3	Germination	Epigeal	Hypogeal	Hypogeal
4	Habit	Annual	Perennial	Perennial
5	Roots (tap root)	Fibrous	Tuberous	Tuberous
6	Fruit surface	Muricate-tubercled	Echinate-soft papillate	Ribbed
7	Seed sides	Rectangular, squarish	Cog wheel, round, oval	Round
8	Male flower bract position	Mid-way or towards axis-not protective	Just below the flower—protective	Absent/ rudimentary
9	Stigma colour	Green	Yellow	Green
10	Leaf shape	Angular	Roundish	Roundish

in major herbaria in India reveals incomplete labelling and misidentification (Joseph 2005). *M. dioica* folders displayed at MH, Coimbatore and CAL (Kolkata) include three distinct entities that vary for many morphological features and represents geographically isolated areas.

Generic characters used to distinguish the genus *Momordica* in most of the earlier works include a calyx tube closed with incurved scales. In fact, instead of the calyx tube it is the corolla which has scales at its base. Similarly, male inflorescence morphology needs explanation as to branched or non-branched nature. Chakravarty (1982) ignored important traits such as anthesis time, petal spot and ridged nature of the fruit. Longitudinally alate or ridged fruits are the key characters for *M. subangulata* (Jeffrey 1980) and blotched petals with black bulls eye patterns that are very specific to *M. subangulata* and *M. cochinchinensis*.

Raj et al. (1993) listed out eight species indigenous to India, namely *M. charantia*, *M. balsamina*, *M. dioica*, *M. cymbalaria*, *M. denudata*, *M. macrophylla*, *M. subangulata* and *M. cochinchinensis*. Of these, *M. macrophylla* is treated as synonymous (Table 4.2) with *M. cohinchinensis* (Jeffrey 1980, 2001; de Wilde and Duyfjes 2002). Joseph and Antony (2010) recently revised the genus for India. Based on an extensive ecogeographic survey in South India including the type of localities, they consider the occurrence/existence of *M. denudata* in India as fairly doubtful (Joseph and Antony 2010). The monoecious taxa are *M. charantia* L. (var. *muricata* (Willd.) Chakrav. and var. *charantia* L.), *M. balsamina* L. and *M. cymbalaria*. The dioecious taxa are *M. dioica* Roxb., *M. sahyadrica* Joseph et. Antony, *M. cochinchinensis* (Lour.) Spreng. and *M. subangulata* Blume subsp. *renigera* (G. Don) W. J. de Wilde.

The taxonomic position of *M. cymbalaria* within the genus *Momordica* had been a matter of considerable debate (Pandey et al. 2006). The two extreme positions are either that *M. cymbalaria* belongs to the genera *Momordica* or *Luffa*. The species *Luffa tuberosa* was established by Roxburgh (1832) and subsequently transferred to the genus *Momordica* as *Momordica cymbalaria* (Clarke 1879). Congiaux (1881) recognised as *Momordica tuberosa* based on Roxburgh's *Luffa tuberosa*. Chakravarty (1959) reported that the leaves of all *Momordica*'s contain true cystoliths on the lower surface which is absent in *M. cymbalaria*. Chakravarty (1982) also mentioned that there is no reason for shift, the species to *Momordica* which has either muricate or echinate fruits but never angular. However, the seed coat anatomy (Singh and Dathan 2001) and seed fat (Azeemoddin and Rao 1967) characteristics supported the retention of this species under the genus *Momordica*. Recently, based on internal transcribed spacer (ITS) sequences of nuclear ribosomal DNA (Ali et al. 2010) and three genome (plastid,

Table 4.2 List of common synonyms of Indian *Momordica* species

SN	IPNI Index	Accepted Nomenclature
1	*Momordica schinzii* Cogn. Ex Schinz (IK)	*Momordica balsamina* Linn.
2	*Momordica garipensis* E. Mey (IK)	*Momordica balsamina* Linn.
3	*Momordica involucrata* E. Mey. (IK)	*Momordica balsamina* Linn.
4	*Momordica cylindrica* Blanco (IK)	*Momordica charantia* Linn.
5	*Momordica muricata* Vell. (IK)	*Momordica charantia* Linn.
6	*Momordica muricata* Wall. (IK)	*Momordica charantia* Linn.
7	*Momordica senegalense* Lam. (IK)	*Momordica charantia* Linn.
8	*Momordica zeylanica* Mill. (IK)	*Momordica charantia* Linn.
9	*Momordica anthelmintica* Schum and Thorn. (IK)	*Momordica charantia* Linn.
10	*Momordica chinensis* Hort. (IK)	*Momordica charantia* Linn.
11	*Momordica elegans* Salisb. (IK)	*Momordica charantia* Linn.
12	*Momordica indica* Linn. (IK)	*Momordica charantia* Linn.
13	*Momordica heyneana* Wall and G. Don (IK)	*Momordica subangulata* Blume. subsp. *renigera* (G. Don) W. J. de Wilde
14	*Momordica renigera* Wall (IK)	*Momordica subangulata* Blume. subsp. *renigera* (G. Don) W. J. de Wilde
15	*Momordica renigera* Wall. and G. Don (IK)	*Momordica subangulata* Blume. subsp. *renigera* (G. Don) W. J. de Wilde
16	*Momordica hispida* Dennst (IK)	*Momordica dioica* Roxb.
17	*Momordica tuberosa* Dennst. (IK)	*Momordica dioica* Roxb.
18	*Momordica wallichii* M. Roem. (IK)	*Momordica dioica* Roxb.
19	*Momordica roxburghiana* G. Don (IK)	*Momordica dioica* Roxb.
20	*Momordica sicyoides* Ser. (IK)	*Momordica dioica* Roxb.
21	*Momordica sicyoides* Sesse and Moc. (IK)	*Momordica dioica* Roxb.
22	*Momordica macrophylla* Gage (IK)	*Momordica cochinchinensis* (Lour.) Spreng.
23	*Momordica mixta* Roxb. (IK)	*Momordica cochinchinensis* (Lour.) Spreng.
24	*Momordica ovata* Cogn. (IK)	*Momordica cochinchinensis* (Lour.) Spreng.
25	*Momordica sphaeroidea* Blanco (IK)	*Momordica cochinchinensis* (Lour.) Spreng.
26	*Momordica suringarii* Cogn. (IK)	*Momordica cochinchinensis* (Lour.) Spreng.
27	*Momordica meloniflora* Hand.-Mazz. (IK)	*Momordica cochinchinensis* (Lour.) Spreng.

Source Compiled from Jeffrey (1980), Chakravarty (1982), Hanelt (2001) and de Wilde and Duyfjes (2002)

mitochondrial and nuclear DNA markers) phylogeny (Schaefer and Renner 2010) the status of this species in *Momordica* is established.

Momordica is monophyletic and the genus can be divided into 11 clades (Schaefer and Renner 2010) that mostly correspond to the morphological clades proposed by Jeffrey and de Wilde (2006). The Asiatic species falls under three sects. Dioecious species like *M. cochinchinensis*, *M. dioica, M. sahyadrica*, *M. denticulata*, *M. denudata*, *M. clarkeana* and *M. subangulata* grouped under the sect. *Cochinchinensis,* and monoecious species *M. charantia* and *M. balsamina* under the sect. *Momordica* and *M. cymbalaria* under the sect. *Raphanocarpus* (Schaefer and Renner 2010).

Taxonomic Key

I. *Germination epigeal*, *annual*, *tap root non-tuberous*, *plants monoecious*, *nectary in male flowers not closed with corolla scales*, *fruits muricate or tubercled*.
   a. Bracts of male flowers about the middle of the flower stalk; fruits small or large,

softly tubercled or muricate with long green ridges; seeds thick, flat on surface, margins edged, thick on sides, broadly rectangular, no distinction between chalazal and micropylar ends, ends subtridentate, heavily or feebly sculptured.
……..…*M. charantia*

b. Bracts of male flowers at the apex of the peduncle, fruits small, distantly soft tubercled, no bumps or ridges; seeds very thin, sides not thick, margins wedged, broadly ovate round with tapering micropylar end, ends roundish, finely pitted and feebly sculptured.
…….. *M. balsamina*

II. *Germination hypogeal*, *perennial*, *tap root tuberous*, *plant dioecious*, *nectary of the male flowers closed with prominent corolla scales*, *fruits echinate*.

a. Petals (3 inner) with black purple blotch, male calyx hypanthium saucer shaped

i. Leaf cordate, unlobed, margins dentate, petiole eglandular, male calyx blackish purple, broad, tip round-oval, fruits faintly ridged, softly echinate, seeds medium sized, rectangularly cog wheel shaped.
……..*M. subangulata* subsp. *renigera*

ii. Leaf unlobed or deeply lobed, margins undulate, petiole gland dotted (6–12 bead like structures, often the lamina base also), male calyx blackish purple, broad, tip triangular, fruits with conical projections, seeds large, penta-hexagonal, subtridentate on ends.
…… *M. cochinchinensis*

b. Petals without purple blotch, male calyx-hypanthium cup shaped.

i. Anthesis in the early morning, flowers large, showy, bright yellow, not scented, male calyx blackish purple, sepals of male flower broad, tip oval, round or scarious.
…….. *M. sahyadrica*

ii. Anthesis in the evening, flowers small, pale yellow, intensely musky scented, male calyx whitish yellow, sepals of male flower narrow acute.
……. *M. dioica*

III. *Germination hypogeal, perennial, tap root tuberous, plant monoecious, male flowers borne in short raceme, anthers asymmetrical, fruits ribbed, arils white, epicarp papery and smooth and seeds shiny, round, non bitten*.
……..*M. cymbalaria*

Biosystematics

Morphology

Morphological studies provide information that can be used for practical plant identification and hypothesising phylogenetic relationships. The limited information available on many important and basic aspects in neglected and underutilised crops hinders their development and sustainable conservation. Besides, the information available about germplasm is scattered and not readily accessible, i.e. found only in regional floras. Pasha and Sen (1989) carried out numerical taxonomic analyses of selected genera of cucurbits, but *Momordica* was represented by *M. charantia* var. *charantia* and *M. charantia* var. *muricata* only. The botanical description of different *Momordica* spp. was not systematic and less information is available in the literature. Comparative morphological features of Indian *Momordica* spp. are presented in Table 4.3 and other south Asian entities in Table 4.4 are based on Chakravarty (1946), de Wilde and Duyfjes (2002), Joseph (2005), Bharathi (2010).

Although both the annual monoecious species (*M. balsamina* and *M. charantia*) share more similarity they can be easily distinguished from each other. The male flower bract is positioned at the base/near the axis or below the middle of the flower stalk in *M. charantia,* whereas in *M. balsamina* it is situated in the upper middle or towards the tip of the peduncle. The anther filaments are fused to give a globose appearance in *M. charantia,* while it is split into lobes in

Table 4.3 Comparative morphology of *Momordica* species of India

Characters	*M. charantia*	*M. balsamina*	*M. dioica*	*M. sahyadrica*	*M. subangulata* subsp. *renigera*	*M. cochinchinensis*	*M. cymbalaria*
Basic chromosome no.	11	11	14	14	14	14	9
Germination	Epigeal	Epigeal	Hypogeal	Hypogeal	Hypogeal	Hypogeal	Hypogeal
Life span	Annual	Annual	Perennial	Perennial	Perennial	Perennial	Perennial
Breeding system	Monoecious	Monoecious	Dioecious	Dioecious	Dioecious	Dioecious	Monoecious
Leaf shape	Angular	Angular	Roundish—triangular	Roundish—triangular	Reniform	Angular	Roundish
Leaf lobing	Lobed	Lobed	Lobed	Lobed	Unlobed	Lobed	Angled
Anthesis	Morning	Morning	Evening	Morning	Morning	Morning	Morning
Reproduction	Sexual	Sexual	Sexual	Sexual	Sexual and vegetative	Sexual	Sexual
Roots (tap root)	Fibrous	Fibrous	Tuberous	Tuberous	Tuberous	Tuberous	Tuberous
Umbilical glands	Absent	Absent	Absent	Absent	Absent	Present	Absent
Production of adventious tubers	Absent	Absent	Absent	Absent	Present	Absent	Absent
Inflorescence type (♂)	Solitary/ pseudoraceme	Solitary/ pseudoraceme	Solitary/ pseudoraceme	Solitary/ pseudoraceme	Solitary/ pseudoraceme	Solitary/ pseudoraceme	Short raceme
Nature of male flower bract	Foliaceous	Foliaceous	Foliaceous	Foliaceous	Foliaceous	Foliaceous	Rudimentary
Flower bract shape (♂)	Flat	Flat	Boat -shaped	Boat -shaped	Hooded	Hooded	Rudimentary
Male flower bract position on stalk	Below middle	Above middle	Tip of the peduncle	Tip of the peduncle	Tip of the peduncle	Tip of the peduncle	Base
Male flower nectary	Closed	Partially closed by corolla scales	Closed by corolla scales	Closed by corolla scales	Closed by corolla scales	Closed by corolla scales	Open from above
Relative size of ♂ and ♀ flowers (corolla)	♂ larger than ♀	♂ larger than ♀	Of equal size	Of equal size	Of equal size	Of equal size	Of equal size
Petal spot	Absent	Absent	Absent	Absent	Present	Present	Absent
Stigma colour	Green	Green	Yellow	Yellow	Yellow	Yellow	Green
Fruit surface	Highly tubercled	Sparsely tubercled	Soft spiny	Soft spiny	Soft spiny	Hard spiny	Pyriform
Nature of epicarp (ripening)	Delicate	Delicate	Delicate	Delicate	Delicate	Shell like - leathery	Papery
Seed shape	Subtridentate	Round oval	Subglobose	Cog wheel	Cog wheel	Cog wheel	Round oval

Table 4.4 Comparative morphology of *Momordica* species of South–East Asia

Characters	*M. clarkeana*	*M. rumphii*	*M. denticulata*	*M. denudata*	*M. subangulata* subsp. *subangulata*
Life span	Perennial	Perennial	Perennial	Perennial	Perennial
Breeding system	Dioecious	Dioecious	Dioecious	Dioecious	Dioecious
Leaf shape	Ovate	Suborbicular	Ovate-oblong	Ovate-lanceolate	Ovate-reniform
Leaf lobing	Unlobed	Trifoliate	Unlobed	Shallow to deeply lobed	Unlobed
Glands on leaf blade margin	Absent	Absent	Present	Absent	Absent
Male flower inflorescence type	Solitary/ pseudoraceme	Solitary	Solitary/ pseudoraceme	Raceme (1–6/node)	Solitary
Petal colour	Pale yellow	Yellow	Creamy white	Yellow	Yellow/orange
Receptacle tube shape	Cupular	Cupular	Saucer shaped	Cupular	Saucer shaped
Fruit shape	Ovoid	Broadly ovoid-ellipsoid/ subglobose	Ellipsoid oblong	Broadly ovoid	Ovoid ellipsoid
Fruit surface	Smooth	Sparsely muricate	Short spiny-sand paper type	Spiny-soft papillate	With irregularly crested ribs
Pericarp	Hard leathery	Leathery	Leathery	Delicate	Delicate
Seed shape	Elliptic/ subcircular	Circular	Subcircular	Ovoid oblong	Ovoid/oblong/ globose
Seed sculpture	Sculptured	Finely corrugated	Finely sculptured	Not sculptured	Slightly sculptured

M. balsamina. The wild variety of bitter gourd (*M. charantia* var. *muricata*), is often misidentified as *M. balsamina* (Maurya et al. 2007) as it has close morphological resemblance to *M. charantia* var. *muricata.* The clear separation of the monoecious from the dioecious species and close similarities within the monoecious species suggest that both the monoecious species (*M. charantia* and *M. balsamina*) have evolved from a common ancestor and has diverged morphologically from the dioecious species.

The presence of umbilical glands in the petiole of *M. cochinchinensis* was reported as a key character in the description given by Chakravarty (1946). However, materials belonging to *M. subangulata* subsp. *renigera* was often misidentified and referred to as *M. cochinchinensis* as evidenced by several publications (Patnaik and Patnaik 1976; Shadeque and Baruah 1984; Handique 1988; Vijay and Jalikop 1980; Mohanty et al. 1994; Ram et al. 2002; Rasul et al. 2004; Sanwal et al. 2011). *M. subangulata* subsp. *renigera* has extra long fruit stalk when compared with other dioecious species. The flowers of *M. dioica* have smaller petals and do not have basal blotches in their petals which are the main distinguishing character from *M. cochinchinensis* and *M. subangulata* subsp. *renigera* (Bharathi et al. 2009). Among the dioecious species, *M. dioica* and *M. sahyadrica* showed close similarities for most of the traits (except for anthesis time, flower size, calyx colour and fruit size) indicating close relationship between them. Although the calyx colour and fruit morphology of *M. sahyadrica* is closer to *M. subangulata* subsp. *renigera*, petal blotch was absent at the base of petals of *M. sahyadrica*. The specimens of *M. sahyadrica* were

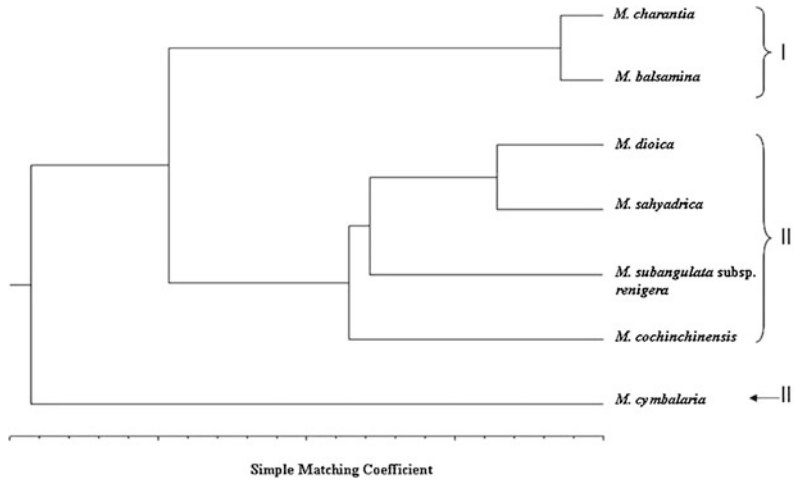

Fig. 4.1 The UPGMA dendrogram based on 40 qualitative characters of *Momordica* species

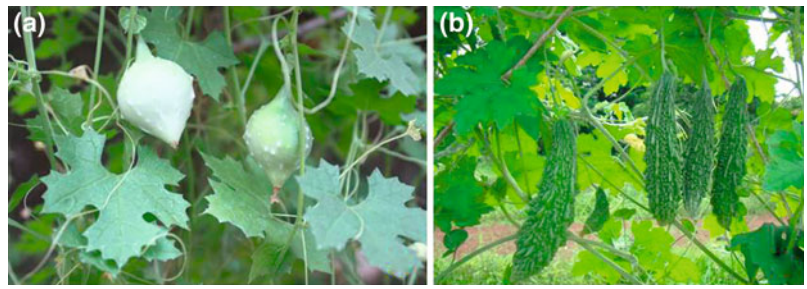

Fig. 4.2 Fruits with muricate-tubercled surface, **a**. *M. balsamina*, **b**. *M. charantia*

placed under *M. dioica* at the Central National Herbarium (CAL), Kolkata due to strong morphological similarity between these two species (Joseph and Antony 2007). However, morphological characters seem to indicate that *M. sahyadrica* is of hybrid origin (Schaefer and Renner 2010).

Analysis of morphological data (50 qualitative and 10 quantitative) for determining the genetic variation within seven *Momordica* species (57 accessions) led to the recognition of three groups (Fig. 4.1; Bharathi 2010). The first group, containing *M. charantia* (var. *charantia*, var. *muricata*) and *M. balsamina* is characterised by $n = 11$, annual, monoecious, non-tuberous roots and muricate—tubercled fruit surface (Fig. 4.2). The second group comprised *M. dioica*, *M. sahyadrica*, *M. subangulata* subsp. *renigera* and *M. cochinchinensis* which is characterised by $n = 14$, perennial, dioecious, tuberous tap roots and echinate—soft papillate fruit surface (Fig. 4.3). The third group contained *M. cymbalaria* which is characterised by $n = 9$, perennial, monoecious, tuberous tap roots and ribbed fruit surface (Fig. 4.4).

Using PCA, the 11 original variables were reduced to three principal components (PC 1–PC 3). PC 1 is represented by fruit weight, fruit length, fruit diameter and 100 seed weight indicating that these variables are related and explain 36.23 % of variation in the data. Leaf length and petiole index were related which together explain 26.04 % variation in the data. In PC 3, petiole length and fruit stalk length together explain 20.59 % variation. A scatter plot on the first two PCs showed that the accessions assigned to the same species are generally grouped together. The obligate cross-pollinated species like *M. cochinchinensis*, *M. subangulata* subsp. *renigera* and *M. sahyadrica* and the facultative cross-pollinated species (*M. cymbalaria*) are well separated. Infra-specific variation was higher in *M. charantia* and formed four distinct groups; the first group comprises

Fig. 4.3 Fruits with echinate—soft papillate fruit surface, **a**. *M. dioica*, **b**. *M. sahyadrica*, **c**. *M. subangulata* subsp. *renigera*, **d**. *M. cochinchinensis*

Fig. 4.4 Fruit of *M. cymbalaria*

the accessions of wild variety (*M. charantia* var. *muricata*); the second contains the accessions of both wild and cultivated varieties. Pusa Do Mausmi (PDM) stands separately in a group, while a wild accession (CHA 1) is clustered with *M. dioica*. The accessions of *M. balsamina* and *M. dioica* also overlap in a group (Bharathi 2010).

Deoxyribonucleic Acid

Advancements in DNA technology have resulted in an array of tools for DNA polymorphism assays. DNA-based molecular markers are useful tools that provide a relatively unbiased estimation of genetic diversity and establish a genetic relation more precisely than morphological and biochemical markers (Soller and Beckmann 1983). Among these, PCR-based random molecular markers such as Random Amplified Polymorphic DNA (RAPDs) and Inter Simple Sequence Repeats (ISSRs) are more commonly used in species in which there is a lack of DNA sequence information. Although a number of varieties belonging to different *Momordica* species have been developed in India, very little information is available about their genetic base.

Understanding the extent of natural variation and phylogenetic relation at molecular level is essential to develop new strategies for genetic improvement of *Momordica*. Although DNA markers are widely used in assessing the phylogenetic relation that they have rarely been used in *Momordica* species. At intra-specific levels relatively few polymorphic markers have been identified in *M. charantia* (Dey et al. 2006; Singh et al. 2007; Gaikwad et al. 2008; Behera et al. 2008) and *M. dioica* (Rasul et al. 2007). The genotypic difference among the varieties of *M. charantia* detected by RAPD was possibly due to their wide geographic distribution, and

considerable ecological and morphological variation with respect to fruit shape, size and colour (Dey et al. 2006). Recently, Wang et al. (2010) developed polymorphic microsatellite markers for *M. charantia* L. to investigate the genetic diversity and population structure within and between *M. charantia* and its four related species (*Cucurbita pepo* L., *Luffa cylindrica* L., *Lagenaria siceraria* L. and *Cucumis sativus* L.).

A combination of 14 RAPD and 7 ISSR informative markers screened by Bharathi et al. (2012a) could precisely identify each of the *Momordica* genotypes and thus it would be of immense value in varietal identification, fingerprinting studies and various genotyping applications in *Momordica*. However, RAPD profiles were found more informative than ISSR profiles in terms of defining varietal identity in *Momordica*. The RAPD and ISSR markers used in this study (Bharathi et al. 2012a) clearly discriminated all the 40 genotypes from each other and resulted in a definitive grouping among different species and varieties of *Momordica* that corresponded well with their known phylogenetic relationships as well as morphological, cytological and taxonomic classifications. The cultivated *M. charantia* and the wild *M. balsamina* being monoecious in nature were clustered closely in one group. The dioecious species of Indian occurrence *M. dioica*, *M. sahyadrica*, *M. subangulata* subsp. *renigera* and *M. cochinchinensis* formed another distinct group. A three-genome phylogeny study (plastid, nuclear and mitochondrial) of *Momordica* (Schaefer and Renner 2010) also grouped the dioecious species of South–East Asia (*M. dioica*, *M. rumphii* [*M. trifolii*], *M. subangulata*, *M. clarkeana*, *M. denudata*, *M. denticulata* and *M. cochinchinensis*) in a single cluster and monoecious species in another single cluster (*M. charantia* and *M. balsamina*). *M. cymbalaria* which has very less similarity with the Asiatic *Momordica* species is grouped with the African species namely *M. kirkii*, *M. boivinii*, *M. humilis* and *M. sessilifolia*.

Higher degree of inter-specific molecular diversity was observed between *M. charantia* and *M. cochinchinensis* (Schaefer and Renner 2010; Bharathi et al. 2012a). The maximum genetic similarity was observed between *M. dioica* and *M. sahyadrica* followed by *M. subangulata* subsp. *renigera* and *M. dioica* and between *M. charantia* and *M. balsamina*. Minimum genetic similarity was observed between *M. charantia* and *M. cochinchinensis*. The relation between *M. dioica* and *M. sahyadrica* was further evident from the interfertile hybrid obtained between these two species (Bharathi et al. 2010a). *M. dioica* was presumed as one of the parents of *M. subangulata* subsp. *renigera* (Bharathi et al. 2010b) and the DNA pattern also indicates the close relation between them. *M. balsamina* showed close similarity to an African species *M. involucrata* (Schaefer and Renner 2010). But among the monoecious annual species, a higher degree of genetic similarity was observed between *M. charantia* and *M. balsamina* (Bharathi et al. 2012a). Occurrence of a high bivalent frequency with normal meiotic cycle in the hybrid progeny of *M. charantia* and *M. balsamina* (Singh 1990) further supported these findings.

Cytology

Karyological studies on the genus are important to enrich the existing knowledge regarding the phylogenetic relations among different species, the evolutionary trends in speciation and taxonomic evaluation. *Momordica* has a basic chromosome number of $x = 9, 11, 14$ and cultivated bitter gourd is diploid ($2n = 22$). All the annual monoecious species had the basic chromosome number of 11; perennial dioecious species had basic chromosome number of 14 while the perennial monoecious species had basic chromosome number of 9. In general, all the species recorded for their common type of chromosomes suggested a common ancestry (Bharathi et al. 2011). *M. charantia* and *M. balsamina* have almost the same number of median and submedian chromosomes although the chromosomes of *M. balsamina* are slightly smaller (Trivedi and Roy 1972). *M. dioica*, a perennial dioecious

species, differs from *M. charantia* and *M. balsamina* in chromosome number as well as through its markedly asymmetrical karyotype (Roy et al. 1966; Trivedi and Roy 1972; Sinha et al. 1997).

Crossability

The cultivated variety of bitter gourd (var. *charantia*) crossed readily with its wild variety (var. *muricata*). The F_1's produced flowers with >80 % stainable pollen and set fruits with abundant seeds from selfed flowers (Agarwal et al. 1957; Joseph 2005; Bharathi 2010). *M. charantia* var. *muricata* does not differ from the true cultivated bitter gourd (*Momordica charantia* var. *charantia*) except for miniature size of fruits and seeds; these were crossed readily and there were many intermediate types (Njoroge and van Luijk 2004). Degner (1947), Walters and Decker-Walters (1988) considered the smaller wild variety (*M. charantia* var. *muricata* syn. with *M. charantia* var. *abbreviata* Ser.) as the progenitor of cultivated bitter gourd.

Hybrid seeds are apparently much more difficult to obtain between *M. charantia* × *M. balsamina* and the reciprocal crosses failed. Nevertheless, F_1 hybrids are highly fertile (54–62 % stainable pollen) and the progeny had a high bivalent frequency with normal meiotic behaviour, suggesting that *M. charantia* have high genetic affinity with *M. balsamina* and thus are intimately related, but they probably stabilised by reproductive isolation due to fertilisation barriers (Singh 1990). These results coupled with morphological (Pandey et al. 2007), karyomorphological (Trivedi and Roy 1972; Bharathi et al. 2011) and molecular (Bharathi et al. 2012a) results reinforce the viewpoint that *M. charantia* and *M. balsamina* are distinct but closely related species (Pandey et al. 2007). However, *M. charantia* was also reported to be closer to the African species *M. angolensis*, and *M. balsamina* was reported closer to *M. welwitschii* (Schaefer and Renner 2010) and *M. foetida* (Ali et al. 2010).

Close affinity between *M. dioica* and *M. sahyadrica* have been reported based on molecular markers (Ali et al. 2010; Bharathi et al. 2012a) as well as morphological markers (Joseph and Antony 2010) and karyomorphological similarity (Bharathi et al. 2011). *M. sahyadrica*, endemic to the Western Ghats of India showed closer morphological similarity to *M. dioica* [considered to be the progenitor of *M. sahyadrica* (Behera et al. 2011; Joseph 2005)] than to other species (Joseph and Antony 2007). High fruit set and fair stainability of inter-specific hybrids between *M. dioica* and *M. sahyadrica* indicated a close relation between these two species. *M. dioica* and *M. sahyadrica* are crossable with *M. cochinchinensis* in one direction, i.e. *M. dioica* and *M. sahyadrica* as female parent (Mondal et al. 2006; Bharathi et al. 2010a, b).

M. dioica and *M. cochinchinensis* are suggested as putative parents of *M. subangulata* subsp. *renigera* (Bharathi et al. 2010b) through morphology and chromosome pairing behaviour of inter-specific hybrids of *M. subangulata* subsp. *renigera*, *M. dioica* and *M. cochinchinensis*. It was further observed that, *M. subangulata* subsp. *renigera* was the only species which had reproductive compatibility in both the directions with *M. cochinchinensis*. It indicated that *M. cochinchinensis* is closer to *M. subangulata* subsp. *renigera* than to any other species. It is considered that *M. subangulata* subsp. *renigera*, the most recent derivative from their diploid ancestors, may not have diverged genetically to that extent so as to create absolute barriers to crossing.

The sect. *Raphanocarpus* is represented in India by only one taxon (*M. cymbalaria*). It had an isolated position and is reported to be closer to the African species like *M. humilis*, *M. kirkii*, *M. boivinii* and *M. sessilifolia* (Schaefer and Renner 2010) and to *M. cabraei* (Ali et al. 2010). *M. cymbalaria* was neither crossable with the sect *Cochinchinensis* nor with sect. *Momordica*. Bharathi et al. (2012a) highlighted its distinctness from other *Momordica* species of Indian occurrence based on molecular and

karyomorphological evidence. It is possible that *M. cymbalaria* that originated along with other African species from a progenitor species differs from the dioecious *Momordica* species of Indian occurrence.

There have been few attempts to raise crosses between sects. Crosses were made between *M. charantia*, *M. balsamina* (sect. *Momordica*) and *M. dioica* (sect. *Cochinchinensis*) exploring possibilities of transferring the desirable attributes of the latter (especially the 'bitterless' trait) to the former but none succeeded (Roy et al. 1966; Joseph 2005) indicating the lack of genetic affinity between them. *M. charantia* and *M. balsamina* failed to cross with dioecious species indicating that they are genetically distantly related and had evolved along a separate line diverging from dioecious species.

Five major patterns of crossing behaviour emerged from the results of the crossing experiments in *Momordica* spp. of Indian occurrence (Bharathi et al. 2012b).

(i) Cross compatible with pollen fertility (*M. charantia* var. *charantia* × *M. charantia* var. *muricata* and *M. dioica* × *M. sahyadrica*).
(ii) Partially compatible with pollen fertility (*M. charantia* × *M. balsamina*).
(iii) Cross compatible with pollen sterility [between diploid species (*M. dioca*, *M. sahyadrica*, *M. cochinchinensis*) and tetraploid species (*M. subangulata* subsp. *renigera*)].
(iv) Partially compatible with pollen sterility (*M. dioica* × *M. cochinchinensis* and *M. sahyadrica* × *M. cochinchinensis*) and
(v) Cross incompatible (between sect.).

Cucurbitacins/Seed Fat

The seed fat of the genus *Momordica* contains alpha-eleostearic acid which is characteristic of this genus. *M. charantia* contains 43.7 % (Khan and Ilyas 1962) to 46.7 % (Hilditch and Williams 1964) and *M. dioica* contains 54.9 % (Hilditch and Williams 1964) alpha-eleostearic acid. From a taxonomic viewpoint, it is noted that all species (three species of each) of *Momordica* and *Trichosanthes* reported have conjugated oils (Chisolm and Hopkins 1964). Seed fat of *M. tuberosa* (=*L. tuberosa)* contains a conjugated triene acid which is characteristic of seed fat of the genus *Momordica*, however, on the other hand, genus *Luffa* does not contain conjugated triene acid (Azeemoddin and Rao 1967) which supported the retention of *L. tuberosa* under the genus *Momordica*.

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Ethnobotany and Nutritive Value

5

Abstract

Momordica species have been used as both food and medicine in the regions in which it grows, for centuries in ancient traditional Indian, Chinese, and African pharmacopoeia as anthelmintic, laxative, digestive stimulant, and to enhance appetite. Usefulness of various *Momordica* species as anthelmintic, vermifuge, cathartic, hypoglycemic, aphrodisiac, antipyretic and in the treatment of burns, bilious disorders, diabetes, cataract, hypertension, leprosy, jaundice, snake bite, hemorrhoids, and piles has been mentioned. However, traditional knowledge related to the use of these species by indigenous tribes is not yet fully documented in the published literature. The leaves and young fruits are cooked and eaten as vegetable in India, Cameroon, Sudan, and Southern Africa. Leaf and fruit extracts of bitter gourd are used in the preparation of tea and is a popular health drink in Japan. Tender clippings of bitter gourd and teasel gourd are used extensively as leafy vegetable in parts of India and elsewhere in Southeast Asia. The fruits of the sweet gourd are esteemed as the fruit from Heaven for its ability to promote longevity, vitality, and health. Fruits of spine gourd contain aliphatic compounds which act as appetizer and astringent. Use of *M. sahyadrica* tuber paste as detergent and toilet soap holds promise in the cosmetic and health care industry. Bitter gourd has a relatively high nutritional value compared to other Cucurbits, due mainly to the iron and ascorbic acid content. *Momordica* is noted for acids with conjugated double bonds and high levels of antioxidant activity were noticed in balsam apple. *M. dioica* have medium protein value, fat, and phenolic compounds, and have maximum calorie value when compared to eight traditional wild vegetables of Indo-Persian region and could be a good supplement for nutrients such as fiber, potassium, zinc, lipid, protein, and carbohydrates. Sweet gourd contains β-carotene and lycopene at very high levels, with those of lycopene being up to 308 μg/g in the seed membrane, about 10-fold higher than in other lycopene-rich fruits and vegetables. Nutritional supplementation trials in Vietnam have shown that children fed with 'xoi gac' (rice cooked with fruit pulp of *M. cochinchinensis*, popularly called gac) have significantly higher plasma β-carotene, compared to those who received synthetic

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β-carotene powder or none. This chapter focuses on the nutritional composition as well as medicinal and therapeutic properties of Asiatic *Momordica* species.

Keywords
Ethnobotany · Proximate principles · Mineral content · Antioxidant · *Momordica* spp

Ethnobotany

The genus *Momordica*, primarily known as bitter gourd, comprises many species of medicinal importance in Asia and Africa. Barring bitter gourd (*M. charantia* var. *charantia*) other species (including *M. charantia* var. *muricata*) occur in wild state and are gathered by tribals as vegetables. Teasel gourd, sweet gourd, and spine gourds (*M. subangulata* subsp. *renigera*, *M. cochinchinensis*, *M. sahyadrica*, and *M. dioica*) are the other *Momordica* species of economic importance, mostly wild gathered but grown to a limited extent in the eastern and northeastern parts of India. Many species of *Momordica* are used as wild vegetable, fodder, and indigenous medicine for treatment of malaria and other diseases in Kenya (Aynesu 1978; Njoroge and Newton 2002). Although, there is a general belief that bitter gourd is good for diabetic cure and recent research (Aktar et al. 1981; Day et al. 1990) reveals its hypoglycemic properties, commercial formulations are scanty in the ayurvedic pharmaceutical industry.

Aboriginal people live in their traditional ranges and largely follow traditionally oriented lifestyles, depending more on bush food than store brought food. Usefulness of various *Momordica* species as anthelmintic, vermifuge, cathartic, hypoglycemic, aphrodisiac, antipyretic, and in the treatment of burns, bilious disorders, diabetes, cataract, hypertension, leprosy, jaundice, snake bite, haemorrhoids, and piles has been mentioned [van Rheede (1678–1693), Watt (1891), Kirtikar and Basu (1933), Uphof (1968), Walters and Decker Walters (1988), Rastogi and Mehrotra (1990), Yang and Walters (1992), Dwivedi (1999), Jeffrey (2001), Bhat et al. (2003), and Deshmukh and Rothe (2003)]. However, traditional knowledge related to the use of these species by indigenous tribes is not yet fully documented in the published literature. Joseph and Antony (2008) give a detailed account of the ethnobotany of the genus in the Western Ghats of India.

M. balsamina. The leaves and young fruits are cooked and eaten as vegetable in India, Cameroon, Sudan, and Southern Africa. The bitter young fruits are reported widely as edible, whereas the ripe fruits cause vomiting and diarrhea, and can be poisonous. However, the bright red pulp is eaten in Namibia. The unripe fruits are also used to prepare pickles, and as salted and sun dried vegetable for lean months in India. The leaves and fruits are sometimes used in sauces and soups.

The leaves and stems are used as fodder in Australia and Senegal. The leaves form a slightly soapy solution in water and are used to clean metal objects and to wash the body. Common and widespread medicinal uses are as anthelmintic (fruits, seeds, and leaves), against fever and extreme uterine bleeding (leaves), to treat syphilis, rheumatism, hepatitis, and skin disorders, stomach and intestinal complaints (Hutchings et al. 1996). Other uses include abortifacient, lactogenic including veterinary (Geidam et al. 2004) and hypoglycemic (Hutchings et al. 1996) and in treating diabetes (Njoroge and Luijk 2004). The whole plant together with *Strophanthus*, is used in the preparation of an arrow poison in parts of Nigeria. In Hausa land of Nigeria and the Republic of Niger, the leaves are cooked as part of green vegetable soup for lactating mothers, where it is believed to help the mother to

regenerate her lost blood during labor and to purify her breast milk (Hassan and Umar 2006).

M. charantia. The immature and ripe fruits are cooked and eaten as vegetable in Asia and Africa. Extremely bitter forms are cooked in water and drained before seasoning. Bitterness may be reduced by parboiling or soaking in salt water. The unripe fruits are also used to prepare pickles and chips in India. Mature fruits are sliced cross sectionally and salted or blanched in salt water and sun dried for off-season use. The young non-bitter fruits are also used as salad in Zimbabwe. Young shoots and leaves are also cooked and eaten as vegetable in India and used as flavoring in Java and Philippines (Anonymous 1952). The growing tips of the vine and the young leaves are parboiled to remove much of the bitterness and then cooked with other vegetables and meat or fish (Barley 1894; Miller et al. 1946). Leaf and fruit extracts are used in the preparation of tea and is a popular health drink in Japan (Tindall 1983; Reyes et al. 1994). The sweet red arils are sucked from the seeds by children and adults (Morton 1962).

It has been used for centuries in ancient traditional Indian, Chinese, and African pharmacopoeia as anthelmintic, laxative, digestive stimulant, and to enhance appetite. In ayurveda, *M. charantia* is grouped under vegetable class of medicine and claimed to possess several therapeutic properties like regulation of digestion and metabolism, softening and clearing the motion, and improving digestion of sweet substances. It also cures fever, harmonizes enzymatic and related metabolic vitiations, is beneficial in anemia and diabetes/polyurea, and also relieves worms (Tiwari 2007). Whole plant, leaves, and especially fruits are used in folk medicine to treat diabetes in Asia (Perry 1980; Khajuria and Thomas 1993; Platel and Srinivasan 1995; Fernandopulle and Ratnasooriya 1996; Decker-Walters 1999), West Africa (Burkhill 1935), and even in the New World (Coe and Anderson 1996; Marr et al. 2004).

Lira and Caballero (2002) have reported the use of the feral wild-type as an aphrodisiac in Mexico. The fruit juice/leaf tea is used for sores and wounds, infections, worms, and parasites and for measles, hepatitis, and fevers. The plant is generally used as a hypoglycemic and anti-diabetic agent (Chen et al. 2003; Vikrant et al. 2001). In Mauritius, apart from its anti-diabetic properties, the oiled leaves are applied on the entire body to attenuate fever. The root decoction has abortifacient properties while the leaf and stem decoction is used against dysentery, rheumatism, and gout (Gurib-Fakim 1996). 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. 2008). The juice of the leaves and fruit is given as an anti-helmintic and the pulverized part is applied externally against malignant ulcers (Oliver 1960). Traditionally, wild bitter gourd (*M. charantia* var. *abbreviata*) leaves are crushed to obtain the juice for applying on the skin for treating insect bites, bee stings, burns, contact rashes, and wounds. Decoction of its leaves and fruits is drunk as preventative or treatment for stomachache, toothache, liver diseases, diabetes, hypertension, and cancer (Chiu and Chang 1995).

M. dioica. Tender fruits and deseeded fruits (both immature as well as ripe) are cooked as vegetable and also roasted and made into chutney with condiments and coconut. Ripe fruits are eaten raw and aril of ripe seeds are consumed as refreshment. Tender leaves, flowers, and tuberous root of female plants are also eaten. It is reported to possess hypoglycemic, hepatoprotective, gastroprotective and ulcer healing activities, analgesic, expectorant, post coital antifertility, nematocidal, antiallergic, antimalarial, antifeedant, antibacterial, and antifungal activities (Fernandopulle and Ratnasooriya 1996). Fruits contain aliphatic compounds and act as appetizer and astringent (Ali and Srivastava 1998). The whole plant is used for treatment of eye diseases, poisoning, and fever (Satyavati et al. 1987). Tubers are extensively used in treatment of intestinal ulcer, piles, and snake bite by the tribes of Kerala (Joseph and Antony 2008) and root paste of male creeper is applied on scorpion sting, snake bite, and rat bite in Rajasthan (Seliya and Patel 2009). The root is

also used to stop bleeding from piles, as an expectorant and also in urinary and bowel complaints (Kirtikar and Basu 1981). The fruits, leaves, and tuberous roots are used in India as a folk remedy for diabetes (Sadyojatha and Vaidya 1996). Tuberous roots are used for curing diarrhea, fever, and rheumatism by the tribals of Odisha and the seeds are used against chest problems and also to stimulate urinary discharge (Bharathi et al. 2007). Decoction of leaves reduces fever; tuberous roots help in relieving headache, excess sweating, stone formation, migraine; while fruit is quite helpful in controlling diabetes and blood pressure (Ram et al. 2001). Across the whole of south, central, and eastern part of India, it is a high value, tender fruit vegetable.

M. sahyadrica. Tender fruits are consumed as health food for asthmatic and intestinal ulcer patients. Tender leaves and shoots of male plants are cooked as a leafy vegetable and are recommended for pregnant women and anemic patients in the "Paniya" community of Wyanad. Use of tuber paste as detergent and toilet soap holds promise in the cosmetic and health care industry. The medicinal uses of *M. sahyadrica* are restricted to Malayarayar, Gowli, and Jain Kurbas, all forest dwelling and grazier tribes. Tuber paste is also used as anti-inflammatory medicine in mastitis of milking cows and treatment of painful eruptions, swellings and breast inflammations in humans. Tuber juice along with *Calotropis* leaves are used as abortifacient in early stages of pregnancy. For the people of Malanadu and Konkan, its fruits are auspicious during "Anantha Padmanabha Pooja"; a 'prasadam-curry or rasam' made of *M. sahyadrica* is served in Shimoga area. In Hassan district, a vegetable dish made of potato, chickpea, and *M. sahyadrica* is a must for 'Ganesha Pooja' celebrations. However, in spite of its extensive edible use as a high value vegetable, its cultivation is not encouraged in the Karnataka part of Western Ghats. The local people believe that its cultivation will bring misfortune to the grower. The taboos discouraging *M. sahyadrica* husbandry has deep roots in conservation ethics.

M. subangulata subsp. *renigera*. Unlike other *Momordica* species, *M. subangulata* subsp. *renigera* do not appear to have multiple ethnobotanical importance. In Malaysia, the fruit and foliage is consumed as vegetable. Uphof (1968) gives a small account of economic importance of *M. subangulata* in Southeast Asia and mentions the use of tender shoots, leaves, and unripe fruits as vegetable under the name "Kambur" in Indonesia. Tender fruits are consumed extensively as fresh vegetable in whole of northeastern and eastern India.

M. cochinchinensis. Traditionally, it has been used as both food and medicine in the regions in which it grows. The fruits are esteemed as the fruit from Heaven (Voung 2001) for its ability to promote longevity, vitality, and health. The ripe fruit arils are cooked with red glutinous rice called '*xoi gac*' to impart its color and flavor in Vietnam and Thailand. Traditionally, '*xoi gac*' is served at weddings, the New Year (Tet), and for other important celebrations (Do 1991). During these occasions, it is essential to mask the white color of rice, since white is considered as the color of death. A document on Vietnamese traditional medicine lists the use of the gac seed membrane, which contains β-carotene and lycopene, to treat infantile rachitis, xerophthalmia, and night blindness. The report notes that the oil extract from the seed membrane can be given to small children to improve growth (Vu 1986).

The tender fruits of the plant are esteemed as vegetable. Young leafy shoots are cooked and eaten in Bali and the Philippines (Anonymous 1952). Tribal settlers like Mundas, Toppo, Tirkey, and Minj of Andamans also use it extensively as a leafy vegetable. It is traditionally used for wound healing, to improve eye health and to promote normal growth in children. The seeds are known in Traditional Chinese Medicine (TCM) as "Mubiezi". It is reported to have resolvent and cooling properties, are used for treating liver and spleen disorders, chest complaints, abdominal pains, dysentery, wounds, hemorrhoids, bruises, swelling, and pus (De Shan et al. 2001) while in India the seeds are

used for treating anemia and arthritis (Nayak 1993).

M. cymbalaria. The fruits are used as a vegetable by the rural people of south Tamil Nadu (Sundararaj and Balasubramanyam 1959; Parvathi and Kumar 2002) and preserved in the form of sun dried chips or after pickling (Anonymous 1952). Tender fruits are used to prepare Kaasara fry, Varugulu, and pickles in Andhra Pradesh, India. It has been used in various Asian traditional systems of medicine for a long time. The plant is traditionally used as abortifacient (Nadkarni and Nadkarni 1982) and for the treatment of diabetes mellitus, rheumatism, ulcer, skin disease, and diarrhea (Jeyadevi et al. 2012; Prashantkumar and Vidyasagar 2006; Rajasab and Isaq 2004). It was reported to possess hypoglycemic (Rao et al. 2003), anti-implantation and anti-ovulatory (Koneri et al. 2006), antidiarrhoeal (Swamy et al. 2008), anticancer (Jeevanantham et al. 2011), anti-microbial (Sangeetha et al. 2010), hepatoprotective (Kumar et al. 2008), nephroprotective (Kumar et al. 2011), anti-ulcer (Bharathidasan et al. 2010), and anticonvulsant activity (Murthy et al. 2007). No information is available on the ethnic uses of *M. clarkeana, M. rumphii*, and *M. denticulata* in Southeast Asia.

Folk Taxonomy

Interpretation of vernacular names given to a plant/species can provide evidence for evaluating the human interaction with the plant. The literature survey reveals innumerable vernacular names for *Momordica* spp, in various Indian languages. However, wild species with narrow distribution range and rarity often do not figure in the vernacular dictionary or may have the same name as the comparatively better known relative. Nevertheless, local dialects may have some names specific to the user community that needs to be recorded for collection and ethnobotanical study of the target taxon. One of the priorities to be evaluated when looking at the viability of a new crop is its acceptability to the consumers. In the case of *Momordica* species, fruits are esteemed and relied upon resource in several areas of its distribution range. A perusal of the available literature reveals many vernacular names in various Indian languages (Table 5.1).

Nutritive Value

Diversified and highly nutritive vegetables are of great importance in alleviating hunger and malnutrition. A balanced diet should contain adequate energy, protein, carbohydrate, fats, minerals, essential amino acids, and vitamins. To understand the place of the genus *Momordica* in the human diet, it is necessary to know about their composition from the nutritional point of view. Based on the available literature, the nutrient composition of *Momordica* species is compiled and presented in Tables 5.2 and 5.3. From these tables can be seen a lot of variations in the chemical composition reported, which may be due to the fact that the composition is influenced by farming practices, prevailing environmental condition, and age of plants. In comparison with other crops like cereals, pulses, and animal products, vegetables especially cucurbitaceous vegetables are not good sources of energy in the human diet. The use of cucurbits as food plants is not primarily for calorie, mineral, or vitamin values as they are poor or only modest sources of these nutrients. They are all relatively low in food value especially in protein. However, there are few exceptions like bitter gourds richer in vitamin C, spine gourd (*M. dioica*) high in protein, and sweet gourd (*M. cochinchinensis*) containing high carotenoid and lycopene pigments.

Bitter gourd has a relatively high nutritional value compared to other Cucurbits, due mainly to the iron, phosphorus, and ascorbic acid content (Oliver 1960; Morton 1967) but poor source of vitamin A and calcium (Morton 1967). The ascorbic acid is retained by the green fruit during storage; if stored after ripening, considerable loss of ascorbic acid occurs. It retains its ascorbic acid for four weeks when refrigerated at 32–35 °C and 85–90 % relative humidity

Table 5.1 Vernacular names of wild *Momordica* spp. in India and SE Asia

SN	Accepted taxon name	Vernacular name	Language/area
1	*M. charantia* var. *muricata*	Mithipaval, Chinna paval	Tamil
		Chundappaval, Karandkappaval, Kattuppaval, Naippaval, Kundupavai, Nadanpaval, Kuttahippaval, Undappaval, Kaduhagalikkai, Jungle karela, Uchchhe, Oochya, Oochi	Malayalam
		Jangli karela	Bengali
		Gidda hagala	Hindi, Marathi
		Kadu hagali	Kannada
		Tulsi karela	Tulu
			Oriya
2	*M. charantia* var. *charantia*	Pavakkai, Pagel	Tamil
		Karela, Kash	Bengali
		Karela, Kareli	Hindi
		Halal	Kannada
		Kaippa, Kaippakka, Kaippavalli, Pavel, Pullayini, Rajavalli	Malayalam
		Karle	Marathi
		Karkotakee, Karavalli, Karavella, Karavellaka, Katika, Sushavi, Vishakantaki	Sanskrit
		Kakara kayi	
		Hagala kayi	Telugu
		Karathay	Kannada
			Konkan
3	*M. balsamina*	Mokha	Hindi
		Mokha	
		Garafuni	Arab
			Nigeria
4	*M. dioica*	Pazhupagel, Thulapava, Kuruvithalaipavai, Palupakkai	Tamil
		Akkarakka	Telugu
		Desi kankad	Oriya
		Kattupaval, Naipaval, Venpaval, Erumappaval, Kattu kappakka	Malayalam
		Karlikai	
		Kartoli	Kannada
		Vahisi	Marathi
		Kakrol	Sanskrit
		Karonda	Hindi
		Thumba-Karavila	Rajasthan
			Sinhala (Sri Lanka)
5	*M. sahyadrica*	Vaikka, Mada Hagalikka, Kadukovakka, Kattupaval, Pothupaval	Malayalam
		Madavala hagalikkai, Katteli, Madahagala, Mattahagala, Karayachakka, Akkachikka	Kannada
			Tulu

(continued)

Table 5.1 (continued)

SN	Accepted taxon name	Vernacular name	Language/area
6	*M. cochinchinensis*	Golkakra	Bengali
		Hathia kankad	Oriya
		Hathi karela	Assam
		Adavi kakrol, Crow cucumber	Telugu
		Jangli Kakrol	Andaman Islands
		Rajkangra	Tripura
		Gac	Vietnam
		Mu bie zi	China
		Terua	Malaya
		Makkao	Indochina
		Makubet sushi	Japan
7	*M. subangulata* subsp. *renigera*	Assam kankad/hybrid kankad	Oriya
		Bhat karela	Assam
		Lamkarote	Manipur
		Kangra	Tripura
		Maitamtok	Mizoram
		Meeta chottele	Nepal-Sikkim
		Kaksa	Bihar
		Kakrol, Kangra	Bengal, Tripura
		Karkul	Mizoram
		Gantola	Bangalore
		Yunnan mu	China
8	*M. subangulata* subsp *subangulata*	Phak mae, Phak Hai	Thailand
9	*M. cymbalaria*	Athalkkai	Tamil Nadu
		Karchikai	Karnataka
		Vasarakayee	Andhra Pradesh
10	*M. denudata*	Batu-Karavila	Sri Lanka

(Anonymous 1952). Drying in sun (green fruit slice) also leads to 80 % loss of ascorbic acid (Anonymous 1952) and cooking destroys 40–50 % (Miller et al. 1946; Anonymous 1952). The proximate analysis shows that the leaf and fruit of *M. charantia* are good sources of carbohydrate and protein; these may serve as sources of energy and nutrients for the body metabolic activities in addition to its medicinal properties (Bakare et al. 2010). The nutritional value of small bitter gourds (*M. charantia* var. *muricata*) is higher or at par in most of the components except phosphorus than that of large bitter gourds (*M. charantia* var. *charantia*). *M. charantia* is a good source of calcium and abundant calcium carbonate crystals in the form of cystoliths and pure crystals as calcium oxalate are found in every part of the plant (Chakravarty 1937). The leaves are a good source of calcium, carotene, riboflavin, and ascorbic acid (Anonymous 1952).

M. charantia var. *abbreviata* (synonymous to var. *muricata*) is reported to have potent antioxidant and free radical scavenging activities and its therapeutic benefits and bioactive compounds warrant further investigation (Semiz and Sen 2007; Wu and Ng 2008; Islam et al. 2011). Jittawan and Siriamornpun (2008) reported that

Table 5.2 Proximate composition of *Momordica* spp. (value per 100 g)

	Moisture (g)	Ash (g)	Fat (g)	Fiber (g)	Protein (g)	Carbohydrate (g)	Energy (K. Cal.)	Reference
M. charantia var. *muricata* (fruit)	83.20	–	1.00	1.70	2.10	10.60	60.00	Gopalan et al. (1982)
M. charantia var. *charantia* (fruit)	92.40	–	0.20	0.80	1.60	4.20	25.00	Gopalan et al. (1982)
M. charantia (boiled, drained, no salt)	93.95	–	0.18	2.0	0.84	4.32	19.00	USDA Nutrient database
M. balsamina (fruit)	89.40	–	0.10	1.80	2.00	5.10	–	Arnold et al. (1985)
M. balsamina (leaf)	89.40	–	0.10	0.90	3.00	3.60	–	Arnold et al. (1985)
M. balsamina (leaf)	85.00	–	0.50	2.75	5.00	6.82	–	Odhav et al. (2007)
M. dioica (fruit)	84.10	–	1.00	3.00	3.10	7.70	52.00	Gopalan et al. (1982)
M. s. subsp. *renigera* (fruit)	90.40		0.10	1.60	0.60	6.40	29.00	Gopalan et al. (1982)
M. cochinchinensis (fruit)	88.60	–	0.10	1.10	1.50	7.60	37.00	Gopalan et al. (1982)
M. cochinchinensis (fruit)	93.00	–	–	1.03	0.94	–	–	AVRDC (2002)
M. cymbalaria (fruit)	84.30	–	–	6.42	2.15	12.60	73.00	Parvathi and Kumar (2002)

leaf extract of bitter gourd showed the higher value of antioxidant activity based on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity and ferric reducing antioxidant power (FRAP), while the green fruit extract showed the highest value of antioxidant activity based on hydroxyl radical-scavenging activity, β-carotene–linoleate bleaching assay, and total antioxidant capacity. Seeds of bitter gourd also possess potent antioxidant activity, which may be directly or indirectly responsible for its hypoglycemic property (Sathishsekar and Subramanian 2005).

Bitter gourd flesh contains high lysine and relatively lower glutamic acid and arginine compared to soy protein isolate. In addition, essential amino acids, including threonine, valine, methionine, isoleucine, leucine, and phenylalanine are comparable in amount to soy proteins and other legume proteins (Islam et al. 2011). Hassan and Umar (2006) detected 17 amino acids with glutamic acid, leucine, and aspartic acid being the

Table 5.3 Mineral composition and vitamin content of *Momordica* spp. (value per 100 g)

	Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Iron (mg)	Zinc	Carotene (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Vitamin C (mg)	Reference
M. charantia var. *muricata* (fruit)	23.00	–	38.00	2.00	–	0.13	0.07	0.60	0.40	96.00	Gopalan et al. (1982)
M. charantia var. *charantia* (fruit)	20.00	–	70.00	1.80	–	0.13	0.07	0.90	0.50	88.00	Gopalan et al. (1982)
M. charantia (boiled, drained, no salt)	9.00	16.00	36.00	0.38	–	6 (μg vitamin A equiv.)	0.05	0.05	0.28	33.00	USDA Nutrient database
M. balsamina (fruit)	35.90	41.20	35.80	2.60	1.00	–	0.04	0.06	–	0.50	Arnold et al. (1985)
M. balsamina (leaf)	340.00	87.10	27.70	12.70	0.90	–	0.01	0.09	0.70	0.40	Arnold et al. (1985)
M. balsamina (leaf)	2688.00	613.00	356.00	23.00	12.00	–	–	–	–	–	Odhav et al. (2007)
M. dioica (fruit)	33.00	–	42.00	4.60	–	1620 (IU)	0.05	0.10	0.60	–	Gopalan et al. (1982)
M. s. subsp. *renigera* (fruit)	27.00	–	38.00	–	–	–	–	–	–	–	Gopalan et al. (1982)
M. cochinchinensis (fruit)	64.00	–	89.00	–	–	–	–	–	–	–	Gopalan et al. (1982)
M. cochinchinensis (fruit)	23.00	–	–	0.34	–	91	–	–	–	–	AVRDC (2002)
M. cymbalaria (fruit)	72.00	–	0.46	1.70	2.82	0.01	–	–	–	290.00	Parvathi and Kumar (2002)

Fig. 5.1 Ripe fruits of *M. cochinchinensis*

predominant amino acids. Isoleucine, leucine, valine, and aromatic acids were found to be higher than the WHO/FAO/UNU (1985) requirement pattern for children, while sulfur containing amino acids are the only limiting amino acids for adults. Bitter melon contained 17 amino acids at satisfactory levels, except cysteine and methionine and this crop could be a very good source in the production of arginine, alanine, gamma amino butyric acid (GABA), and other amino acids found in high concentrations, on a commercial basis (Kim et al. 2011).

Crude fiber decreases the absorption of cholesterol from the gut and also delays conversion of starch into sugars and such attributes would be desirable for the diabetic and the higher crude fiber content of *M. cymbalaria* which is a desirable attribute (Parvathi and Kumar 2002). Calcium is required for growth of bones and teeth as well as for maintaining normal heart rhythm, blood coagulation, muscle contraction, and nerve responses and ascorbic acid is important in immune response, wound healing, and allergic reactions. The higher content of calcium, potassium, and ascorbic acid in *M. cymbalaria* may be exploited and used for health benefits (Parvathi and Kumar 2002).

M. dioica has medium protein value (19.38 mg/g), fat (4.7 mg/g) and phenolic compounds (3.69 mg/g) and have maximum calorie value (4125/83 kcal/Kg) when compared to eight traditional wild vegetables of Indo-Persian region (Ali and Deokule 2009) and could be a good supplement for nutrients such as fiber, potassium, zinc, lipid, protein, and carbohydrates (Ali 2010, 2011a). Plant foods that provide more than 12 % of their calorific value from protein are a good source of protein (Pearson 1976) and in this context, *M. dioica* fruits are good sources of protein (Ali 2011b). *M. dioica* is also suitable for high temperature food processes, because it has very low free sugar concentrations, thereby reducing the possibility of Maillard reaction and subsequent acrylamide formation (Ali and Deokule 2010). Teasel gourd is rich in carotene, protein, carbohydrate (Rashid 1993), and vitamin C (154.7 mg/100 g of edible portion) (Bhuiya et al. 1977). *M. sahyadrica* being a recently established taxonomic entity, reliable estimate of its nutritional contents are not available. However, being closely related to *M. dioica*, it can be reasonably inferred to be similar to it.

Vegetables do not contain vitamin A but have carotenoids with active ingredient carotene, mostly β-carotene, a precursor of vitamin A, also known as pro-vitamin A. Vitamin A deficiency (VAD) causes loss of vision, night blindness, and damages eye cornea leading to total blindness. The ripe fruit of *M. cochinchinensis* (Fig. 5.1) is becoming known as a premier source of carotenoids and its aril was extensively studied for β-carotene and lycopene. The aril contains β-carotene and lycopene at very high levels, with those of lycopene being up to 308 μg/g in the seed membrane, about 10-fold higher than in other

lycopene-rich fruits and vegetables (Vuong 2001; Aoki et al. 2002; Vuong et al. 2003, 2006). Aril tissues contained 2,227 μg total lycopene and 825 μg total carotenoids (718 μg of total β-carotene and 107 μg α-carotene/g FW). The aril also contains 102 mg oil/g of fruit weight (Voung 2001) and of the total fatty acids in sweet gourd aril, 69 % are unsaturated and 35 % of these are polyunsaturated (Voung and King 2003). Oil extracted from the fruit aril showed a total carotenoid concentration of 5,700 μg/ml, with 2,710 μg of that being β-carotene. This oil also included high levels of vitamin E (Vuong and King 2003; Kuhnlein 2004). The fatty acids in the aril are important for the absorption of fat-soluble nutrients including carotenoids in a diet typically low in fat (Kuhnlein 2004; Vuong 2001). Thus, *M. cochinchinensis* provides an acceptable source of high levels of valuable antioxidants that have good bioavailability. However, these studies have been conducted in ripe fruits of *M. cochinchinensis* and the nutrient content of tender fruit is least studied. Apart from *M. cochinchinensis* arils of other *Momordica* species (except *M. cymbalaria*) are also bright red in color and may contain high levels of lycopene and β-carotene. For example, bitter gourd contains bright red seeds due to high lycopene, a pigment that can be used as an artificial food colorant (Yen and Hwang 1985). However, the yield of arils/fruit is much higher in *M. cochinchinensis* and extraction may be economically feasible.

Pre-school children up to 4 years of age and pregnant mothers are the most affected by VAD. Nutritional supplementation trials in Vietnam have shown that children fed with '*xoi gac*' (rice cooked with fruit pulp of *M. cochinchinensis*, popularly called *gac*) have significantly higher plasma β-carotene, compared to those who received synthetic β-carotene powder or none (control). Increases in plasma retinol, α-carotene, zeaxanthin, and lycopene levels were also significantly greater in children fed with gac (Vuong et al. 2003). It is likely that the fatty acids in gac are what make its β-carotene more bioavailable than that of the synthetic form (Vuong et al. 2003).

The leaves of *M. balsamina* are a popular vegetable, consumed regularly in the eastern parts of South Africa (Fox and Young 1982; Van Wyk and Gericke 2000; Hart and Vorster 2006; Jansen van Rensburg et al. 2007; Odhav et al. 2007). The ash content, which is an index of mineral contents in biota, is high (18.00 ± 0.56 % DW) in leaves which indicates *M. balsamina* leaves could be good sources of mineral elements and could be a good supplement for some mineral elements particularly K, Ca, Mg, Fe, Cu, and Mn when compared with RDA values (Hassan and Umar 2006). Odhav et al. (2007) also recommended the commercial cultivation of *M. balsamina* as the mineral content is much higher than typical mineral concentrations in conventional edible leafy vegetables. *M. balsamina* leaves can provide 20–33 %, 59–87 %, 16 %, 16 % of protein, 31 %, 31 %, 23 %, 19 % of carbohydrate to daily requirement of adults, children, pregnant, and lactating mothers respectively (Hassan and Umar 2006). These results show that *M. balsamina* leaves could be important green leafy vegetables as a source of nutrients to supplement other major sources. However, chemical analysis alone should not be the sole criteria for judging the nutritional importance of a plant's parts. It is imperative to consider other aspects such as presence of anti-nutritional/toxicological factors and biological evaluation of nutrients' form, content, availability, and utilization. However, research efforts in these areas are rather meager. Wild vegetables like *M. balsamina* leaves could be promoted as a protein supplement for cereal-based diets in poor rural communities, while its high potassium content can be utilized for the management of hypertension and other cardiovascular conditions. The relatively high concentrations of zinc, iron, and manganese could contribute toward combating the problem of micronutrient deficiencies (Flyman and Afolayan 2007). In addition to its nutritive value, *M. balsamina* has efficient free radical scavengers (94 % inhibited) and could potentially be exploited as sources of antioxidants (Odhav et al. 2007).

Other Phytochemicals

A number of phytochemicals of potential medical components have been isolated from *M. charantia*, like the ribosome inactivating protein (RIP), MAP30 (*Momordica* anti-HIV protein), which suppresses HIV (human immunodeficiency virus) activity, *M. charantia* lectin (MCL), *M. charantia* inhibitor (MCI), and momordicoside A and B, both of which can inhibit tumor (Lee-Huang et al. 1990; Bourinbaiar and Lee-Huang 1996; Beloin et al. 2005). Lee-Huang et al. (1995) cloned *Map30* gene and used to express biologically active re-MAP 30 which exhibited anti-HIV and anti-tumor activities from bitter gourd. *Momordica* fruit contains steroids, charantin, momordicosides (G, F1, F2, I, K, L), acyl glucosyl sterols, linolenoyl glucopyranosyl elenosterol, amino acids, fatty acids, and phenolic compounds. The phytochemicals isolated from the whole plant, vines, or leaves include saponins, sterols, steroidal glycosides, alkaloids, amino acids, and proteins (Raman and Lau 1996). Phytochemicals of pharmaceutical importance like momordicin II (ribosome inactivating protein) and rosmaric acid (caffeic acid ester) have been isolated from *M. balsamina* (Bosch 2004) and phytochemical screening of its leaves revealed the presence of tannins, saponins, and lectins (Akinniyi et al. 1983). Lectins, β-sitosterol, saponin glycosides, triterpenes of ursolic acid, hederagenin, oleanolic acid, α-spiranosterol, stearic acid, gypsogenin, momodicaursenol, and some aliphatic constituents were isolated from different parts of *M. dioica* (Ghosh et al. 1981; Sadyojatha and Vaidya 1996; Ali and Srivastava 1998 and Luo et al. 1998).

Charantin, a typical cucurbitane-type triterpenoid obtained from *M. charantia* is a potential substance with antidiabetic properties (Krawinkel and Keding 2006) and demonstrated to treat diabetes and can potentially replace treatment (Pitiphanpong et al. 2007). It was identified by Lolitkar and Rao (1960) who showed that when charantin is taken orally or intravenously in rabbits, it produces hypoglycemic effects (Lolitkar and Rao 1966). This compound is a mixture of two compounds (1:1), namely, β-sitosteryl glucoside ($C_{35}H_{60}O_6$) and 5,25-stigmasteryl glucoside ($C_{35}H_{58}O_6$). A number of patents have been submitted on activities and processes of *Momordica* spp. for insulin-type properties. Cochinin B, a novel ribosome-inactivating protein (RIP) is purified from the seeds of *M. cochinchinensis* (Chuethong et al. 2007) manifested strong anti-tumor activities. Wong et al. (2004) isolated five trypsin inhibitors, exhibiting a molecular weight of 5100, 4800, 4400, 4100, and 3900, respectively, from seeds of *Momordica cochinchinensis* differing in specific trypsin-inhibitory activity.

Postharvest research leading to product utilization as nutraceuticals and nutritional supplements needs attention. While *M. cochinchinensis* is reported to be the richest source of β-carotene and is shown to play a big role in alleviating vitamin A deficiency in tropical countries, there is no concerted effort on its development. Other species of Asian *Momordica* including bitter gourd offer high potential for developing vitamin A supplements from seed aril and fruit pulp. Use of wild species as leafy vegetables is reported from Asia and Africa. *M. balsamina* is one of the most nutritious leafy vegetables in Africa. Similary, *M. subangulata* and *M. cochinchinensis* are used extensively in Asia as a leafy vegetable. They need to be studied for popularization and use as leafy vegetable crops. There is an export market demand for *M. cochinchinensis* and other Asian *Momordica* from ethnic communities living outside Asia. Postharvest processing and export open up avenues for more income generation in India, Vietnam, Sri Lanka, and other SE Asian countries.

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Cytogenetics and Genetics

6

Abstract

Chromosome size was found to be considerably uniform between the monoecious and dioecious group except *M. subangulata* subsp. *renigera* and *M. cymbalaria*. High numbers of submedian to nearly terminal chromosomes were observed in *M. subangulata* subsp. *renigera* which might be due to breakage and reunion of metacentric chromosomes and their duplication in the natural process of evolution. *M. cymbalaria* (sect. *Raphanocarpus*) diverged from the other two sections of *Momordica* occurring in Asia some 30 million years ago and hence the cytological differences. Among all the possible cross combinations, only two viz., *M. charantia* × *M. balsamina* and *M. dioica* × *M. sahyadrica*, produced fertile hybrids. Complete cross incompatibility was observed between the monoecious and dioecious species while partial to complete compatibility was observed within the groups (monoecious and dioecious). Based on the evaluation of hybrid progeny between *M. dioica* and *M. sahyadrica* it seems that *M. sahyadrica* is more advanced and might have evolved from *M. dioica* in the Western Ghats and may be considered as neo-endemic. Studies on the inheritance of some qualitative traits in bitter gourd revealed that, green fruit skin colour is monogenically dominant over the white fruit colour (*w*); the dark brown seed coat colour is dominant over the light brown seed (*lbs*) coat colour in a monogenic inheritance; the small seed is completely dominant over the large size seed where one pair of genes is involved. Yield per plant had high positive and high significant correlation with the number of fruits per plant, number of nodes per vine, fruit weight, fruit length and number of flowers per plant. This chapter attempts to cover the cytogenetics and evolutionary relation among the species and genetics of different characters.

Keywords

Gene effect · Inheritance · Cytogenetics · Interspecific hybridisation · Evolution

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Cytogenetics

Information about cytological and cytogenetic aspects can help in the transfer of desirable traits from related wild species to the cultivated species. *Momordica* species are not easily amenable to cytological analysis as the chromosomes are very small and do not stain well (Bhaduri and Bose 1947) vis-a-vis the cytoplasm (Trivedi and Roy 1972). Cytologically, the genus has not received much attention and a comprehensive account is lacking. In the literature, the chromosome number of one species of *Momordica* is ascribed to that of another due to taxonomic misidentification of the studied species.

The *Momordica* species are a difficult group for cytogenetic investigations because of the following reasons:

1. The chromosomes are relatively small, are usually not well separated from each other and do not stain well (Roy et al. 1966; Bhaduri and Bose 1947).
2. Pollen mother cells of these species are not amenable for manipulation using conventional cytological techniques. Cytoplasm also takes stain and it is very difficult to differentiate the chromosomes from the cytoplasm (Trivedi and Roy 1972).
3. Root tips are convenient to study the somatic chromosome. But in dioecious *Momordica* spp. seed germination is very poor and the method to break dormancy is not yet standardised.

Yet in spite of these handicaps, some data on cytogenetics have been generated for all the *Momordica* species occurring in India.

The Tools

This section briefly describes the various techniques used in the chromosome analysis of species and their hybrids (Table 6.1). Root meristems are commonly used to study the somatic chromosomes as they are devoid of chloroplasts (Roy et al. 1966; Trivedi and Roy 1972; Sinha et al. 1997; Bharathi et al. 2011a). In dioecious wild species where seed germination is poor, tendril tips have also been used to study the somatic chromosomes (Agarwal and Roy 1976; Sinha et al. 1996). Chemicals were mostly used to pretreat the root tips and cold water (4 °C) was rarely used for pretreatment (Bharathi et al. 2011a). In many flowering plants, particularly where the chromosomes are small like *Momordica* spp., the cytoplasm also takes up much of the stain (Trivedi and Roy 1972) due to high cytoplasmic contents. A prior fixation reduces the staining of cytoplasm (McClintok 1929) and a 1:3 (acetic acid:ethanol) mixture is commonly used as fixative (Beevy and Kuriachan 1996; Roy et al. 1966; Trivedi and Roy 1972; Sinha et al. 1997; Richharia and Ghosh 1953; Jha et al. 1989; Bharathi et al. 2011a) for a period of 12–48 h. A combination iron–mordant fixative like ferric chloride (Roy et al. 1966; Trivedi and Roy 1972; Agarwal and Roy 1976) and 4 % iron alum (Richharia and Ghosh 1953) has been found useful in preparing small plant chromosomes for carmine stained squashes. Cytomolecular assays such as flurochrome staining techniques and Fluorescent in situ Hybridisation (FISH) with rDNA were proved to be useful to amplify karyotype definition and increase cytogenetic information in chromosomes of *Momordica charantia* (Lombello and Pinto-Magilo 2007).

The *Momordica* Genome

The chromosome number of a species is a valuable parameter in biosystematics study owing to its implications in phylogeny and evolution (Steussy 1990). The genus *Momordica* is considered to be dibasic with $x = 11$ and 14 (Coleman 1982; Beevy and Kuriachan 1996). However, *M. cymbalaria* has basic chromosome number of 9 (Bharathi et al. 2011a). *M. cymbalaria* belong to the section Raphanocarpus which diverged from the other two sections of *Momordica* occurring in Asia some 30 million years ago and may be the reason for the cytological differences (Schaefer and Renner 2010).

Table 6.1 Cytological methods used in *Momordica* spp.

Pretreatment	Fixative	Hydrolysis	Stain	Reference
Mitosis				
Alpha bromo naphthalene for 25 min	1:3 (acetic acid:ethanol)	–	Warmed in acetocarmine	Roy et al. (1966)
Paradichlorobenzene for 4 h at 10–15 °C	1:3 (acetic acid:ethanol)	5N HCl at 10 °C for 15 min	2 % aceto orcein overnight	Sinha et al. (1996)
Paradichlorobenzene for 4 h at 10–15 °C	1:3 (acetic acid:ethanol)	5N HCl for 14–15 min	2 % aceto orcein overnight	Sinha et al. (1997)
Paradichlorobenzene	Carnoy's fluid	–	1 % aceto carmine	Agarwal and Roy (1976)
Alpha bromo naphthalene for 25 min	1:3 (acetic acid:ethanol)	–	Aceto carmine	Trivedi and Roy (1972)
Cold water at 4 °C for 12 h	1:3 (acetic acid:ethanol)	1N HCl at 60 °C for 12 min	Fuelgen for 2–3 h	Bharathi et al. (2011a)
Half-saturated p-dichlorobenzene and asculine mixture for 3 h at 18 °C	1:3 (propionic acid:ethanol)	5N HCl at 4 °C for 6 min	2 % propionic orcein	Bharathi et al. (2011b)
Meiosis				
–	1:3 (acetic acid:ethanol)	–	Squashed in aceto carmine	Roy et al. (1966)
–	1:3 (acetic acid:ethanol)	–	Smeared in aceto carmine	Richharia and Ghosh (1953)
–	1:3 (acetic acid:ethanol)	–	Squashed in aceto carmine	Trivedi and Roy (1972)
–	1:3 (propionic acid:ethanol)	1N HCl at 60 °C for 10 min	Fuelgen for 2–3 h	Bharathi et al. (2011a)

Table 6.2 Chromosome numbers, ploidy, breeding system, perenniality of *Momordica* spp.

Species	2*n*	Ploidy	Breeding system	Habit
Momordica balsamina	22	2x	M	A
M. charantia	22	2x	M	A
	33	3x	M	–
M. cymbalaria	18	2x	M	P
M. cohinchinensis	28	2x	D	P
M. dioica	28	2x	D	P
	42	3x	D	P
M. subangulata subsp. *renigera*	56	4x	D	P
M. sahyadrica	28	2x	D	P

M monoecious, *D* dioecious, *A* annual, *P* perennial

The chromosome number is $2n = 2x = 22$ (Table 6.2; Fig. 6.1) for *M. charantia* and *M. balsamina* (McKay 1930; Whitaker 1933; Bhaduri and Bose 1947; Roy et al. 1966; Trivedi and Roy 1972; Varghese 1973; Sen and Dutta 1975; Bharathi et al. 2011a); $2n = 2x = 28$ for *M. cochinchinensis, M. dioica* and *M. sahyadrica* (Jha et al. 1989; Richharia and Ghosh 1953; Bharathi et al. 2011a).

Chromosome number of $2n = 4x = 56$ was reported in *M. subangulata* subsp. *renigera* (Bharathi et al. 2011a) in contrast to the report $2n = 28$ (Sarkar and Majumdar 1993). The chromosome number of the cultivated teasel gourd (*M. dioica*) from Tripura and Bangladesh was reported as $2n = 4x = 56$ (Sinha et al. 1997; Cho et al. 2006). However, field and herbarium studies conducted on teasel gourd (Bhat karela, Assam kakrol) indicate that the

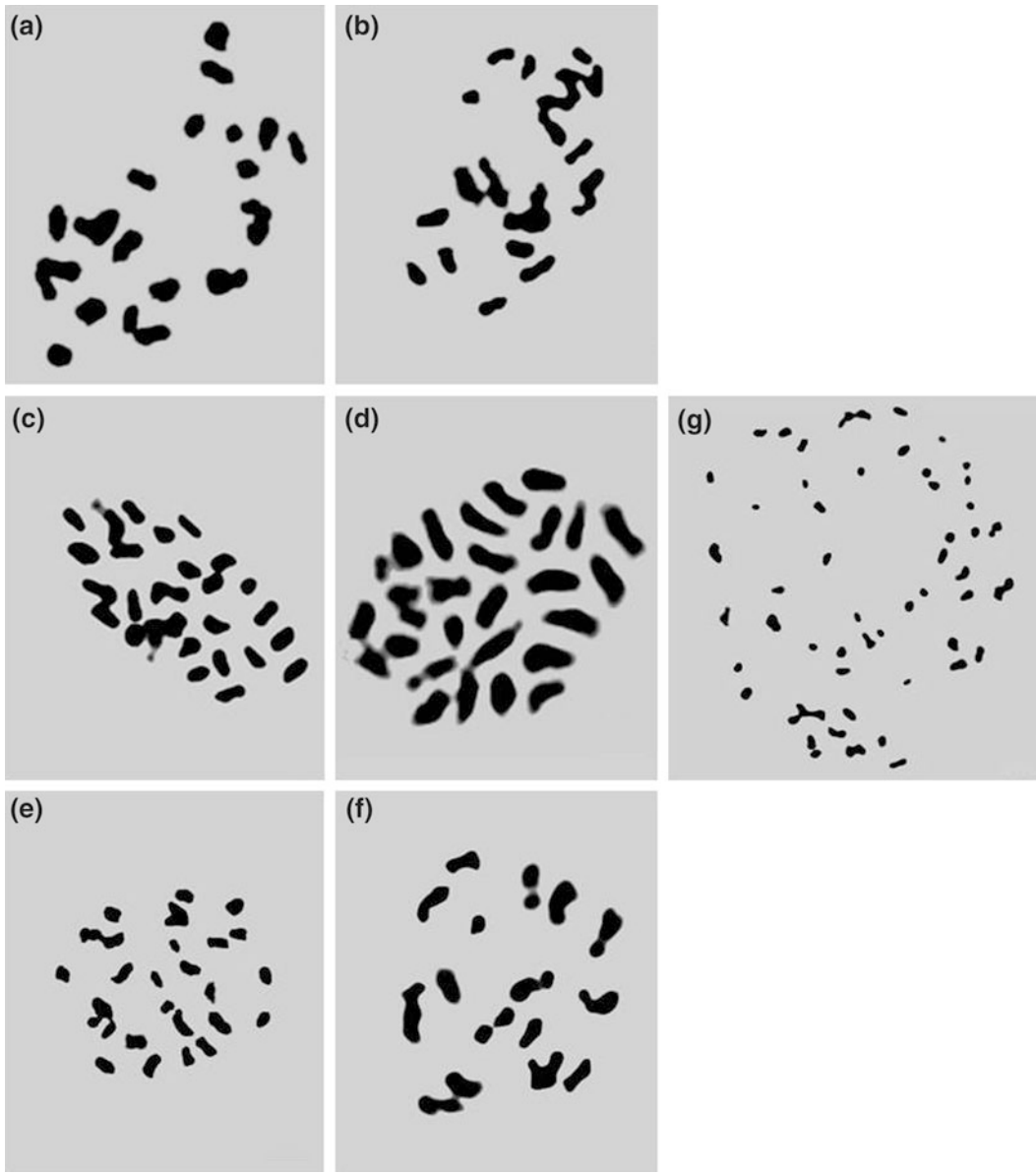

Fig. 6.1 Mitotic metaphase chromosomes of *Momordica* spp. **a** *M. charantia* ($2n = 22$) **b** *M. balsamina* ($2n = 22$) **c** *M. dioica* ($2n = 28$) **d** *M. sahyadrica* ($2n = 28$) **e** *M. cochinchinensis* ($2n = 28$) **f** *M. cymbalaria* ($2n = 18$) **g** *M. subangulata* subsp. *renigera* ($2n = 56$) (*Source* Bharathi 2010)

cultivated dioecious *Momordica* specimen of north-east India is actually *M. subangulata* subsp. *renigera* and not *M. dioica* (Joseph et al. 2007). Hence, reports by Sinha et al. (1997) and Cho et al. (2006) of $2n = 4x = 56$ deserve to be ascribed to *M. subangulata* subsp. *renigera* and not to *M. dioica*. In a recent study, Bharathi et al. (2011a) reported $2n = 18$ in *M. cymbalaria* in contrast to earlier reports of $2n = 22$ (Beevy and Kuriachan 1996) and $2n = 16$ (Mehetre and Thombre 1980). In meiotic studies at diakinesis/metaphase I regular formation of 11 bivalents and regular anaphase I with equal segregation of 11 chromosomes to each pole have been noticed

in *M. charantia* and *M. balsamina* (Roy et al. 1966; Trivedi and Roy 1972; Sen and Dutta 1975; Jha and Trivedi 1989); 14 chromosomes to each pole in *M. dioica* (Richharia and Ghosh 1953; Jha and Trivedi 1989; Trivedi and Roy 1972; Bharathi et al. 2011a) and in *M. cochinchinensis* (Sen and Dutta 1975; Bharathi et al. 2011a).

Cultivated bitter gourd is a diploid ($2n = 22$) species, but natural triploid ($2n = 33$) has also been discovered from Sikkim (Pandey and Saran 1987). Synthetic tetraploid had also been induced by colchicine treatment of germinating seedling (Roy et al. 1966) which are characterised by irregular meiosis and do not show much advantage over the diploid form in economic characters such as fruit size, number of fruits per plant, etc. Naturally occurring tetraploid and triploid forms of *M. dioica* (Agarwal and Roy 1976) have also been recorded and characterised. But the tetraploid mentioned by them does not seem to be *M. dioica* but in all probability is *M. subangulata* subsp. *renigera* (Bharathi et al. 2011a). During meiosis, the tetraploid species (*M. subangulata* subsp. *renigera*) showed the presence of uni-, bi-, tri- and quadrivalents with preponderance of bivalents and occasional presence of 28 bivalents in some pollen mother cells (PMC's) (Sinha et al. 1997; Bharathi et al. 2010a, 2011a). The meiosis was highly irregular in a natural triploid *M. dioica* (Agarwal and Roy 1976); in artificially induced colchiploid *M. charantia* (Roy et al. 1966) and artificial triploids of *M. dioica* × *M. subangulata* subsp. *renigera* and *M. cochinchinensis* × *M. subangulata* subsp. *renigera* (Bharathi et al. 2010b).

Karyotype

Chromosome size was found to be considerably uniform for the annual monoecious and perennial dioecious group with the exception of *M. cymbalaria*. Polyploidy is observed in *M. subangulata* subsp. *renigera* (Table 6.3) which had more condensed chromosomes than those of the presumed parental diploids (*M. dioica* and *M. cochinchinensis*). The average chromosome length and volume was minimum (0.93 μm and 0.48 μm^3, respectively) in the tetraploid species *M. subangulata* subsp. *renigera* and maximum (2.62 μm) was found in *M. cymbalaria* (Bharathi et al. 2011a). One pair of satellite (SAT) chromosome was observed in *M. charantia* (Bhaduri and Bose 1947; Bharathi et al. 2011a) and *M. balsamina* (Bharathi et al. 2011a).

M. dioica, a perennial dioecious species, differs from *M. charantia* and *M. balsamina* in chromosome number as well as through its markedly asymmetrical karyotype (Roy et al. 1966; Trivedi and Roy 1972). One heteromorphic bivalent was reported in *M. dioica* (Richharia and Ghosh 1953) but, later studies (Roy et al. 1966; Agarwal and Roy 1976; Jha 1990; Sarkar and Majumdar 1993; Bharathi 2010) failed to establish any chromosomal heteromorphy for sex. Sex mechanism in *M. dioica* does not follow the X/Y chromosomal basis, rather the sex genes are located on autosomes (Jha 1990). One pair of SAT chromosomes was observed in *M. dioica*, *M. sahyadrica*, *M. cochinchinensis* (Bharathi et al. 2011a) and two pairs in *M. subangulata* subsp. *renigera* (Sinha et al. 1997; Bharathi et al. 2011a).

High numbers of submedian to nearly terminal chromosomes were observed in *M. subangulata* subsp. *renigera* which might be due to breakage and reunion of metacentric chromosomes and their duplication in the natural process of evolution (Bharathi et al. 2011a). Artificial triploid hybrids were produced by crossing *M. dioica* and *M. cochinchinensis* with *M. subangulata* subsp. *renigera* and karyotype analysis of F_1 hybrids and the parents revealed that, F_1 is a triploid with 42 chromosomes (Bharathi et al. 2010a, 2011b). The DNA contents were estimated only in two species of which *M. cochinchinensis* contains 6.76 pg and *M. subangulata* subsp. *renigera* contains 12.95 pg. No positive linear relation could be established between the amount of DNA and the total chromosome length (Sinha et al. 1996, 1997).

Table 6.3 Karyotype data of different species of *Momordica*

Species	Karyotype formula	Total chromosome length (μ)	Form (%)	Reference
M. charantia	4M + 7SM[a]	37.42	43.02	Trivedi and Roy (1972)
	2A + 8B + 12C[b]	29.04 ± 0.78	40.21	Bharathi et al. (2011a)
M. balsamina	5M + 6SM[a]	35.72	45.15	Trivedi and Roy (1972)
	2A + 10B + 10C[b]	28.61 ± 1.25	38.55	Bharathi et al. (2011a)
M. cymbalaria	2A + 12B + 4C[b]	50.00 ± 1.45	42.89	Bharathi et al. (2011a)
M. dioica	3M + 11SM[a]	48.68	41.82	Trivedi and Roy (1972)
	2A + 16B + 10C[b]	38.53 ± 0.95	43.88	Bharathi et al. (2011a)
M. sahyadrica	2A + 18B + 8C[b]	37.53 ± 0.35	44.42	Bharathi et al. (2011a)
M. cochinchinensis	2A + 14B + 12C[b]	46.05 ± 1.15	42.56	Bharathi et al. (2011a)
Male	2A + 20B + 6C[c]	41.60 ± 0.30	41.70	Sinha et al. (1996)
Female	2A + 22B + 4C[c]	41.80 ± 0.50	41.40	Sinha et al. (1996)
M. subangulata subsp. *renigera*	4A + 14B + 38C[b]	51.88 ± 1.40	32.26	Bharathi et al. (2011a)
Male	4A + 46B + 6C[c]	77.53 ± 0.61	43.13	Sinha et al. (1997)
Female	4A + 46B + 6C[c]	78.28 ± 0.60	43.17	Sinha et al. (1997)
F1 (*M. dioica* × *M. subangulata* subsp. *renigera*)	4A + 20B + 18C	42.05 ± 1.25	35.42	Bharathi et al. (2011b)

[a] *M* Chromosomes with metacentric primary constriction, *SM* Chromosomes with submetacentric primary constriction
[b] *A* Chromosomes are medium sized with two constrictions in nearly median to median and nearly submedian to submedian in position, respectively, *B* Medium to small-sized chromosomes with nearly median to median primary constrictions, *C* Chromosomes are medium to small chromosomes with submedian to nearly terminal primary constrictions
[c] *A* Short chromosomes with two constrictions, both are submedian in position, *B* Short chromosomes with median and nearly median constriction, *C* Short chromosomes with nearly submedian constriction

Interspecific Hybridisation

Within monoecious species. Experimental hybridisation between the varieties resulted in high fruit and seed set (Agarwal et al. 1957; Roy et al. 1966; Joseph 2005; Bharathi et al. 2012a). However, the F_1 hybrid showed a reduction in fruit size (Joseph 2005; Behera et al. 2010, 2011). Hybrid seeds were apparently much more difficult to obtain between *M. charantia* × *M. balsamina* and the F_1 hybrid showed a high bivalent frequency, normal meiotic cycle and high fertility in the F_1 hybrids (Singh 1990; Bharathi et al. 2012a). However, complete crossability failure between *M. charantia* and *M. balsamina* has also been reported (Roy et al. 1966; Joseph 2005). In higher plants, post-zygotic failure of hybrid embryos was often not due to incompatibility between the parental

chromosomes, but because of incompatibility problems in the endosperm. From the breeding point of view, the barriers appear to be post zygotic and methods liken embryo rescue may be employed to rescue the hybrids for further evaluation.

Within dioecious species. In recent years, crosses among *M. dioica*, *M. cochinchinensis* and *M. subangulata* subsp. *renigera* have been used both to explore the evolutionary history and for improvement. F_1 hybrids have been developed with the aim of combining the quality traits and agronomic characters of *M. dioica* and *M. subangulata* subsp. *renigera* (Mohanty et al. 1994; Bharathi et al. 2011b), but F_1 hybrid was highly sterile. However, after a number of pollinations (>1000), a backcross generation was produced following *M. subangulata* subsp. *renigera* pollination and from these second generation backcross plants were developed and are being evaluated (Bharathi et al. 2012b). Bharathi et al. (2010b, 2011a) obtained successful hybrids between *M. cochinchinensis* and *M. subangulata* subsp. *renigera* while Mondal et al. (2006) reported complete incompatibility between these two species. *M. sahyadrica*, being a recently described entity, very less hybridisation work has been carried out with other *Momordica* spp. Fertile interspecific hybrids were obtained with the use of *M. dioica* (Joseph 2005; Bharathi et al. 2012a) indicating the possibility for improvement of *M. dioica* through interspecific hybridisation especially for fruit fly resistance.

Between monoecious and dioecious species. There have been few attempts at inter-specific crosses between *M. charantia* and *M dioica*, the bitterless, small fruited, tuberous perennial to explore possibilities of transferring desirable attributes of the latter (especially the 'bitterless' trait) to the former but none succeeded so far (Roy et al. 1966; Joseph 2005; Bharathi et al. 2012a). Later studies on the reasons for incompatibility indicated poor pollen germination and growth of pollen tubes stopped in the upper part of the style and it did not reach the embryo sac to complete fertilisation (Trivedi and Roy 1972) and abnormal behaviour of pollen tubes and heavy deposition of callose at their tips which obstructed transfer of male gamete and fertilisation (Dutt and Pandey 1983; Hoque et al. 2003). In spite of the fact that most of the reports revealed complete incompatibility, successful inter-specific hybrid between *M. charantia* and *M. dioica* was also reported and the F_1 hybrid was reported to have more resemblance with *M. charantia* (Anonymous 2004). Vahab and Peter (1993) reported high fruit set (>90 %) in the cross *M. charantia* × *M. dioica* and non-synchronisation of anthesis was the reason stated for failure of fruit set in earlier studies.

Bharathi et al. (2012a) reported five major patterns of crossing behaviour among the *Momordica* species of Indian occurrence viz.

(i) cross-compatibility with fertile hybrids: between two varieties of *M. charantia* (var. *charantia* and var. *muricata*), also between *M. dioica* and *M. sahyadrica*;
(ii) partial cross-compatibility with fertile hybrids: between *M. charantia* and *M. balsamina*;
(iii) cross-compatibility with sterile hybrid: between *M. subangulata* subsp. *renigera* and *M. dioica*, *M. subangulata* subsp. *renigera* and *M sahyadrica*, *M. subangulata* subsp. *renigera* and *M. cochinchinensis*;
(iv) partial cross-compatibility with sterile hybrids: between *M. cochinchinensis* and *M. dioica*, *M. cochinchinensis* and *M. sahyadrica*
(v) cross-incompatibility: between monoecious and dioecious species.

Genetics

The large field space requirements for cucurbits and the need for laborious hand pollinations for selfing and crossing cucurbits have been constraints for genetic investigations (Robinson and Decker-Walters 1997). Moreover, the genus *Momordica* was not given due attention earlier consequently, very little work of this nature has been reported in the genus *Momordica*. Table 6.4 summarises some of the studies used for assigning gene symbols for few characters by the Committee of the Cucurbit Genetics

Table 6.4 Genes in *Momordica*

Character	Gene symbol	Reference
Gynoecious sex: recessive gene for high degree of pistillate sex expression from Gy263B (100 % gynoecious line)	*gy-1*	Ram et al. (2006), Behera et al. (2009)
Light brown seed: recessive to dark brown	*lbs*	Srivastava and Nath (1972), Ram et al. (2006), Kole et al. (2012)
Large seed: recessive to small seed size	*ls*	Srivastava and Nath (1972)
White immature fruit skin colour: recessive to green	*w*	Srivastava and Nath (1972), Suribabu et al. (1986), Vahab (1989), Alcazar and Gulick (1983), Kole et al. (2012)

Taja and Wehner (2008)

Co-operative (Taja and Wehner 2008). Genetical studies in *Momordica* species have been meagre which can be divided into two categories namely that is concerned with the inheritance of morphological characters and that dealing with pest and disease resistance.

Studies on the inheritance of some qualitative traits in bitter gourd revealed that, green fruit skin colour is monogenically dominant over white fruit colour (*w*) (Srivastava and Nath 1972; Suribabu et al. 1986; Vahab 1989; Alcazar and Gulick 1983; Kole et al. 2012); the dark brown seed coat colour is dominant over the light brown seed (*lbs*) coat colour in a monogenic inheritance (Srivastava and Nath 1972; Ram et al. 2006; Kole et al. 2012); the small seed is completely dominant over the large size seed where one pair of genes is involved. Inheritance of fruit surface is monogenic, spiny fruit surface is completely dominant over smooth surface and controlled by a single dominant gene (*FrSrf*) (Vahab 1989; Kole et al. 2012). Reyes and Rasco (1994) reported a suppressed shoot growth mutant due to a recessive gene *ssg*. Kole et al. (2012) found fruit luster (*FRLsr*) and stigma colour (*StCol*) to be monogenic and dominant. Gynoecy in bitter gourd has been reported to be under the control of a single recessive gene gy-1 (Ram et al. 2006; Behera et al. 2009). Crossing experiments indicated that sex is controlled by a single factor, with heterozygous males and homozygous recessive females in *M. dioica* (Hossain et al. 1996) and *M. cochinchinensis* (Sanwal et al. 2011). But, while reading these papers it is found that these studies have been conducted in *M. subangulata* subsp. *renigera*. Fruit yield and its component traits are polygenic and exhibits continuous variation (Kole et al. 2012).

In bitter gourd, non-additive gene effects were involved in earliness days to first female flowering fruit weight, fruit volume, fruit flesh weight, fruit girth, number of seeds per fruit, number of fruits per vine and total as well as marketable yield per plant (Khattra et al. 2000; Choudhury and Sikdar 2005; Islam et al. 2009). The characters like earliness, node to first female flower, vine length, number of female flowers per plant, number of primary branches per plant, average fruit weight, fruit length, number of fruits per vine, average flesh thickness, yield per plant (Singh and Joshi 1980; Khattra et al. 2000; Sharma and Bhutani 2001; Panda et al. 2008; Islam et al. 2009; Dey et al. 2009; Raja et al. 2007), bitter principle (Devadas and Ramadas 1994) were under additive gene control. Yield per plant had high positive and high significant correlation with number of fruits per plant (Srivastava and Srivastava 1976; Ramachandran 1978; Kole et al. 2012), number of nodes per vine (Islam et al. 2009), fruit weight, fruit length and number of flowers per plant (Ramachandran 1978; Parhi et al. 1995). In spine gourd, number of fruit/plant and fruit yield/plant exhibited high heritability coupled with high genetic advance (Bharathi et al. 2006; Singh et al. 2009).

Bitter gourd Distortion Mosaic Virus (BDMV) resistance is controlled by polygenes and their expressions are highly influenced by environment (Arunachalam 2002). Inheritance of resistance to melon fruit fly indicated that fruit fly resistance is dominant over susceptibility (Tewatia and Dhankhar 1996).

The literature contains very little information about genetics and cytogenetics of Asiatic species especially that occur in south-east Asia (other than India). It seems necessary first to study the basic cytological information like ploidy level, chromosome number, chromosome structure, etc., to understand cytogenetic affinities between the species. The tools used in cytological studies were conservative and they should be combined with novel methods of molecular biology. Further, more detailed studies on reproductive compatibility and chromosome pairing behaviour to explore the possibilities of gene transfer through meiotic recombination are warranted. Experience with the available hybridisation studies between different ploidy levels indicate that different methods like back cross-breeding and chromosome doubling may be carried out to transfer the desirable trait and create more genetic variation. Few cross-combinations showed embryo abortion, sterility and reduced fertility and the techniques of somatic hybridisation, in vitro embryo culture, chromosome doubling may be exploited. Genetics of several characters have not been studied and are very limited. More genetical studies are required to know the inheritance of morphological characters as well as pest and disease resistance to apply in crop improvement programmes.

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Genetic Resources, Germplasm Characterisation/Evaluation and Maintenance

7

Abstract

Gene pool serves as a tool for conceptualising the ability of plant populations to cross with the conspecific population and with those of other species. Classification of gene pool of *Momordica* spp. has been discussed here on the basis of hybridisation studies. *M. dioica* and *M. subangulata* in India are reported under endangered category. However, these reports are based on assumption and do not have the support of authentic fieldwork. A large collection of *M. charantia* is maintained in the national gene bank and by different organisations in India and other countries. A good representation of diversity in *M. charantia* has been assembled from the Western Ghats, India, though there are still a few grey areas to be explored more intensely. However, other species and areas need extensive coverage. *Momordica* species assume significance for conservation as crop relative, source of economic product of aesthetic and ecological interest, of potential horticultural value and as future raw material for the medicinal and pharmaceutical industry. Establishment of genetic reserves within protected areas must be attempted for conserving diversity in *M. dioica* and *M. sahyadrica*. Ex situ conservation in home gardens and on-farm conservation in tribal homesteads in forest pockets are viable options for conservation of *Momordica* gene pool as the taxa are still wild or semi-domesticate with high dependence on biotic agents for pollination and seed dispersal.

Keywords

Momordica gene pool · Endangered · In situ and ex situ conservation · Genetic reserves

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Genetic Resources

The importance of germplasm as a basic tool for crop improvement is well recognised. They provide the basic material for selection and improvement through breeding to ensure food security needs of the world's rapidly rising population. Wild relatives and progenitors of cultivated plants together with semi-domesticates represent a strategic part of germplasm collections. Genetic variation is fast eroding as natural habitats of wild relatives of cultivated species are being destroyed. As the genetic base of modern varieties is narrow and variability fast eroding, introgression of genes from wild species can substantially influence the breeding progress. Generally, the Indian genetic resources of *Momordica* are not threatened.

Gene Pool Classification

Gene pool serves as a tool for conceptualising the ability of plant population to cross with the conspecific population and with those of other species (Harlan and de Wet 1971). Based on the available literature on inter-specific hybridization and evaluation of their progeny, the following gene pool classification of the cultivated/semi-cultivated species is proposed (Bharathi et al. 2012a). The nature of these relations is important for the application of appropriate technologies to transfer desirable genes from wild *Momordica* species to the cultivated/semi-cultivated species.

Gene pools of *M. charantia.* The primary gene pool of *M. charantia* is again divided into two subclasses I and II. Gene pool I consists solely of its various commercial cultivars and its interfertile variety, the wild-type var. *muricata*. There is evidence for introgression of *M. charantia* var. *charantia* genes into wild-type in Taiwan (Liao et al. 2012). There are a great many commercial cultivars with particular characteristics that together with local land races and populations of wild varieties constitute extraordinary genetic resources. The next level of compatibility involves the *M. balsamina* (wild species). Despite the high degree of morphological/cytological similarity between these two species, they are reproductively isolated from each other in terms of barriers to hybridisation and is very difficult to obtain hybrid seeds (that too only in one direction—*M. charantia* as seed parent) and therefore *M. balsamina* is placed in primary gene pool II. The dioecious species represent the tertiary gene pool.

Gene pools of *M. dioica*. None of the dioecious species is reproductively isolated from the other completely. The primary gene pool is represented by its land races/varieties and *M. sahyadrica*. The anthesis of *M. dioica* occurs in the evening while that of *M. sahyadrica* and their hybrid progeny in the morning, which can be explored to get greater pollinator choice. Its secondary gene pool includes *M. cochinchinensis* and *M. subangulata* subsp. *renigera* while all the monoecious species are included in tertiary gene pool.

Gene pools of *M. subangulata* subsp. *renigera*. As it is a tetraploid species and the rest of the dioecious species is diploid, the hybrid progeny are triploid and sterile. Therefore, primary gene pool includes only infra-specific types and secondary gene pool includes the rest of the dioecious species and tertiary gene pool is formed by monoecious species.

Genetic Erosion and Threat Status

The only reference to the threatened status of *Momordica* is found (Anonymous 1997) in ICUN Red Data Book where *M. subangulata* Blume. from Wyanad (Kerala) and south Canara (Karnataka) is accorded threatened-indeterminate status (taxa known to be extinct, endangered, vulnerable or rare but where there is not enough information to say which of the four categories is appropriate). The material referred to as *M. subangulata* from Kerala and Karnataka is actually *M. sahyadrica* and true *M. subangulata* is of restricted distribution in north–east India. Jha and Ujawane (2002) consider *M. balsamina* as nearing extinction in Saurashtra, Gujarat and *M. cochinchinensis* as endemic to

Assam forests. However, *M. cochinchinensis* is not endemic to Assam as the authors have spotted the species in abundance in the north, south and middle Andamans and also there are reports of its distribution in a vast region in South–East Asia. Zuberi and Biswas (1998) reports *M. dioica* in Bangladesh in the endangered category. Dwivedi (1999) considers *M. dioica* as endangered in Madhya Pradesh. However, most of these reports are based on certain assumptions and do not have the support of authentic fieldwork. Recent studies revealed a grave threat for *M. dioica* in its entire range and *M. sahyadrica* in the Western Ghats of Kerala. Overall, *M. charantia* var. *muricata* faces a medium level of threat across its geographic range. Habitat loss and fragmentation brought about by population pressure and developmental activities, poor distribution and low population density of *Momordica* species coupled with inadequate in situ conservation efforts, and acculturation of the forest dwelling communities are the major factors attributed to their heightened threat status affecting their long-term survival in the wild (Joseph and Antony 2007).

Present Status of Germplasm Holdings

Bettencourt and Konopka (1990) have given a compilation of ex situ holdings of *Momordica* germplasm worldwide. A large collection of *M. charantia* is maintained in the national gene bank and by different organisations in India and in other countries (Table 7.1). Species representation of the genus *Momordica* in various herbaria/gene banks around the world is presented in Table 7.2. It seems that wild *Momordica* are underrepresented in gene banks. Recently, descriptors for dioecious *Momordica* spp. have been published (Joseph and Antony 2011). Evaluations of genetic resources for traits of horticultural interests are regularly conducted for yield and fruit quality or for pest and disease resistance.

Plant Descriptors

Habit

All dioecious species [*M. subangulata* (subsp. *renigera*, subsp. *subangulata*), *M. dioica*, *M. sahyadrica*, *M. cochinchinensis*, *M. rumphii*, *M. clarkeana*, *M. denticulata*, *M. denudata*] and a monoecious species (*M. cymbalaria*) are perennial climbers with tuberous roots. Monoecious species, viz. *M. charantia* and *M. balsamina* are annuals with fibrous roots. Perennial species undergo dormancy during winter/summer months and new shoots are produced upon favourable conditions. However, in *M. cochinchinensis*, the aerial stem does not wither or dry up completely upon cessation of favourable growth season.

Seedlings

All species have distinct seedling morphology. Annual species have epigeal germination (Fig. 7.1a), whereas perennial species have hypogeal germination (Fig. 7.1b). Polyembryony was observed rarely in *M. dioica*, *M. subangulata* subsp. *renigera* and *M. sahyadrica* (Fig. 7.2). Robustness and size of the cotyledon was greater in *M. charantia* var. *charantia* and progressively reduced to *M. charantia* var. *muricata* and *M. balsamina* was most fragile. In the dioecious group, *M. cochinchinensis* is most robust and fast in emergence and has triangular non-cordate leaves. *M. dioica* and *M. sahyadrica* differ in lobing of first few leaves, *M. dioica* being more deeply lobed and very fragile.

Roots

The annual species produce fibrous roots, which die at senescence along with the aerial parts. However, the perennial taxa produce storage roots with which they perennate during the unfavourable growth period. In *M. sahyadrica* and *M. dioica*, the seedling tap root gets

Table 7.1 Present status of germplasm holdings in *Momordica* species

Crop	Number of accessions	Institute	Reference
M. charantia var. *charantia*	519	National Genebank of NBPGR, New Delhi	Ram and Srivastava (1999)
	1	Institute of Agrobotany, Hungary (ABI)	Horvath (2002)
	15	N.I.Vavilov Research Institute of Plant Industry (NIR), Russia	Piskunova (2002)
	1	Cukurova University, Turkey	Kucuk et al. (2002)
	95	Kerala Agricultural University, Vellanikkara, India	Raj et al. (1993)
	65	Indian Institute of Horticultural Research, Bangalore, India	Raj et al. (1993)
	219	Indian Institute of Vegetable Research, Varanasi, India	Ghosh and Kalloo (2000)
	30	Vivekananda Parvathiya Krishi Anusandhan Shala, Uttar Pradesh, India	Ghosh and Kalloo (2000)
	2	Aburi Botanic Gardens, Ghana	Harriet Gillett (2002)
	281	AVRDC, Taiwan	AVGRIS (2009)
	12	Southern Regional Plant Introduction Station, Georgia, USA	Raj et al. (1993)
	1	National Seed Storage Laboratory, Fort Collins, USA	Raj et al. (1993)
	2	National Institute of Agricultural Sciences, Ibaraki, Japan	Raj et al. (1993)
	72	Institute of Plant Breeding, Laguna, Philippines	Raj et al. (1993)
	7	Division of Plant and Seed control, Pretoria, South Africa	Raj et al. (1993)
	250	Kasetsart University, Bangkok, Thailand	Raj et al. (1993)
	Unknown	National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Nigeria	Borokini et al. (2010)
M. charantia var. *muricata*	11	National Genebank of NBPGR, New Delhi	Joseph and Antony (2009)
M. cochinchinensis	6	AVRDC, Taiwan	AVGRIS (2009)
	8	Central Horticultural Expt. Station, Bhubaneswar, India	Collected during 2011–2012 by the authors
	2	Krishna Chandra Mishra Research Institute of Wild Vegetable Crops	Ghosh and Kalloo (2000)
M. dioica	60	Central Horticultural Expt. Station, Bhubaneswar	Vishalnath et al. (2008a, b)
	8	Indian Institute of Vegetable Research, Varanasi, India	Ghosh and Kalloo (2000)
	2	AVRDC, Taiwan	AVGRIS (2009)
	5	Krishna Chandra Mishra Research Institute of Wild Vegetable Crops	Ghosh and Kalloo (2000)
	93	AICRP on UU crops	Joshi et al. (2002)
M. subangulata ssp. *renigera*	70	Central Horticultural Expt. Station, Bhubaneswar, India	Collected during 2011–12 by the authors
	<12	AAU Research Centre, Kahikuchi	Ram et al. (2002)
	2	Krishna Chandra Mishra Research Institute of wild vegetable crops	Ghosh and Kalloo (2000)

(continued)

Table 7.1 (continued)

Crop	Number of accessions	Institute	Reference
M. balsamina	1	AVRDC, Taiwan	AVGRIS (2009)
	1	NBPGR, New Delhi	Joseph (2005)
	1	Krishna Chandra Mishra Research Institute of wild vegetable crops	Ghosh and Kalloo (2000)
	3	Czech gene bank, Czech Republic	Karlova (2008)
M. sahyadrica	10	NBPGR, New Delhi, India	Joseph (2005)
Momordica species	31	European gene bank	Diez et al. (2002)

Source Modified from Behera et al. (2011)

thickened with the accumulation of food and secondary thickening and side roots which are formed from the base of the bulged part are fibrous and non tuberous. In the case of *M. subangulata* subsp. *renigera* tap root gets branched slightly below the caudex, gets swollen at intermittent places and undergoes repeated branching (Fig. 7.3a). The number of swollen tubers in the case of *M. dioica* and *M. sahyadrica* were one each (taproot sometimes forked), whereas in the case of *M. subangulata* subsp. *renigera*, it varied from 5 to 15. In *M. cochinchinensis*, the tap root and its primary branches becomes woody (Fig. 7.3b) and areal stem remains alive to a considerable height during unfavourable season. After a period of active growth, with the advent of unfavourable season for growth, the plants of these dioecious species show symptoms of senescence, leaves become yellow and dry up, vine also withers and the plant perennates with the help of storage roots underneath. In case of *M. dioica* the stem portion consisting of basal 2–3 nodes remains alive while in *M. cochinchinensis* all the nodes of the main vine remain alive with only reduction in new foliar growth, which upon favourable conditions, put forth branched sprouts. In case of *M. sahyadrica*, sprouts emerge from the root–shoot transition zone (caudex). In case of *M. subangulata* subsp. *renigera*, there is no polarity and specification; sprouts emerge from any part of the tuber surface, even from wiry roots.

Sexual Reproductive System

Most of the species (*M. subangulata* (subsp. *renigera* and subsp. *subangulata*), *M. dioica*, *M. sahyadrica*, *M. cochinchinensis*, *M. denudata*, *M. denticulata*, *M. rumphii*, *M. clarkeana*) are dioecious and only three (*M. charantia*, *M. balsamina* and *M. balsamina*) are monoecious. Occasionally, hermaphrodite flowers in *M. subangulata* subsp. *renigera* are observed in nature (unpublished).

Tendrils

Tendrils are simple and unbranched. However, in some wild varieties of *M. charantia* bifid tendrils (Fig. 7.4) are also observed. In *M. cochinchinensis*, tendrils are robust.

Leaves

In *Momordica* the leaves are simple, with the blade either entirely or variously (deeply) lobed or (sub) pedately 3–5 foliate. The lobing may be variable within a species. The leaves of *M. subangulata* subsp. *renigera* are entire or angled while the leaves of other species are much dissected. However, in *M. dioica* mixed occurrence of entire as well as lobed leaves in the same plant has also been noticed. Umbilical glands in

Table 7.2 Species representation in various herbaria/gene banks around the world

SN	Country/herbaria/gene bank	Species/accessions	Source country
1	Virtual herbarium, Cayman Islands	*M. charantia* var. *abbreviata*	Asiatic
2	Argentina	*M. charantia*	Asiatic
3	Peru	*M. charantia*	Asiatic
		M. balsamina	African
4	Amazonas, Manaus	*M. charantia*	Asiatic
5	Bangladesh National Herbarium, Dhaka	*M. dioica*	Asiatic
		M. cochinchinensis	Asiatic
		M. charantia var. *charantia*	Asiatic
		M. charantia var. *muricata*	Asiatic
6	Forest Research Institute of Malaysia, Kuala Lumpur	*M. charantia*	Asiatic
		M. subangulata	Asiatic
		M. cochinchinensis	Asiatic
7	Natural History Museum, Seychelles	*M. charantia*	Asiatic
8	Philippines	*M. cochinchinensis*	Asiatic
		M. charantia	Asiatic
9	Institute of Jamaica, Jamaica	*M. charantia*	Asiatic
		M. balsamina	African
10	South Pacific Regional Herbarium, Suva, Fiji	*M. charantia* var. *abbreviata*	Asiatic
11	Bolus Herbarium, University of Cape Town, South Africa	*M. balsamina*	African
		M. charantia	Asiatic
12	National Botanical Institute of Tropical Africa consisting of Namibia, Botswana, Swaziland, Lesotho	*M. balsamina*	African
		M. charantia	Asiatic
13	National Herbarium of Surinam	*M. charantia*	Asiatic
14	Honduras	*M. charantia*	Asiatic
15	Jardin Botanico, Dominican republic	*M. charantia*	Asiatic
16	Nicaragua	*M. charantia*	Asiatic
17	LMU Herbarium, Universidale	*M. balsamina*	African
		M. charantia	Asiatic
18	CAL Herbarium, Kolkata, India	*M. charantia*	Asiatic
		M. balsamina	Asiatic
		M. cochinchinensis	Philippine
		M. subangulata	Malaysian

Source Joseph (2005)

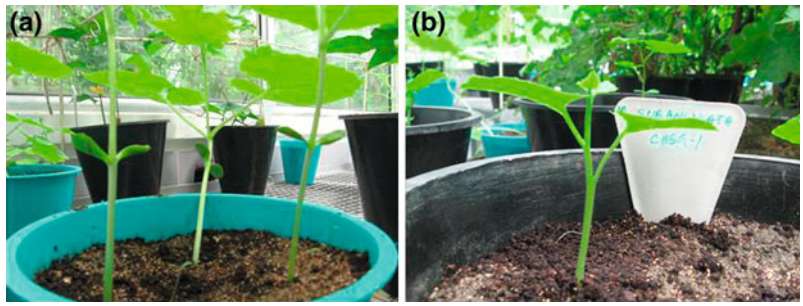


Fig. 7.1 Germination behaviour. **a** *M. charantia* showing epigeal germination, **b** *M. subangulata* showing hypogeal germination

Fig. 7.2 A polyembryonic seedling of *M. dioica*

petiole and lamina base (which is present in *M. cochinchinensis*) act as a good taxonomic trait (Fig. 7.5).

Inflorescences/Flowers

Male flowers are solitary or in short loose pseudo-racemes, each flower stalk with a persistent hooded bract (Fig. 7.6). Female flowers are solitary, in axils also with a conspicuous or rudimentary bract. Male flower pedicels are short or long; the receptacle is short, cupular (*M. charantia*, *M. balsamina*, *M. dioica*, *M. sahyadrica*, *M. rumphii*, *M. clarkeana*) or saucer shaped (e.g. *M. cochinchinensis*, *M. subangulata* subsp. *renigera*, *M. denticulata*) or obconical (*M. cymbalaria*) calyx lobe entire or scarious, adnate at base. Petals 5, free, entire; stamens 5, anthers 3, 1—one thecous, 2—two thecous, filaments very short, free inserted at mouth of the receptacle tube; thecae usually coherent, connective sometimes swollen, pistil lode absent. Female flowers calyx as in the male or distinct, petals as in the male, ovary oblong-fusiform, warty or soft papillose, ovules mostly many, horizontal, stigma 3-lobed; staminode absent.

Fruits

The fruit is fleshy, various in size and shape, pyriform, globose, ovoid or ellipsoid. Fruits are spiny (*M. dioica*, *M. subangulata* subsp. *renigera*, *M. sahyadrica*, *M. cochinchinensis*) or warty (*M. balsamina*) or tuberculate (*M. charantia*) or ribbed (*M. cymbalaria*, *M. subangulata* subsp. *subangulata*). The nature of epicarp is delicate in all the species except *M. cochinchinensis* which is shell like and leathery. The

Fig. 7.3 Nature of roots. **a** Teasel gourd showing adventitious root tubers. **b** Woody roots of *M. cochinchinensis*

Fig. 7.4 Bifid tendril of *M. charantia*

Fig. 7.5 Leaf of *M. cochinchinensis* with umbilical glands

soft pulp inside the mesocarp cavity contains the seeds and has a scarlet red colour and slimy aril (Fig. 7.7) characteristic of the genus.

Seeds

Many enclosed in orange red sarcotesta or creamish yellow (aril), small or large, flattened or turgid on faces, smooth or sculptured margins often undulate and dentate. *M. balsamina* and *M. cymbalaria* stand out in its seed shape and sculpturing. *M. charantia* var. *muricata* has close resemblance to cultivated bitter gourd and is difficult to distinguish except for the small size. The dioecious group has a general resemblance, all being basically black and cog wheel shaped. Fresh seeds of *M. dioica* have golden striation on testa which fades away on drying. *M. subangulata* subsp. *renigera* had short rectangular seeds with six projections. *M. cochinchinensis* has the biggest seed with deep sculpturing and irregular projections on the sides in a broadly stellate fashion. The surface is flat without any sculpturing. Seeds of *M. cymbalaria* are ovoid-subglobose and obscurely sculptured and are different from the seeds of other Asiatic *Momordica* spp.

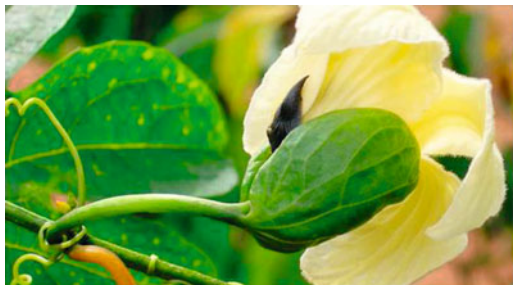


Fig. 7.6 Male flower of *M. cochinchinensis* with hooded bract

Fig. 7.7 *M. subangulata* subsp. *renigera* fruit exposing the seeds with *red* coloured arils

Descriptors and Descriptor States

Internationally recognised descriptor lists are published by Biodiversity International for major crops. However, there is no published descriptor for bitter gourd, teasel gourd, sweet gourd or spine gourd or any *Momordica* species by Biodiversity International. Only few references to *Momordica* descriptor are available (Srivastava et al. 2001; Rasul et al. 2004; Joseph 2005; Joseph and Antony 2011). As a preliminary step, sets of most significant descriptors (minimal descriptor list) for *Momordica* (Srivastava et al. 2001) were prepared under the National Agricultural Technology Project in which bitter gourd, sweet gourd and spine gourd were treated together. They, being evolutionarily divergent groups (bitter gourd on the one hand, sweet gourd and spine gourd on the other hand), should be treated separately as they vary by more than 75 % characters by virtue of their breeding behaviour and growth forms (Joseph 2005).

Rasul et al. (2004) proposed a descriptor with 29 morphological and physiological characters for *M. dioica*. Descriptor lists for monoecious species (Joseph 2005) and dioecious species (Joseph and Antony 2011) have been developed (Tables 7.3, 7.4, 7.5, 7.6 adapted from Joseph 2005; Joseph and Antony 2011) based on the observed variability in national collections (observable from herbarium sheets), published descriptions of these taxa in various flora together with ex situ study of germplasm collections comprising *M. dioica*, *M. sahyadrica*, *M. subangulata* subsp. *renigera* and *M. cochinchinensis*. Exploitation of some characters for inter- and infra-specific categorisation is based on the current state of the author's knowledge of both levels of variation. Further collection and study of variability across the country will lead to spotting of more diverse types and accordingly the descriptor states need elaboration and modification. Present treatment of some traits such as leaf shape, fruit shape, etc., are not exhaustive as numerous types are difficult to describe in technical terms, but easy to depict through illustrations found in the existing collection itself.

Collection, Regeneration and Maintenance

Lack of information about a taxon's precise distribution in different ecosystems is a major constraint to biodiversity conservation (Arora 1998). The findings of the ecogeographical analysis give a clear-cut picture of areas of distribution, hotspots, infra-specific variability and phenology. The distribution maps give a holistic picture of the distribution of component taxa, areas of overlapping distribution and higher concentrations that need to be targeted for maximum assemblage of genetic diversity, using which a prospective collector can have access to the exact site.

Table 7.3 Descriptors and descriptor states for characterization of balsam pear and balsam apple

Number	Descriptor name	Scale and descriptor state
A.	**Vegetative characters**	
A1	Seedling growth habit	1. Robust
		2. Fragile
A2	Seedling stem thickness	1. Very thin
		2. Medium
		3. Thick
A3	Cotyledon size I	1. Very small
		2. Medium
		3. Large
A4	Epicotyls length (cm)	
A5	Hypocotyls length (cm)	
A6.1	Primary leaf size I	1. Very small
		2. Medium
		3. Large
A6.2	Primary leaf shape	1. Squarish angular
		2. Reniform
		3. Fan shaped
		4. Others (describe)
A6.3	Primary leaf margin	1. Smooth (entire)
		2. Dentate
		3. Serrate
		4. Wavy (undulate)
A6.4	Primary leaf gland dottedness	1. On the margins
		2. Absent
A6.5	Primary leaf colour	1. Dark green
		2. Light green
A7	Vine tip pubescence I	1. Glabrous
		2. Scarcely pubescent
		3. Densely pubescent
		4. Wooly
A8.1	Leaf shape (to be recorded at flowering stage-describe)	
A8.2	Leaf colour	1. Light green
		2. Green
		3. Dark green
A8.3	Leaf thickness	1. Thin
		2. Medium
		3. Thick
A8.4	Leaf glossiness of upper side	1. Absent or very weak
		2. Weak
		3. Medium
		4. Strong
		5. Very strong

(continued)

Table 7.3 (continued)

Number	Descriptor name	Scale and descriptor state
A8.5	Leaf margin I	1. Entire
		2. Serrate
		3. Dentate
		4. Wavy
		5. Others (describe)
A8.6	Dentation of margin	1. Fine
		2. Medium
		3. Coarse
A8.7	Leaf pubescence	1. Glabrous
		2. Sparse
		3. Medium
		4. Wooly
		5. Others (specify)
A8.8	Leaf lobing	1. Absent (entire)
		2. Shallowly lobed
		3. Deeply cleft
A8.9	Lobe tip	1. Acute
		2. Acuminate
		3. Ovate
		4. Obovate
		5. Others (specify)
A9.1	Tendril robustness	1. Fragile
		2. Medium
		3. Robust
A9.2	Tendril length (measure from axil to tip of coil)	1. Short
		2. Medium
		3. Very long
A10	Vine branching (at full growth) I	1. Less branched
		2. Medium branched
		3. Densely branched forming thickets
B.	**Reproductive characters**	
B1	Days to first male flower opening	
B2	First male flower node (node number)	
B3	Days to first female flower opening	
B4	First male female flower node (node number)	
B5	Male flower bract shape	1. Scar like
		2. Foliar
		3. Reniform
		4. Hooded
		5. Frilled
		6. Others (describe)

(continued)

Table 7.3 (continued)

Number	Descriptor name	Scale and descriptor state
B6	Male bract position on flower stalk I	1. Towards axil
		2. Mid way
		3. Towards flower base
		4. Others
B7	Flower colour	1. Light yellow
		2. Orange yellow
		3. Creamish yellow
B8	Flower size I	1. Small
		2. Medium
		3. Large
B9	Petal shape	1. Ovate
		2. Obovate
		3. Linear
		4. Rhomboid
		5. Others (specify)
B10	Petal tip	1. Cleft
		2. Lipped
		3. Entire
B11	Petal base colouration (if any describe)	
B12	Male flower petal size (average length and breadth of five petals)	
B13	Female flower bract size	1.Scar-like remnant
		2. Small
		3. Medium
		4. Large
B14	Female bract position	1. Towards axis
		2. Midway
		3. Below gynoecium
B16	Ovary shape I	1. Round
		2. Fusiform
		3. Urn shaped
		4. Cylindrical
		5. Others
B17	Ovary surface	1. Smooth
		2. Warty
		3. Tubercled
		4. Bumps and ridges
		5. Others (specify)
B18	Ovary colour	1. Light green
		2. Whitish green
		3. Dark green
B19	Staminal column colouration S	1. Absent
		2. Black
		3. Orange
		4. Others

(continued)

Table 7.3 (continued)

Number	Descriptor name	Scale and descriptor state
B20	Days to first maturity (at dead ripe split stage)	
B21	Days to first fruit harvest (number of days from sowing to first marketable fruit harvest)	
B22	Days to last harvest (number of days from sowing to last marketable fruit harvest)	
B23	Fruit stalk length (from axil to fruit attachment)	
B24	Fruit shape	1. Disc
		2. Rhomboid
		3. Cylindrical
		4. Spindle shaped
		5. Elliptical
		6. Oblong
		7. Globular
		8. Others (specify)
		
B25	Fruit colour (at marketable stage) I	1. White
		2. Whitish green
		3. Light green
		4. Green
		5. Dark green
		6. Others (specify)
B26	Fruit size	1. Small
		2. Medium
		3. Large
B27	Fruit ends I	1. Both ends pointed
		2. Only blossom end pointed
		3. Both ends round
		4. Others (describe)

(continued)

Table 7.3 (continued)

Number	Descriptor name	Scale and descriptor state
B28	Fruit ribs I	1. Continuous
		2. Broken
		3. Not distinct
		
B29	Density of tubercles	1. Sparse
		2. Medium
		3. Dense
		4. Others (describe)
B30	Nature of fruit tubercles I	1. Soft and flat
		2. Sharp and pointed
		3. Soft and raised
		4. Merging with bumps
		5. Others
B31	Seed colour I	1. White
		2. Brownish tan
		3. Brownish yellow
		4. Black
		5. Black and brown patched
		6. Cement colour
		7. Straw colour
		8. Whitish brown
		9. Others (describe)
B32	Seed luster (on washed de-pulped seeds extracted from ripe fruits)	1. Matt
		2. Intermediate
		3. Glossy
		4. Others (specify)
B33	Seed size I	1. Large
		2. Small
		3. Very small
B34	Seed surface evenness	1. Flat and creeked
		2. Pitted (uniformly)
		3. Invaginated
B35	Seed sides	1. Dented-bitten appearance
		2. Smooth
B36	Seed ends	1. Clearly sub tridentate
		2. Oval
		3. Feebly sub tridentate
		4. Smooth
		5. Others (specify)
B37	Seed surface sculpturing	1. Markedly sculptured
		2. Feebly sculptured
		3. Only pitted

(continued)

Table 7.3 (continued)

Number	Descriptor name	Scale and descriptor state
B38	Seed shape	1. Broad triangular
		2. Narrow triangular
		3. Squarish oval
		4. Round
		5. Others

Source Joseph (2005)
I - discriminates an infraspecific variation
S - indicates a species characterising descriptor

Table 7.4 Descriptors and descriptor states for evaluation of balsam pear and balsam apple

Descriptor number	Descriptor name	Scale
1	Leaf size (L × B)—average of five leaves at first flowering node	
2	Number of primary branches—to be recorded at the end of flowering stage	
3	Number of secondary branches—to be recorded at the end of flowering stage	
4	Number of tertiary branches—to be recorded at the end of flowering stage	
5	Inter node length (in cm)—at early flowering nodes	
6 7	Plant height (length of main stem from base to terminal branch, measured at senescence)	
8	Fruit length (average of five well developed fruits)	
9	Fruit circumference (average of five well developed fruits)	
10	Fruit cavity (measure at the central part, diameter of C.S. of mature fruits	
11	Fruit flesh thickness (measure with a caliper)	
12	Clutch size	
13	Single fruit weight (g)	
14	Seed size (L × B)—measure with a caliper	
15	Seed thickness measure with a caliper	
16	Seed germinability (% germination and speed of emergence—combined assessment)	
17	Number of fruits per plant	
18	Yield/plant	
19	Senescence (months after planting)	
20	100 seed weight (g)	
	Biotic stress tolerance	
21	Reaction to prevalent diseases (score in 1–9 scale)	
	21.1 Cucurbit mosaic virus, 21.2 Witches broom, 21.3 Damping off, 21.4 Downey mildew, 21.5 Leaf spot, 21.6 Fruit rot, 21.7 Root knot nematode	

(continued)

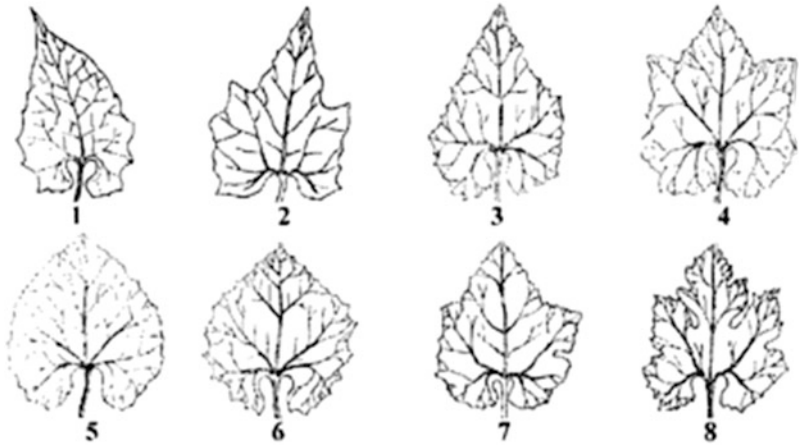
Table 7.4 (continued)

Descriptor number	Descriptor name	Scale
22	Reaction to prevalent pests (score in 1–9 scale)	
	22.1—Fruit fly, 22.2—fruit borer 22.3—Vine gall fly, 22.4—Lady bird beetle, 22.5—Leaf miner, 22.6 Leaf hopper 22.7—Red pumpkin beetle, 22.8—Cut worm infestation at seedling stage, 22.9—Aphid	
23	Reaction to abiotic stresses (a combined assessment based on growth, survival and yield)	
	23.1—drought, 23.2—high temperature, 23.3—shade, 23.4— heavy monsoon	
24	Organoleptic tests	
	24.1 Bitterness of fruits (cooked mature fruits)	1. Very bitter
		2. Medium
		3. Low
	24.2 Taste	1. Very good
		2. Good
		3. Average
		4. Poor
25	Consumer acceptability	1. High
		2. Medium
		3. Low
26	Economics of production in homesteads	1. High
		2. Medium
		3. Low
27	Physico-chemical evaluation of tender fruits	
	27.1—Moisture, 27.2—carbohydrate, 27.3—protein, 27.4—fat, 27.5—calcium, 27.6—phosphorus, 27.7—Iron, 27.8—magnesium, 27.9—vitamin C, 27.10—antioxidants, 27.11—flavonoids, 27.12—dietary fibre, 27.13—others (specify)	

Source Joseph (2005)

Area-wise gaps in germplasm collection can be ascertained by comparing the gene bank passport data with the distribution maps. Analysis of species distribution maps based on herbarium survey and locality data of collections reveal the need for more intensive exploration in species hotspots. A good representation of diversity in *M. charantia* has been assembled in India through various explorations conducted by various organisations like NBPGR, New Delhi; Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh; Indian Agricultural Research Institute (IARI), New Delhi; Indian Institute of Horticultural Research (IIHR), Bengaluru, Karnataka; Vivekananda Parvathiya Krishi Anusandhan Shala (VPKAS), Almora, Uttar Pradesh; Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu; Kerala Agricultural University (KAU), Thrissur, Kerala, University of Agricultural Science, Dharwad, Karnataka; Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad, Andhra Pradesh; Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra; Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar, Uttaranchal; Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, etc., though there are still a few grey areas to be explored more intensely. However, other species and areas need extensive coverage. Similarly, more than 70 samples of teasel gourd were collected from north-eastern India by the Central Horticultural Experiment Station, Bhubaneswar, in collaboration with NBPGR, New Delhi, which represent good morphological variability.

Table 7.5 Descriptors and descriptor states for characterisation of sweet gourds (to be used in continuation of passport data)

Descriptor number	Descriptor name	Descriptor state (with code)
1.1.1 S	Germination (Except 1.1.1, all other traits may be recorded in tuber sprouts/ratoon crop also)	1. Epigeal
		2. Hypogeal
1.1.2 S	Primary leaf size	1. Minute
		2. Small
		3. Medium
		4. Large
1.1.3	Primary leaf shape (See figure and describe)	
		
1.1.4 I	Primary leaf margin	1. Smooth
		2. Wavy
		3. Dentate
		4. Lobed
1.2.1	Vine tip pubescence	1. Glabrous
		2. Scarcely pubescent
		3. Pubescent
1.2.2	Stem nodal region—shape	1. Quadrangular
		2. Round
1.2.3	Leaf shape (to be recorded at flowering stage—see figure and describe)	
		
1.2.4 S	Leaf margin	1. Entire
		2. Serrate
		3. Dentate
		4. Wavy
		5. Other (describe)

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
1.2.5	Leaf pubescence	1. Glabrous
		2. Sparse
		3. Medium
		4. Dense
		5. Wooly
		6. Other (describe)
1.2.6	Leaf colour (fresh leaf)	1. Light green
		2. Green
		3. Dark green
1.2.7 S	Leaf venation	1. Fine network (areoles)
		2. Spaced network
		3. Intermediate
1.2.8 S	Leaf lobing (1st flowering node)	1. Entire
		2. Lobed
		3. Mixed occurrence in same plant
		4. Other (specify)
1.2.9	Extent of lobing	1. Shallowly lobed
		2. Broadly angled margins
		3. Deeply lobed and sub-lobed
1.2.10	Lobe tip	1. Acute
		2. Acuminate
		3. Ovate
		4. Obovate
		5. Other (specify)
1.2.11 S	Leaf smell (odour when crushed)	1. Foetid (intense)
		2. Not foetid
		3. Mild
1.2.12	Leaf thickness	1. Thin
		2. Medium
		3. Thick
1.2.13 I	Extent of leaf margin dentation	1. Close
		2. Spaced
		3. Remote
1.2.14 S	Petiole-Lamina juncture shape	1. Subangulata
		2. Round
		3. Cordate
		4. Other (describe)
1.2.15 S	Petiole-umbilical glands (viewed with naked eye)	1. Absent
		2. Present
1.2.16 S	Tendril robustness	1. Robust
		2. Fragile
		3. Medium

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
1.2.17	Tendril length (when uncoiled)	1. Short (5–10 cm)
		2. Medium (11–20 cm)
		3. Very long (21–30 cm)
2.1.1 S	Male inflorescence—nature of branching	1. Solitary
		2. Psuedo raceme
		3. Loose fascicle
		4. Truly branched (above the bract)
2.1.2 S	Bract—position on peduncle	1. At base
		2. Midway
		3. At tip
2.1.3	Male bract shape	1. Scar like
		2. Small foliar
		3. Reniform
		4. Fan shaped (cleft)
		5. Hooded
		6. Frilled
		7. Any other (specify)
2.1.4 S	Male bract size	1. Minute
		2. Small
		3. Medium
		4. Large
2.1.5 I	Male bract pubescence	1. Stiff short hairy-conspicuous
		2. Sparse
		3. Absent
2.1.6	Male bract colour	1. Light green
		2. Dark green
		3. Whitish green
2.1.7	Male bract tip	1. Coloured black–purple
		2. No colour distinction
2.1.8 S	Flower colour (petal colour at full bloom). Use RHS colour charts (1995)	1. Lemon yellow
		2. Dull yellow
		3. Bright yellow
		4. Creamish yellow
		5. Whitish yellow
		6. Any other (specify)
2.1.9 S	Flower size	1. Small
		2. Medium
		3. Large
2.1.10 S	Floral scent	1. Odourless
		2. Faint
		3. Detectable from 1 m distance
2.1.11 S	Floral odour sensation	1. Musky
		2. Other (specify)

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
2.1.12 S	Petal spot	1. Absent
		2. Present
2.1.13 S	Nature of petal spot	1. Purple blotch on 3 inner petals
		2. Purple blotch on all 5 petals
		3. Light greenish yellow region on base of petals
		4. Other (describe)
2.1.14 S	Male flower calyx shape	1. Linear acute
		2. Round oval
		3. Broad elliptic
		4. Ovate oblong
		5. Other (specify)
2.1.15 S	Calyx cup colouration	1. Non pigmented
		2. Pigmented purple–blackish
		3. Light creamish yellow
		4. Greenish yellow
		5. Blackish
2.1.16 S	Corolla tip	1. Acute
		2. Broad ovate
		3. Round
		4. Other (specify)
2.1.17 S	Petal base	1. Just touching each other
		2. Overlapping
		3. Spaced
		4. Other (specify)
2.1.18	Petal pubescence	1. Glabrous
		2. Glandular hairy
2.1.19 S	Petal shape	1. Ovate
		2. Linear acute
		3. Rhomboid
		4. Other (specify)
2.1.20 S	Petal spur (at base) = scale	1. Absent
		2. Present, but inconspicuous
		3. Prominent
2.1.21 S	Petal venation	1. Less prominent
		2. Medium
		3. High (embossed)
2.1.22 S	Pollen dust colour	1. Yellow
		2. Orange
		3. Brown
2.1.23 S	Pollen abundance	1. Scanty
		2. Medium
		3. Abundant
2.1.24 S	Male flower anthesis	1. Early morning 2. Evening

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
2.1.25	Insect visitors observed (list out)	
2.2.	Female inflorescence and flower	
2.2.1 I	Female flower bract size	1. Minute (scar like)
		2. Medium large
		3. Large
2.2.2 I	Female flower bract position	1. Just below gynoecium
		2. Midway on pedicel
		3. Near axis
2.2.3 S	Gynoecium	1. Small
		2. Medium
		3. Large
2.2.4	Ovary surface	1. Smooth
		2. Warty
		3. Tubercled
		4. Echinate (softly)
		5. Ridged
		6. Other (describe)
2.3.	Fruit	
2.3.1 S&I	Fruit size	1. Small
		2. Medium
		3. Large
2.3.2 I	Immature fruit colour	1. Whitish green
		2. Light green
		3. Dark green
2.3.3 I	Fruit surface echination	1. Absent = smooth
		2. Mild sparsely echinate
		3. Densely echinate
2.3.4 I	Fruit surface bumps and ridges	1. No ridges
		2. Obscurely ridged (feeble)
		3. Clearly ridged
		4. Ridged at base only
		5. Ridged at base and top
		6. Other (describe)
2.3.5 S	Fruit C.S (mature fruit at equatorial point)	1. Uniformly soft echinate
		2. Clear cut ridges and echination
		3. Ridges faint but echinate
		4. Other (describe)
2.3.6 I	Fruit shape (see figure)	1. Round oval
		2. Winged
		3. Doom shaped
		4. Ellipsoid oblong
		5. Top shaped
		6. Others (specify with drawing)

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
		
2.3.7 S	Fruit pericarp reddening	1. Slowly building up
		2. Sudden expression leading to ripening
2.3.8 I	Fruit (blossom end) rostration	1. Faint
		2. Medium
		3. Appreciable length
2.3.9	Fruit blossom end surface murication	1. Ridged and flat
		2. Ridged and echinate
		3. Uniformly echinate
		4. Uniformly smooth
		5. Other (describe)
2.3.10 S	Calyx persistence	1. Caducous
		2. Semi persistent
		3. Persistent
2.3.11 I	Fruit bitterness (chewing)	1. Not bitter
		2. Slightly bitter
		3. Very bitter
2.4.	Seed	
2.4.1	Seed aril colour (at ripening)	1. Yellow
		2. Orange
		3. Scarlet
		4. Blood red
2.4.2 S	Seed shape	1. Oval
		2. Round
		3. Globular
		4. Stellate
		5. Squarish
		6. Cog-wheel
		7. Rectangular
		8. Other (describe)
2.4.3 I	Seed sculpturing	1. Absent
		2. Present
2.4.4 I	Extent of sculpturing	1. Faint
		2. Medium
		3. Filigree type
		4. Pitted and ridged
		5. Other (describe)

(continued)

Table 7.5 (continued)

Descriptor number	Descriptor name	Descriptor state (with code)
2.4.5	Seed ornamentation	1. Absent
		2. Present
2.4.6	Type of ornamentation	1.Golden lines on black seed coat
		2. Other (specify)
2.4.7 I	Seed sides (margins	1. Smooth
		2. Wavy = bitten
2.5	Tuber (Specify age of tuber—only seedling tuber to be observed)	
2.5.1	Seedling (tap root) tuber shape	1. Conical
		2. Napiform
		3. Round bulged
		4. Fusiform
		5. Other (describe with drawing)
2.5.2 S	Protrusion of lenticels on tuber surface	1. Weak
		2. Medium
		3. Strong
2.5.3	Seedling tuber branching	1. Absent
		2. Present
2.5.4 S	Occurrence of adventitious tubers	1. Absent
		2. Present
2.5.5	Seedling tuber life span	1. 1–5 years
		2. 2 < 5 years
		3. 3 > 5 years

I - discriminates an infraspecific variation
S - indicates a species characterising descriptor

Experience of germplasm collection of *Momordica* species across the Western Ghats revealed certain general factors affecting wild species survival. *Momordica* species were found to be subjected to varied types of threats such as changes in agricultural practices affecting species dependent on prevailing agricultural systems and other factors such as forestry plantations, monoculture practices, continuous weeding preventing reproductive maturity, pressure from introduced plants (smothering by *Mekania micrantha*, competition from *Mimosa incisa*, *Lantana camera,* etc.) and collecting for horticultural purpose thus leading to critically low population level with subsequent danger of breeding collapse (Rajashekaran et al. 2011).

Characterisation and Evaluation

The nature and magnitude of genetic diversity in any crop determines and often limits its utilisation in breeding programmes. Genetic diversity was studied by various authors using various tools and materials. Characterisation studies employing solely morphological methods typically focused on revealing valuable horticultural traits. Indian researchers gave considerable attention to the evaluation of local *M. charantia* germplasm with the goal of identifying valuable accessions for breeding which resulted in the development of many varieties across India. However, other *Momordica* species of Indian

Table 7.6 Descriptors and descriptor states for sweet gourds evaluation

Descriptor No.	Descriptor name	Descriptor state with code
1. Seedling		
1.1	Days to emergence (specify after ripening period)	
1.2	Germination percentage	
1.3	Seedling vigour (visual score at 3–5 leaf stage)	1. Low
		2. Medium
		3. High
2. Mature vines		
2.1. Stem characteristics		
2.1.1	Growth habit	1. Less viny
		2. Moderately viny
		3. Highly viny
2.1.2	Plant height (vine length measured at senescence) [m]	
2.2. Leaf		
2.2.1	First flowering node leaf size (L × B)	
2.2.2	Petiole length (average of five leaves at flowering node) [cm]	
2.2.3	Lamina—gland dottedness (10X) on lower surface	1. Sparse
		2. Dense
		3. Medium
2. 3. Flowers		
2.3.1	Days to first male flower opening (specify seed or tuber origin)	
2.3.2	Days to 50 % male flowering	
2.3.3	Days to first female flower opening	
2.3.4	Days to 50 % female flowering	
2.3.5	Male flower prolificacy—number of flowers/plant/day (average count of 5 days)	
2.3.6	Female flower prolificacy (average count of 5 days)	
2.3.7	Male bract size (L × B—average of five flowers)	
2.3.8	Female bract size (L × B—average of five flowers)	
2.3.9	Male Peduncle length (axis to base of bract) [cm]	
2.3.10	Female peduncle length (axis to bract base) [cm]	
2.3.11	Male pedicel length (bract to calyx base) [cm]	
2.3.12	Female pedicel length (bract to gynoecium) [cm]	
2.3.13	Male flower diameter (average of five flowers) [cm]	
2.3.14	Female flower diameter (average of five flowers) [cm]	
2.3.15	Male flower receptacle size	1. Small
		2. Medium
		3. Large
2.3.16	Pollen viability (fruit set upon hand pollination)	1. Up to 12 h
		2. Up to 18 h
		3. Up to 24 h
		4. Beyond 24 h

(continued)

Table 7.6 (continued)

Descriptor No.	Descriptor name	Descriptor state with code
2.3.17	Stigma receptivity (fruit set upon hand pollination)	1. Up to 12 h
		2. Up to 18 h
		3. Up to 24 h
		4. Beyond 24 h
2.4. Fruit		
2.4.1	Days to first fruit maturity (flowering to fruit-split)	
2.4.2	Fruit length (including rostration) [cm]	
2.4.3	Fruit circumference (around fruit) [cm]	
2.4.4	Fruit diameter [cm] (measured in C.S of fruit)	
2.4.5	Cavity size (measured at widest point in fruit CS) [cm]	
2.4.6	Flesh thickness (measured from C.S of ripe fruit) [cm]	
2.4.7	Single fruit weight (average of five fruits) [g]	
2.4.8	Number of fruits/plant/season	
2.4.9	Seediness (number of seeds/fruit, average of five fruits)	
2.4.10	Fruit stalk length (average of five fruits) [cm]	
2.4.11	Inter specific crossability (extent of fruit set with pollen of related species—specify pollen parent)	1. Above 95 %
		2. 50 %
		3. 25 %
		4. Aborted
		5. No response
2.4.12	Fruiting period (number of days from first to last female flower opening)	
2.4.13	Fruit tenderness index (from pollination to seediness calculated as days up to which a sharp knife easily passes through)	
2.4.14	Fruit preference for vegetable preparation (based on consumer preference after organoleptic tests)	1. Excellent
		2. Good
		3. Average
		4. Poor
2.4.15	Suitability of ripe fruits as vegetable salads (based on organoleptic tests and eye appeal)	1. Excellent
		2. High
		3. Medium
		4. Low
2.4.16	Usefulness as pot herb and leafy vegetable	1. Excellent
		2. Good
		3. Average
		4. Poor
2.4.17	Suitability for organic farming (a combined assessment of yield and biotic tolerance)	1. Good
		2. Average
		3. Poor
2.4.18	Shelf life under refrigeration (vegetable stage)	1. High (2 weeks)
		2. Medium (1 week)
		3. Low (<1 week)

(continued)

Table 7.6 (continued)

Descriptor No.	Descriptor name	Descriptor state with code
2.4.19	Shelf life under room temperature	1. High (1 week)
		2. Medium (3 days)
		3. Low (1 day)
2.5.	Seed	
2.5.1	100-seed weight [g]	
2.5.2	Seed storability (viability under normal storage)	1. 6 months
		2. 1 year
		3. Above o1 year
2.6	Biotic stress susceptibility (on a 0–9 scale)	1. No incidence
		2. Very low
		3. Low
		4. ntermediate
		5. High
		6. Very high
2.6.1	Witches broom/little leaf disease, seedling damping off, fruit rot, powdery mildew, anthracnose, root knot nematode, fruit fly, lady bird beetle, vine gall fly, pumpkin caterpillar, leaf miner, leaf hopper, red pumpkin beetle	
2.7	Abiotic stress susceptibility (indicator- yield performance)	
2.7.1	Susceptibility to shade	1. Low
		2. Medium
		3. High
2.7.2	Susceptibility to high temperature	1. Low
		2. Medium
		3. High
2.7.3	Susceptibility to heavy monsoon	1. Low
		2. Medium
		3. High
2.7.4	Susceptibility to drought	1. Low
		2. Medium
		3. High
2.8	Biochemical evaluation of (a) tender fruits, (b) green leaves/tips	
	2.8.1—Moisture, 2.8.2—Carbohydrates, 2.8.3—Proteins, 2.8.4—Fat, 2.8.5—Calcium, 2.8.6—Iron, 2.8.7—Magnesium, 2.8.8—Vitamin A (ripe fruit arils), 2.8.9—Vitamin C, 2.8.10—Antioxidants, 2.8.11—Flavonoids, 2.8.12—Dietary Fibre	

Source Joseph and Antony (2011)

occurrence are not given due attention in collection and characterisation of germplasm and reports are scanty.

Morphological characters have been widely used to characterise the collections while lately, DNA markers are popular in these studies. Wide morphological variations have been reported in *M. charantia* accessions collected from six countries namely India, China, Japan, Taiwan, Thailand and USA (Kole et al. 2010), Asia (Marr et al. 2004; Dalamu et al. 2012); India (Sirohi and Choudhury 1983; Behera 2004;

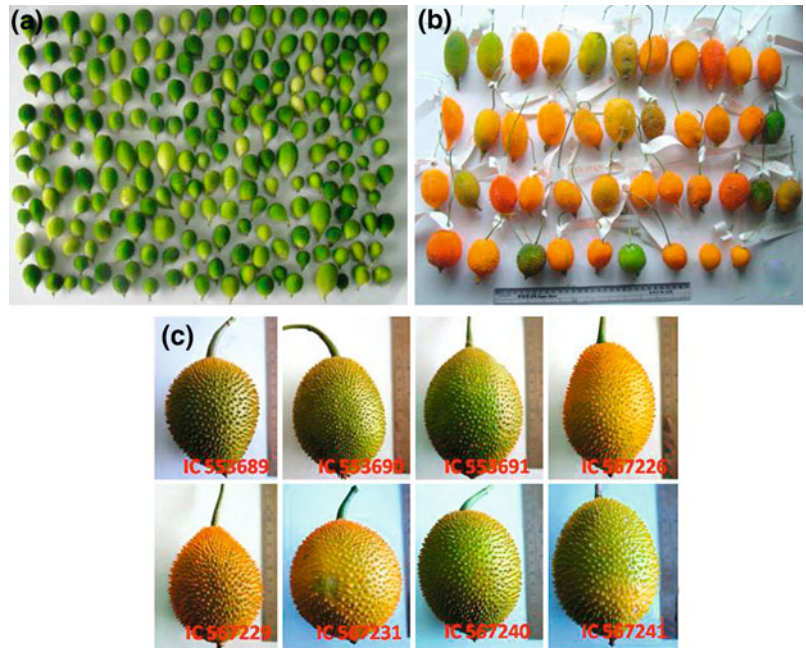


Fig. 7.8 Variability for fruit shape in dioecious *Momordica* species. **a** *M. dioica*, **b**. *M. subangulata* subsp. *renigera*, **c**. *M. cochinchinensis*

Yadav et al. 2008; Joseph and Antony 2009; Paul et al. 2010); Bangladesh (Islam et al. 2010); Thailand (Promote et al. 2011) and Romania (Botau et al. 2010). The accessions of *M. dioica* collected from eastern and northern India (Ram et al. 2001; Bharathi et al. 2005, 2010) and Bangladesh (Rasul and Okubo 2002; Rasul et al. 2004) also showed a considerable range of diversity in qualitative and quantitative traits. The above studies provide broad phenotypic species variation in morphological (qualitative and quantitative) characters like sex expression, growth habit, maturity, fruit shape, fruit size, fruit length, fruit colour, surface texture, number of fruits per plant, yield per plant, etc. The entities collected represented a wide range of variability from almost near wild-types, semi-domesticated to cultivated types.

Based on evaluation the accessions of bitter gourd viz. IC-44428B, IC-85604A, IC-85608BC, IC-85611, IC-85636, EC-110596 have been identified as high yielders (Ghosh and Kalloo 2000). At the Central Horticultural Experiment Station (CHES, IIHR), Bhubaneswar, India, 60 accessions each of *M. dioica*, and *M. subangulata* subsp. *renigera* and 8 accessions of *M. cochinchinensis* have been studied for morphological variability (Fig. 7.8) which lead to identification of two high yielding clones, viz., Arka Neelachal Sree and Arka Neelachal Gaurav in *M. dioica* and *M. subangulata* subsp. *renigera,* respectively, for commercial cultivation (Vishalnath et al. 2008a, b).

Isozyme variation in *M. charantia* germplasm supported a single domestication event but did not clarify the place of domestication (Marr et al. 2004). In domesticated *M. charantia,* the absence of multiple alleles at allozyme loci and fixation for the same alleles across a great geographical distance indicate that gene flow from wild *M. charantia* into the domesticate is rare. This suggests that the morphological variation is due to conscious or unconscious selection on a local scale, rather than to introgression with the wild form. In a genetic diversity study involving seven genera of the family Cucurbitaceae, isozymes could not distinguish between *Momordica* and *Luffa* (Sikdar et al. 2010).

Many molecular markers have been used to characterise *Momordica* germplasm including both plastid and nuclear markers. The random molecular markers like random amplified polymorphic DNA (RAPD) and inter simple sequence repeat (ISSR) are particularly useful

Table 7.7 Molecular characterization of *Momordica* accessions

Taxon	Marker type	Number of accessions	Reference
M. charantia	RAPD	45	Changyuan et al. (2005)
M. charantia	RAPD	38	Dey et al. (2006)
M. dioica, *M. cochinchinensis*	RAPD	29	Rasul et al. (2007)
M. charantia	ISSR	38	Singh et al. (2007)
M. charantia	RAPD	20	Rathod et al. (2008)
M. charantia	AFLP	38	Gaikwad et al. (2008)
M. charantia	RAPD, ISSR	38	Behera et al. (2008b)
M. charantia	RAPD, ISSR, AFLP	38	Behera et al. (2008a)
M. charantia	AFLP, SSR	22	Kole et al. (2009)
M. charantia	SSR	36	Wang et al. (2010)
M. charantia	RAPD, SCAR	12	Paul et al. (2010)
M. charantia	RAPD, ISSR	50	Dalamu et al. (2012)
M. charantia, *M. balsamina*, *M. s.* subsp. *renigera*, *M. dioica*, *M. cochinchinensis*, *M. cymbalaria*, *M. sahyadrica*	RAPD, ISSR	35	Bharathi et al. (2012b)
M. cochinchinensis	RAPD	25	Bootprom et al. (2012)

for studying polymorphism and genetic diversity pattern in plant species where no genomic information is available. Species-specific fragments detected by RAPD and ISSR have potential applications in introgression breeding of *Momordica* and these markers can be utilised for inter-specific hybridisation followed by marker-assisted monitoring of introgression. A wider range of molecular diversity detected in various studies (Table 7.7) by both RAPD and ISSR markers reflected the presence of high level of genetic variation among the species. High level of polymorphism was detected in dioecious species than monoecious species (Bharathi et al. 2012b). Genetic affinities among the cultigens were defined by their geographic origin, suggesting that opportunities exist for broadening the existing Indian germplasm collection (Behera et al. 2008a). RAPD and ISSRs to describe patterns of genetic variation among seven species of *Momordica* gave similar results for each marker type (Bharathi et al. 2012b); however, ISSR was more effective than RAPD analysis at intra-specific variation studies in *M. charantia* (Behera et al. 2008b).

Apart from RAPD, ISSR other molecular markers such as simple sequence repeats (SSRs), sequence characterised amplified region (SCAR), amplified fragment length polymorphism (AFLP) have also been used to assess the genetic diversity of different *Momordica* species in India and Bangladesh (Table 7.7). Simple sequence repeats due to the advantage of high variability, co-dominance and ubiquity in eukaryotic genomes, have become a useful molecular marker in population genetic analysis (Walter and Epperson 2001). AFLP analysis was discriminatory and allowed for a more complete dissection of unique differences within and between collection sites (Behera et al. 2008a) while RAPD and ISSR were not able to uniquely discriminate (Dey et al. 2006; Singh et al. 2007).

Recently, Wang et al. (2010) developed polymorphic microsatellite markers which will be useful to study the genetic diversity and population structure within and between *M. charantia* and other related species. Among the Asiatic *Momordica* species only *M. charantia* germplasm have been characterised for SSR variation (Kole et al. 2009; Wang et al. 2010).

Plastid markers are typically conserved, making them especially valuable for revealing phylogenetic relations at or above species level (Chung and Staub 2004). The first report investigating mt, cp and n DNA sequence analysis was presented by Schaefer and Renner (2010). They studied 122 accessions of 58 *Momordica* species including the Asiatic species and suggested that the genus consists of 11 well-supported clades and monoecy evolved from dioecy seven times independently.

Conservation Strategies

In agro biodiversity conservation, wild plant genetic resources have received relatively lesser emphasis and attempts to conserve them face considerable constraints basically due to lack of information about the biology and ecology of the species and their precise distribution in different ecosystems (Arora 1998). The presence of genetic resistance to pathogens in wild populations is a reason frequently cited for the importance of conserving the genetic diversity present in the wild ancestors of domesticated species. Genetic erosion is very high due to habitat destruction, spread of alien weeds and anthropogenic factors. In this context, conservation of genetic diversity in the genus *Momordica* assumes significance by virtue of being a wild relative of bitter gourd which is an important vegetable and has manifold medicinal uses, e.g. to treat cancer, diabetes, psoriasis and many infectious diseases. References to conservation of *Momordica* species are scanty. Neglect of genetic resources of wild species and semi-domesticates in ex situ gene banks has been a universal feature (Heywood 1998). *Momordica* species assume significance for conservation as crop relative, source of economic product of aesthetic and ecological interest, of potential horticultural value and as future raw material for the medicinal and pharmaceutical industry.

Tissue culture, pollen storage and in situ conservation can be a valuable conservation tool especially in species which are amenable to vegetative propagation, viz., spine gourd, teasel gourd, sweet gourd and *M. sahyadrica*. In vitro conservation was attempted in dioecious *Momordica* species, viz., *M. subangulata* ssp. *renigera*, *M. sahyadrica* and *M. dioica* (Rajashekaran et al. 2011). The species were established in vitro (MS medium supplemented with growth regulators) and the cultures could be maintained in vitro (standard culture conditions) for 6 months without any subculture. Application of cryogenic techniques for conserving nuclear genetic diversity of rare, endangered and threatened plant species sourced from wild habitats would enable extended use of the male gametophyte for providing access to the conserved nuclear genetic variability, biotechnology research besides genetic enhancement of derived crops. The pollen of *M. dioica* can be stored at 0° C for 45 days (Islam and Khan 1998) but pollens showed little tolerance under long-term freezing conditions (−5 °C). However, the pollen viability was determined based on aceto-carmine staining which is not a vital stain (Lebeda et al. 2006). Cryopreserved pollen (−196 °C) of *M. dioica* and *M. sahyadrica* showed 67–74 % germination after 48 h (Rajashekaran et al. 2010).

By establishing a few genetic reserves in selected protected areas in the Western Ghats, North–East and Andaman Islands *Momordica* species can be afforded in situ protection. Good populations of *M. balsamina* thrive in Machia safari park, Jodhpur, Rajasthan, India. Artificial seeding and in situ protection in sacred groves, especially for *M. dioica* needs consideration in the light of its endangerment especially in coastal lowlands in Kerala. Several tribal families across India were found to grow various species of wild *Momordica* in their homesteads

in a simulated in situ condition. Often in the case of *M. dioica* and *M. sahyadrica*, the planting material, i.e. tuber is collected from the forest. *M. charantia* var. *muricata* being exclusively seed propagated, domestication attempts have progressed further. Hence, the conservation of semi-domesticates and pre-domesticates in home gardens is a viable option.

Momordica species including balsam pear, balsam apple, spine gourd and sweet gourd are treated as ornamentals in Europe and America, where it is grown in glasshouses since Victorian times for its beautiful foliage, pendant orange ripe fruits embedded in green foliage and star-like configuration of bursting fruits (Walters and Decker-Walters 1988; Robinson and Decker-Walters 1997). Miniature fruited *M. charantia* var. *muricata* and *M. balsamina* have beautiful foliage and orange red fruits. *M. dioica* has musky scented flowers and *M. sahyadrica* has large showy yellow flowers in profusion, besides both have ivy-like beautiful foliage and pendant fruits turning orange and bursting in star-like configuration. All this offers scope for adoption by urban gardeners, thus giving another dimension to on-farm conservation.

It has been observed that in primitive societies, gathering of wild vegetables is usually done by women. Often they do this while collecting firewood or fodder, which is a regular work, carried out by tribal women. On-farm conservation is carried out by them intentionally or unknowingly. As it is always the women who cook food, it is she who disburses mature or ripe seeds, some of which germinate and develop as new plants.

A careful breeding strategy involving extensive field survey in the fruiting season followed by rescue collection and seed multiplication in on-farm sites and a subsequent ex situ approach is needed for the conservation of variability in semi-domesticate landraces of *M. charantia* var. *muricata*. Artificial seeding and rehabilitation in sacred grooves may be attempted for *M. dioica* in coastal Kerala. Establishment of genetic reserves inside protected areas must be attempted for conserving diversity in *M. dioica* and *M. sahyadrica* in the Western Ghats. Ex situ conservation in home gardens and on-farm conservation in tribal homesteads in forest pockets is a viable option for conservation of *Momordica* gene pool as the taxa are still wild or semi-domesticate with high dependence on biotic agents for pollination and seed dispersal. Popularisation as ornamental plants and kitchen garden vegetables will enhance survival of the taxa and establishment of farms for tuber production will reduce pressure on wild population.

The study of genetic diversity, population ecology and conservation of *Momordica* species is inadequate and limited. As all wild *Momordica* species are potential vegetables besides genetic resources of bitter gourd, sweet gourd and spine gourd, IPGRI through AVRDC should initiate a collection and ex situ conservation programme for all the Asiatic wild *Momordica* species. A good representation of diversity in *M. charantia* has been assembled from India though there are still a few grey areas to be explored more intensely. However, other species and areas need extensive coverage. In the absence of any earlier attempt to collect and conserve this diversity, immediate steps need to be taken in this direction. This perhaps also serves as introspection to the poor state of wild *Momordica* gene pool collection and conservation in the National Agricultural Research System (NARS).

There is a need to conserve the highly heterozygous germplasm of dioecious species by establishing field gene banks. Further, under MTA, it should be made available to gene banks across South and SE Asia for domestication and utilisation. *M. clarkeana, M. denticulata, M. rumphii* (all SE Asia-Malesia) and *M. denudata* (Sri Lanka) need special attention. AVRDC/National agricultural research agencies should develop a strategy for (a) an update of conservation (ex situ) status of wild *Momordica* genetic resources, (b) ex situ regeneration protocol for rare endemics, (c) regulated supply of genuine planting materials to researchers across nationality borders under MTA, (d) clear and concise distribution maps for individual species based on field and herbarium survey and (e) a database on ethno-botanical uses of various species by aboriginal people.

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Crop Improvement

8

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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Keywords
Sex expression · Pollinator · Breeding methods · Improved varieties/hybrids

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 interspecific 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

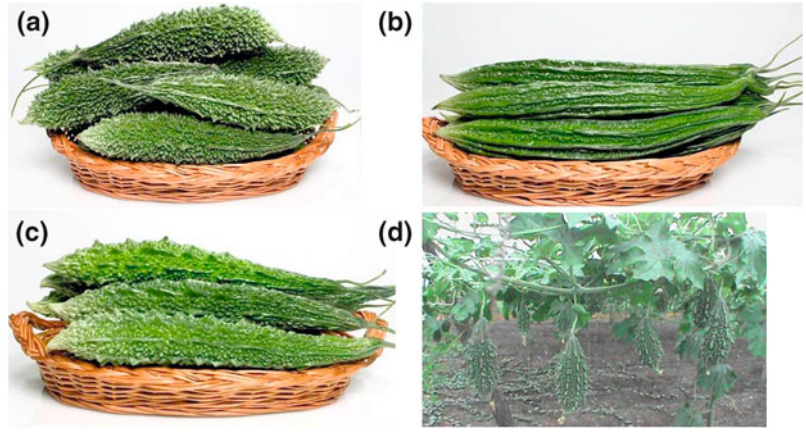

Fig. 8.2 Improved varieties/hybrids of bitter gourd. **a** Chaman, **b** Sarkar, **c** Amanshri, **d** Racer (*Source* Nunhems India Pvt. Ltd., Bangalore)

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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