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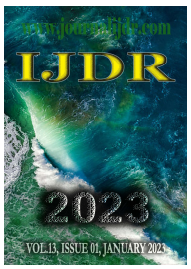

RESEARCH ARTICLE OPEN ACCESS

ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF BITTER GOURD (*Momordica charantia L.)*

***Swamy, K.R.M**

Retd. Principal Scientist & Head, Division of Vegetable Crops, ICAR-Indian Institute of Horticultural Research, Bengaluru- 560089

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****Corresponding author: Swamy, K.R.M***

ABSTRACT

Bitter gourd (*Momordica charantia L.*; 2n= 2x=22.) belongs to the family Cucurbitaceae, the genus Momordica and the species Momordica charantia. It is known as bitter melon, bitter cucumber, bitter squash, balsam pear, karela, cassilla and maiden apple. It is also vernacularly designated as bitter melon, bitter squash, balsam pear, karela, bitter apple, or wild cucumber in different countries and regions The English name is Bitter Gourd, Hindi name is Karela, Sanskrit name is Karvellak, karvelli, Katphala, and Gujrati name is Karelo, Kadhwa. M. charantia originated in Africa and probably was domesticated in eastern India and southern China. It, is an important fast growing warm seasonal climbing annual cucurbit vegetable grown in tropics and subtropics. It is widely cultivated in India, China, Malaysia, Africa, and South America. The immature fruits are used as fried, stuffed, dried and pickled. It is mainly valued for its nutritional and medicinal properties. It has been used for centuries in the ancient traditional medicine of India, China, Africa, and Latin America. Bitter gourd fruits also possess anti-oxidant, anti-microbial, anti-viral, anti- diabetic activities. Among the cucurbits, bitter gourd is considered a prized vegetable because of its high nutritive values in respect of ascorbic acid and iron besides, its immense medicinal values, mainly, for its hypoglycemic properties. Fruit also contains two major alkaloids viz., momordicin and cucurbitacin; momordicin is the momordicoside glycoside of tetracyclic triterpinoides with cucurbitane skeleton (Vandana and Chandra, 1990). Success in any plant breeding program solely depends upon the existence of genetic variability present in the population. It is proved that larger the variability, greater is the scope for selection and improvement. Improvement in yield is normally attained through exploitation of the genetically diverse parents in hybrid breeding programs. Since, the crossing program involving genetically diverse parents is likely to produce high heterotic effects and also more variability could be expected in the segregating generations. In this review article origin, distribution, taxonomy, botanical description, cytogenetics, genetic diversity, breeding, uses, nutritional value, and health benefits of bitter gourd are discussed.

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INTRODUCTION

Bitter gourd (*Momordica charantia L.;* 2n= 2x=22.) belongs to the family Cucurbitaceae, the genus Momordica and the species Momordica charantia. It is known as bitter melon, bitter cucumber, bitter squash, balsam pear, karela, cassilla and maiden apple (Morton, 1967). It is also vernacularly designated as bitter melon, bitter squash, balsam pear, karela, bitter apple, or wild cucumber in different countries and regions (Fang and Ng, 2016). According to Jaiswal (2015) the English name is Bitter Gourd, Hindi name is Karela, Sanskrit name is Karvellak, karvelli, Katphala, and Gujrati name is Karelo, Kadhwa. Recent biogeographic analyses suggest that M. charantia originated in Africa (Schaefer and Renner 2010) and probably was domesticated in eastern India and southern China (Reyes *et al*., 1994).

It, is an important fast growing warm seasonal climbing annual cucurbit vegetable grown in tropics and subtropics. It is widely cultivated in India, China, Malaysia, Africa, and South America (Minraj *et al*., 1993). Bitter melon, balsam pear, or most commonly known as bitter gourd, is a unique fruit-vegetable combination. People worldwide consume this edible pod that belongs to the Cucurbitaceae family (Shukla, 2022). Bitter gourd is an important vegetable crop and is grown for its immature tuberculate fruits which have a unique bitter taste (Vikaspedia, 2022). Most species produce floral oils and are visited by specialist pollinators in the apid tribe Ctenoplectrini (Wikipedia, 2022). It is mainly valued for its nutritional and medicinal properties. It has been used for centuries in the ancient traditional medicine of India, China, Africa, and Latin America. Bitter gourd fruits also possess anti-oxidant, anti-microbial, anti-viral, anti- diabetic activities (Welihinda *et al*., 1986; Raman and Lau, 1996).

The immature fruits are used as fried, stuffed, dried and pickled (Morton, 1967). Among the cucurbits, bitter gourd is considered a prized vegetable because of its high nutritive values in respect of ascorbic acid and iron (Behera, 2004) besides, its immense medicinal values, mainly, for its hypoglycemic properties. The ripe fruits are rich in vitamin A. Fruit also contains two major alkaloids viz., momordicin and cucurbitacin; momordicin is the momordicoside glycoside of tetracyclic triterpinoides with cucurbitane skeleton (Vandana and Chandra, 1990).

Success in any plant breeding program solely depends upon the existence of genetic variability present in the population. It is proved that larger the variability, greater is the scope for selection and improvement. It is the genotypic variability and more specifically the additive variances, which is most important for a plant breeder as, it determines the genetic gain through selection. Yield is a complex entity which is associated with a number of component characters. Before aiming at an improvement in yield, it is necessary to have information on genetic variability and heritability, in respect of important characters associated with yield. Genotypic and phenotypic coefficients of variation are useful in detecting the amount of variability present in the available genotypes. The main purpose of estimating heritability and the genetic parameters that compose the heritability estimate is to compare the expected gains from selection based on alternative selection strategies (Holland *et al*., 2003). Improvement in yield is normally attained through exploitation of the genetically diverse parents in hybrid breeding programs. Since, the crossing program involving genetically diverse parents is likely to produce high heterotic effects and also more variability could be expected in the segregating generations. Genetic diversity between genotypes indicates the differences in gene frequencies. The important bitter gourd growing states are Maharashtra, Gujarat, Rajasthan, Punjab, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, West Bengal, Odisha, Assam, Uttar Pradesh and Bihar. Consumer preferences in bitter gourd vary from region to region depending on size, color, presence or absence of tubercles / ridges and bitterness of fruits (Vikaspedia, 2022).

Origin and Distribution: Recent biogeographic analyses suggest that *M. charantia* originated in Africa (Schaefer and Renner 2010) and probably was domesticatedin eastern India and Southern China (Reyes *et al*., 1994). The genus *Momordica* is a native of the Paleotropics and comprises about 60 species. Bitter gourd grows in tropical and subtropical areas, including parts of East Africa, Asia, the Caribbean, and South America, where it is used not only as a food but also as a medicine (Asna *et al*., 2020). Bitter gourd, *Momordica charantia* L., plausibly originated in Eastern Asia, is traditionally cultivated as a vegetable and medicinal crop in tropical and subtropical areas in Asia, South America, East Africa, and the Caribbean (Behera *et al*., 2020). It is also extensively grown in China, Japan, South East Asia, tropical Africa and South America. It is also known as hitter melon balsam pear Estimated area in India is 60,000 hectares (Vidhi, 2022). Bitter gourd is extensively cultivated in numerous Asian countries (especially China, India, Japan, and Malaysia), East Africa, the Caribbean, the Amazon, and also some parts of South America (Fang and Ng, 2016).

TAXONOMY

Momordica, is a genus of annual or perennial climbers. It is a large genus consisting of about 80 species, of which *Momordica charanti*a Linn is widely cultivated (Mini Raj and Peter, 2012). Bitter gourd (*Momordica charantia* L.) belongs to the genus *Momordica* that includes 45 species. It is cultivated extensively in tropical, subtropical, and rarely under temperate climates (Saglam Yilmaz and Khawar, 2020). Genus Momordica blongs to the family Cucurbitaceae, subfamily Cucurbitoideae and the tribe Momordiceae. *Momordica* is a genus of about 60 species of annual or perennial climbers herbaceous or rarely small shrubs belonging to the family Cucurbitaceae (Wikipedia, 2022).

Synonyms of *Momordica* (Long An, 2015; Wikipedia, 2022).

1. *Calpidosicyos* Harms
2. *Dimorphochlamys* Hook.f.
3. *Dimorphoclamys* Hook.f.
4. *Eulenburgia* Pax
5. *Muricia* Lour.
6. *Neurosperma* Raf.
7. *Neurospermum* Bartl., orth. var.
8. *Nevrosperma* Raf., orth. var.
9. *Raphanistrocarpus* (Baill.) Pax
10. *Raphanocarpus* Hook.f.
11. *Zucca* Comm. ex Juss.

Accepted species of *Momordica* are as follows (Long An, 2015; Wikipedia, 2022**):**

1. *Momordica angolensis* R.Fernandes
2. *Momordica angustisepala* Harms
3. *Momordica anigosantha* Hook.f.
4. *Momordica balsamina* L.
5. *Momordica boivinii* Baill.
6. *Momordica cabrae* (Cogn.) C.Jeffrey
7. *Momordica calantha* Gilg
8. *Momordica camerounensis* Keraudren
9. *Momordica charantia* L. - Bitter melon
10. *Momordica cissoides* Planch. ex Benth.
11. *Momordica clarkeana* King
12. *Momordica cochinchinensis* (Lour.) Spreng. - Gac
13. *Momordica corymbifera* Hook.f.
14. *Momordica cymbalaria* Hook.f.
15. *Momordica denticulata* Miq.
16. *Momordica denudata* C.B.Clarke
17. *Momordica dioica* Roxb. ex Willd.
18. *Momordica enneaphylla* Cogn.
19. *Momordica foetida* Schumach.
20. *Momordica glabra* Zimmerman
21. *Momordica henriquesii* Cogn.
22. *Momordica involucrata* E.Mey.
23. *Momordica jeffreyana* Keraudren
24. *Momordica laotica* Gagnep.
25. *Momordica leiocarpa* Gilg
26. *Momordica littorea* Thulin
27. *Momordica macrophylla* Gage
28. *Momordica mannii* Hook.f.
29. *Momordica mossambica* H.Schaef.
30. *Momordica multiflora* Hook.f.
31. *Momordica obtusisepala* Keraudren
32. *Momordica parvifolia* Cogn.
33. *Momordica peteri* A.Zimm.
34. *Momordica pterocarpa* Hochst.
35. *Momordica repens* Bremek.
36. *Momordica rostrata* A.Zimm.
37. *Momordica sessilifolia* Cogn.
38. *Momordica silvatica* Jongkind.
39. *Momordica spinosa* Chiov.
40. *Momordica suringarii* Cogn.
41. *Momordica trifoliolata* Hook.f.
42. *Momordica welwitschii* Hook.f.

Important species of the genus *Momordica* (Long An, 2015)

***Momordica balsamina* L.-Africa cucumber:** *Momordica balsamina* L. is a tendril-bearing annual vine native to the tropical regions of Africa, introduced and invasive in Asia, Australia, and Central America. It has pale yellow, deeply veined flowers and round, somewhat warty, bright orange fruits, or "apples". When ripe, the fruits burst apart, revealing numerous seeds covered with a brilliant scarlet, extremely sticky coating. The balsam apple was introduced intoEurope by 1568 and was used medicinally to treat wounds. The outer rind and the seeds of the fruit are poisonous. *Momordica balsamina* and the related *Momordica charantia* share some common names: "African cucumber", "balsam apple", and "balsam pear".

Other names for *Momordica balsamina* are "balsamina" or "southern balsam pear". It is known in Africa under a broad range of names, e.g. in Mozambique as *cacana* and in South Africa as *nkaka* (Long An, 2015). *M. balsamina* is a wild bitter gourd in Northern and Eastern states of India. The fruit of this species are spindle shaped, green with 6–9 regular or irregular rows of cream or yellowish blunt spines. It is genetically diverse from the genepool of *M. charantia* and accession THMC 281 has been found resistant to melon fly, *Bactrocera cucurbitae* (Dhillon *et al*., 2016b).

***Momordica charantia* L. – Bitter Melon**: *Momordica charantia* L., known as Bitter melon, bitter gourd, bitter squash or balsam-pear in English, has many other local names. Goya from Okinawan and karela from Sanskrit are also used by English-language speakers. It is a tropical and subtropical vine of the family Cucurbitaceae, widely grown in Asia, Africa, and the Caribbean for its edible fruit, which is extremely bitter. Its many varieties differ substantially in the shape and bitterness of the fruit. Bitter melon originated on the Indian subcontinent, and was introduced into China in the 14th century (Long An, 2015).

***Momordica cochinchinensis* (Lour.) Spreng. – Gac:** *Momordica cochinchinensis* (Lour.) Spreng. - Gac is a Southeast Asian fruit found throughout the region from Southern China to Northeastern Australia, including Thailand, Laos, Myanmar, Cambodia and Vietnam. It is commonly known as Gac from the Vietnamese *gấc* or *quả gấc* (*quả* being a classifier for spherical objects such as fruit). It is known as *mùbiēguǒ* in Chinese and variously as *red melon*, *baby jackfruit*, *spiny bitter gourd* or *cochinchin gourd* in English. In Thai, it is pronounced *fahk khao* and *taw thabu* in Myanmar. Gac or Red Melon, grows on dioecious vines and is usually collected from fence climbers or from wild plants. The vines can be commonly seen growing on lattices at the entrances to rural homes or in gardens. It only fruits once a year, and is found seasonally in local markets. The fruit itself becomes a dark orange color upon ripening, and is typically round or oblong, maturing to a size of about 13 cm in length and 10 cm in diameter. Its exterior skin is covered in small spines while its dark red interior consists of clusters of fleshy pulp and seeds (Long An, 2015).

***Momordica cymbalaria* Hook.f./ *Luffa tuberose* (Roxb.)/ *Momordica tuberosa* (Roxb.):** *Momordica cymbalaria* (Hook., Fenzl ex Naud.) is a vine of the *Momordica* genus found in the Indian states of Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra and Tamil Nadu. It is used in the local folk medicine as an abortifacient and for the treatment of diabetes mellitus. It is a relative of the bitter melon plant (*Momordica charantia*) which is also used against diabetes (Long An, 2015).

***Momordica dioica* Roxb. ex Willd - Spine gourd:** Species *Momordica dioica* Roxb. ex Willd., commonly known as spiny gourd and also known as kantola, is a species of flowering plant in the gourd family. Spine gourd is a highly nutritious and underutilized vegetable containing high amount of protein as compared to other cucurbitaceous vegetables. It is used as a vegetable in all regions of India and some parts in South Asia. It has commercial importance and is exported and used locally. The fruits are cooked with spices,or fried and sometimes eaten with meat or fish (Long An, 2015).

***Momordica enneaphylla* Cogn:** *Momordica enneaphylla* is a species of plant in the Cucurbitaceae family. It is found in Cameroon, the Democratic Republic of the Congo, and Gabon. Its natural habitats are subtropical or tropical moist lowland forests and subtropical or tropical swamps. It is threatened by habitat loss. This little known species was first collected in Gabon, being described in 1888. Found in primary forest, including riverine and swamp forest; occasionally in secondary forest growth; 450-1,070 m alt. Collections from the Democratic Republic of Congo are all from the central Congo Basin. In Cameroon, the discovery of two sites in the Kupe-Bakossi area, on Mt Kupe above Kupe Village and at Ngomboku in the Bakossi Mts, extends this species' range northwestwards. On Mt Kupe, this species is recorded in forest down to 900 m, which is below the lower limit of effective protection on this mountain, thus this subpopulation is threatened by forest clearance (Long An, 2015).

***Momordica foetida* Schumach:** *Momordica foetida* is a perennial climbing vinenative of tropical Africa, closely related to the bitter melon (*Momordica charantia*) and balsam apple (*Momordica balsamina*). Its species name ("bad-smelling") refers to its unpleasant smell. It was previously named *Momordica morkorra* (A. Rich) and *Momordica cordata* (Cogn.). The plant grows in forest edges and similar habitats (including disturbed and cultivated land), woodland, and wooded grassland. Its leaves are wrinkled, heart-shaped with irregular edges, up to 18 cm wide. The flowers are yellow to yellow-orange. The fruit is a elongated/prolate spheroid, 3.5-7.5 cm long and 2.5-5 cm wide, bright orange and covered with soft spines. When fully ripe it splits from the bottom into three valves, exposing a cluster of black seeds, individually covered by a bright red, sticky, sweet pulp. The plant has perennial tuberous roots (Long An, 2015) (Fig. 1).

Asiatic species of different sects are as follows (BDBG, 2022):

Sl. No.	Sects	Species
1	*Cochinchinensis*	*M. cochinchinensis* *M. dioica* *M. sahyadrica* *M. denticulata* *M. denudata* *M. clarkeana* *M. subangulata*
2	*Momordica*	*M. charantia* *M. balsamina*
3	*Raphanocarpus*	*M. cymbalaria*

According to Kasera (2012) the related species are *M. dioica* Roxb. ex Wild., *M. Tuberosa* (Roxb.) Cogn., *M. balsamina* L., *M. cochinchinensis* and *M. cabriei.* The Wild species are *M. subangulata* Bl., *M. denudata* and *M. macrophylla.* Two botanical varieties *viz.*, var. c*harantia* synonymous with large-fruited cultivated Chinese bitter melon and var. *muricata* representing small-fruited, predominantly wild forms were recognized (Asna *et al*., 2020).

BATONICAL DESCRIPTION

After seeding, *Momordica* develops leaves in about 11 days and flowers after 40 to 50 days. After fertilisation, the *Momordica* fruit will be developed in about 10 days (Wikipedia, 2022). It is a luscious, climbing vine with slightly fuzzy stems clothed with dark green, deeply lobed leaves and yellow, dioecious flowers (Vikaspedia, 2022). *Momordica charantia* L. - Bitter Melon is an herbaceous, tendril-bearing vine grows to 5 m. It bears simple, alternate leaves 4-12 cm across, with three to seven deeply separated lobes. Each plant bears separate yellow male and female flowers. The fruit has a distinct warty exterior and an oblong shape. It is hollow in cross-section, with a relatively thin layer of flesh surrounding a central seed cavity filled with large, flat seeds and pith. The fruit is most often eaten green, or as it is beginning to turn yellow. At this stage, the fruit's flesh is crunchy and watery in texture. The skin is tender and edible. Seeds and pith appear white in unripe fruits; they are not intensely bitter and can be removed before cooking. As the fruit ripens, the flesh (rind) becomes somewhat tougher and more bitter, and many consider it too distasteful to eat. On the other hand, the pith becomes sweet and intensely red; it can be eaten uncooked in this state, and is a popular ingredient in some Southeast Asian salads. When the fruit is fully ripe, it turns orange and mushy, and splits into segments which curl back dramatically to expose seeds covered in bright red pulp (Long An, 2015) (Fig. 2). As the name says, bitter gourd has a bitter and sharp pungent taste. It has ugly-looking gourd-bumps all over it. It is not so attractive but a complete package of benefits. This is a green vegetable that grows on vine-tendril. And it is a flowering plant. When the fruit gets fully ripe and yellow-green in color. it bears bright red pulps that are used for the cultivation of the plant. Generally, it is grown all over India. It has a soft and hairy stem. The plant bears leaves which are 3.5 cm broad, round with deep serrated corners and divided into 5-7 sections.

Fig. 1. Accepted species of *Momordica*

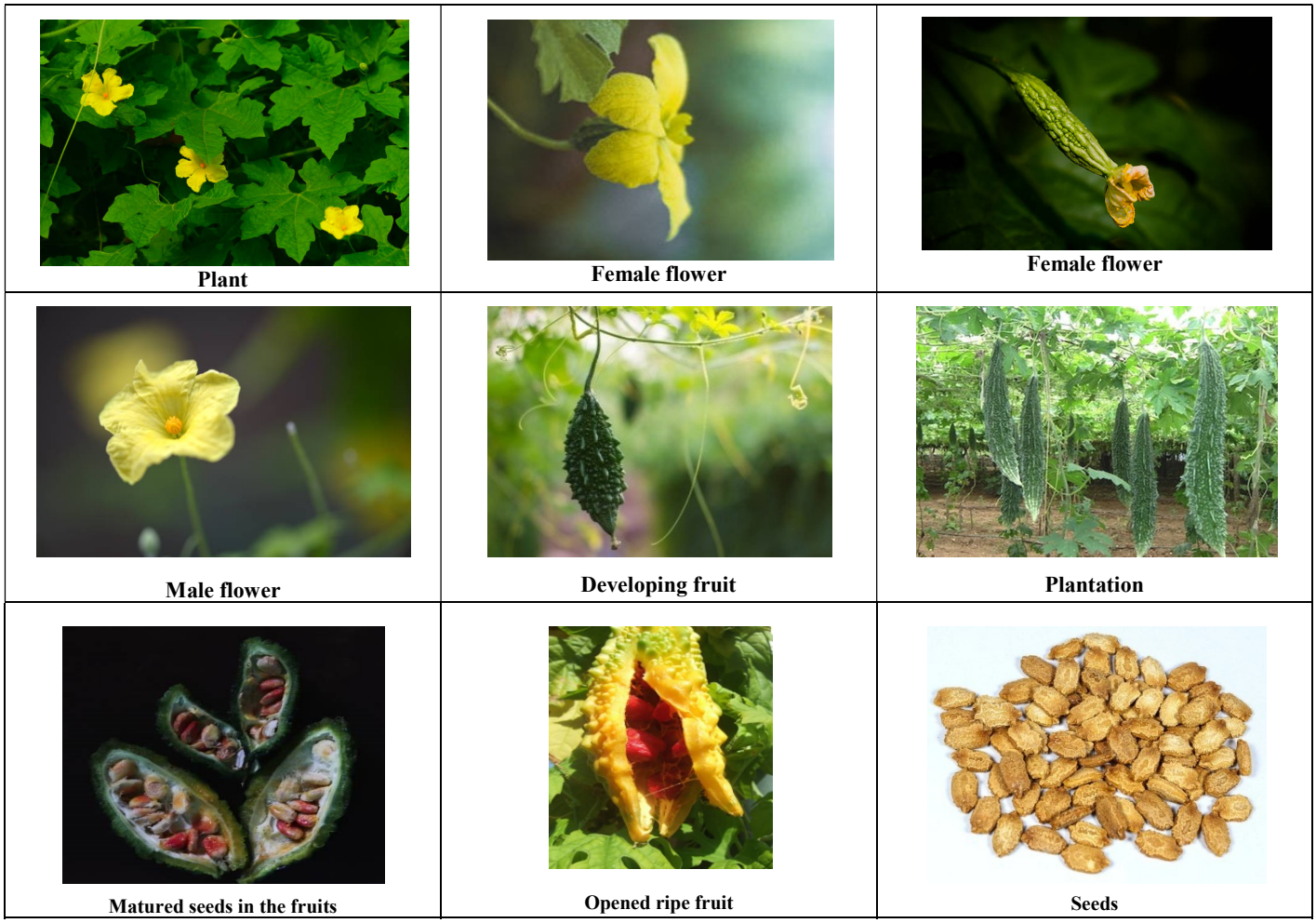

Fig. 2. Botanical description of bitter gourd

It bears flowers which are yellow and shiny. The fruits *i.e.,* Bitter gourd is triangular oval in shape, with triangular eruptions which give them rough surface. When it gets ripe, it turns into yellow (Jaiswal, 2015). Because bitter gourd is monoecious, both male and female flowers are borne on the same plant. The oblong fruit, which is also named bitter gourd, matures 30–50 days after the onset of flowering as depicted by changes in the color of the warty exterior from green to orange. At the time the fruit has fully matured, the tender pericarp splits into segments and curls back to expose the seeds. Figure 1 depicts its main morphological characteristics.

Because bitter gourd has many varieties and cultivars, the fruits in the market are also seen in different shapes (cylindrical and plump) and colors (e.g., white, light green, and dark green) (Fig. 3) (Fang and Ng, 2016). The fruit of ridge gourd is the main part of the plant that has been used for food and medicinal purposes. It is oblong in shape, narrow at both ends, and 6–16 cm long. The outer skin of the fruit is thick and ribbed, green when raw, and orange when ripe. When ripe, it becomes soft and fleshy, opening to reveal pendulous seeds covered with red pulp (Garg, 2016).

GENETICS AND CYTOGENETICS

The somatic chromosome number of bitter gourd is 2n = 2x = 22. The length of chromosome ranges from 1 to 2 µm. Six chromosome pairs are median (centromere in middle of chromosomes), three sub-median (centromere between mid-point and terminal end of chromosomes) and two sub-terminal (Vidhi, 2022). It has a simple genome with $2n = 22$ chromosomes having a genome size of around 339 Mb (Behera *et al*., 2020). There are many studies about chromosomal characteristics of *Momordica charantia*, known as bitter gourd, a vegetable species with medicinal properties. The published data include characterization of the meiosis; haploid and diploid chromosome number; description of chromosome morphology, with chromosome length and primary constriction position; more recently there has been a focus of cytomolecular investigations, with localization of ribosomal DNA (rDNA) sequences and distribution pattern of heterochromatin bands. Usually, the *M. charantia* karyotype is presented as symmetric, composed of 22 small chromosomes with similar morphology, with two pairs of 45S rDNA, colocalized with CMA positive bands, and one pair of 5S rDNA. The chromosome counts for *Momordica* genus indicate two basic numbers: $x = 11$ and $x = 14$, dividing the genus into two groups with distinct characteristics. Polyploid counts were observed in both species' groups. Variation in number and position of the cytogenetical markers were registered between the different species, evidenced by CMA fluorochrome banding. The karyotype evolution for *Momordica* may be related to the structural chromosome mutation associated with numeric chromosome variations (Lombello, 2020).

Sex expression in the bitter gourd is mainly categorized into monoecious—staminate and pistillate flowers are produced separately in the same plant. Genes for its sex determination mechanism are quite important for genetic improvement through breeding, including the production of hybrid cultivars. For elucidating on sex determination in bitter gourd, a few gynoecious bitter gourd lines, showing only the female flowers, are found and employed as the maternal parent of F_1 hybrid cultivars. Each of these gynoecious lines was predicted to be determined by a single recessive locus, which was genetically mapped. In monoecious bitter gourd, various ratios between female and male flowers per a plant (sex ratio) were observed and frequency of female flowers is an influential trait for the yield of fruits. By genetic mapping approaches, quantitative trait loci for female flower frequency were found. According to bitter gourd draft genome sequences, putative orthologs of these sex determination genes could be identified. In other *Momordica* species, both monoecious and dioecious species were diverged. Genetic and genomic studies of sex determination in bitter gourd will greatly contribute to elucidate the evolution of monoecy and dioecy (Matsumura *et al*., 2020). Much progress has been attempted in classical genetics and traditional breeding of bitter gourd which are mainly related to qualitative traits but significant advancement in several quantitative traits is difficult to achieve. The study on classical genetics of bitter gourd has added an advantage to the breeders in the development of new varieties and F_1 hybrids for earliness and higher productivity due to the involvement of gynoecious lines as one of the parents in breeding of these varieties. The selection based on morphological traits for high and stable yield requires the evaluation of germplasm in multiple environments over several seasons; which is very expensive and time-consuming process. Molecular markers technology have great potential to overcome many of the obstacles presented by traditional breeding techniques, but it is imperative that the development and utilization of these markers works in conjunction with traditional breeders who have necessary skill to evaluate the germplasm lines of economic value. Marker-assisted selection (MAS) certainly accelerates the breeding process and is a powerful tool for selecting for desirable traits. The construction of a genetic map is a common approach to detect quantitative trait loci (QTLs) for genetic improvement of bitter gourd (Behera *et al.,* 2020).

GENETIC DIVERSITY

The species is monoecious (produces separate male and female flowers on the same plant) and tends to cross-pollinate, a mechanism that tends to promote phenotypic and genotypic diversity (Schaefer and Renner 2010). Wide variability was noticed especially among cultivated types for fruit and seed morphology (Asna *et al*., 2020). Fruit colors range from white or cream to light-green to dark-green, and shapes include cylindrical, elliptical, spin- dle and conical types. Fruits develop irregular longitudinal ridges and warty skin, depending upon the variety. Based on these fruit traits, nearly 20 market types of bitter gourd exist in Asia, and nearly half are cultivated in India, China, Nepal, Bangladesh, and Sri Lanka (Fig.4) (Dhillon *et al*., 2016). Analysisof 38 Indian bitter gourd landraces from eastern India indicated that genotypes Mohanpur Sel-215 and Jayanagar Sel-1 were highly diverse, based on AFLP markers (Gaikwad *et al*., 2008). Analysis of 212 bitter gourd accessions from 15 countries in Asia, South America and Africa using 36 SSR markers demonstrated that accessions from China, India and South America were genetically divergent and clustered in three separate subpopulation groups. Twenty eight F1 crosses developed from 8 x 8 diallel analysis excluding reciprocals were evaluated at, Hyderabad to determine the various parameters of genetic variability and nature of interrelationships among traits affecting yield in bitter gourd. Analysis of variance showed highly significant differences for all the characters studied. High heritability in association with high genetic advance as per cent of mean was observed for yield/vine, number of fruits/vine, average fruit weight, fruit length, vine length and number of laterals/vine. Yield /vine expressed positive and significant genotypic association with number of fruits/vine, average fruit weight, vine length, number of laterals/vine and fruit length whereas significant negative association with sex ratio, days to 1st female flower and node number at 1st female flower appeared. Path analysis studies revealed that number of fruits/vine is the most important yield attributing trait followed by average fruit weight. Hence, due emphasis should be given to these traits while selecting the genotypes for improvement of yield in bitter gourd (Rani *et al*., 2015).

Forty genotypes of bitter gourd collected from different agro-climatic regions of India were evaluated to assess the variability, heritability, genetic advance. Quantitative and qualitative characters like days to first male flower, days to first female flower, node number of first male flower, node number of first female flower, sex ratio, vine length (m), number of primary branches per vine, days to first fruit harvest, fruit length (cm), fruit girth (cm), average fruit weight (g), number of fruits per vine, seeds per fruit, TSS (^{0}Brix), ascorbic acid content (mg/100g) and fruit yield per plant (kg) were studied. Analysis of variance revealed that there were significant differences among the genotypes studied for all the characters. In variability studies, among 40 genotypes MC 13 was identified as the best genotypes as it recorded higher yield per vine followed by MC 1, MC 20 and MC 14. Maximum phenotypic and genotypic coefficient of variation (PCV and GCV) was found for fruit yield per vine followed by the number of fruits per plant and sex ratio. High heritability was observed for all the characters. Genetic gain was maximum for fruit yield per vine followed by number of fruits per vine. The characters like yield per vine, number of fruits per plant and sex ratio had high heritability along with high genetic gain which reveals the predominance of additive gene action of these characters (Singh and Kandasamy, 2020). Thirty one genotypes of bitter gourd (*Momordica charantia* L.) were evaluated for 10 quantitative traits. Significant differences among bitter gourd genotypes indicated the presence of wide variation for all the traits. All the 10 traits showed significant and positive association with yield. Genotype IIHR-147-4 took the shortest time to first female flower appearance (26.57 days after planting). A close proximity in the phenotypic and genotypic coefficients of variability was observed for peduncle length, fruit length, fruit girth, number of fruits, fruit weight and fruit yield indicating little influence of environment for the expression of these traits. High heritability was recorded for peduncle length, fruit length, fruit girth and fruit weight. Number of fruits followed by fruit weight, fruit length and fruit girth exhibited maximum positive direct effect on fruit yield. Principal component analysis revealed that first three principal components (PC1, PC2 and PC3) accounted for 72.28% of the total variation with the proportionate contribution values of 40.83, 17.43, and 14.01 respectively.

Fig. 3. Genetic variability for shape, color and size of bitter gourd

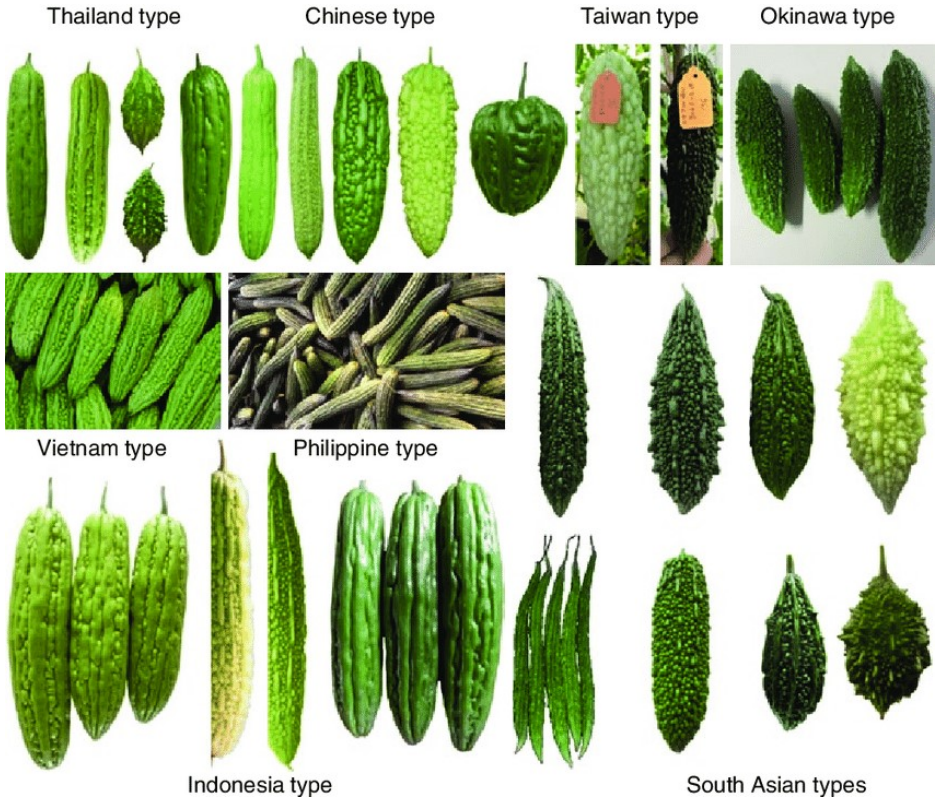

Fig. 4. Genetic variability of bitter gourd in market types

The genotypes were grouped in to four different clusters based on the genetic distance. The divergence value for cluster analysis indicated that the genotypes from clusters I and II had the highest inter-cluster distance and were expected to provide high heterosis if crossed and to show wide variability in genetic architecture (Prasanth *et al*., 2020). Ample genetic diversity has been found to exist in this crop as assessed by the use of molecular markers. Association mapping led to the detection of molecular markers linked to some fruit traits and content of a couple of phytomedicines. A few molecular genetic maps have been constructed and a number of agroeconomically important qualitative and quantitative fruit traits have been mapped. Recently, a draft genome sequence has also been reported and a few studies on genotyping by sequencing and RAD sequencing have been accomplished (Behera *et al*., 2020). In the species *M. charantia*, a huge diversity is reported for important morphological traits including fruit shape, size, yield, and earliness besides several other vegetative and commercial traits. The genus *Momordica* is known for its antidiabetic and other medicinal properties. Huge diversity is reported in terms of concentration of different phytomedicinal compounds including momordicin, momorcharin, β-carotene, and lycopene. While studying diversity in molecular level, RAPD, ISSR, SSR, and other sequence-based markers were used that revealed the molecular diversity. The combined information available in terms of morphological, nutritional, and molecular diversity present in this important crop can help the breeder in deciding the breeding material and approach to harness more productivity and enhance nutritional traits in bitter gourd using different methods (Behera *et al*., 2020).

BREEDING

Genetic Resources: Bitter gourd genetic resources are conserved *in situ* in various genebanks in Asia. Nearly 1000 accessions of bitter gourd are stored in the national genebanks of India at various locations (New Delhi, Jodhpur, Hyderabad, Thrissur, Shillong, Ranchi), and 250 accessions are available in the genebanks of Kasetsart University, Thailand. The Chinese Academyof Agricultural Sciences holds 177 bitter gourd accessions in several provinces such as Guangdong, Guangxi and Yunnan. The World Vegetable Center (WorldVeg) (http://avrdc.org/seed/ seeds/) listed 425 bitter gourd accessions in 2016, with 139 (33 %) of them available for distribution, the others were either unavailable (4 %) or inactive (63 %; Table 1). The U.S. Germplasm Resources Information Network (GRIN [Internet]. Beltsville (MD): United States Department of Agriculture, Agricultural Research Service. http://www.ars-grin.gov/) listed 103 *M. charantia* accessions, as seeds, from 22 countries, including 48 from India, but only one accession was avail-able in 2016 (Dhillon *et al*., 2016). Kerala Agriculture University, Vellanikkara and Indian Institute of Horticultural Research, Bangalore, are rich sources of bitter gourd germplasm lines. In northern India, NDUAT, Faizabad, CSAUAT-Vegetable Research Station, Kalayanpur, GBPUA&T, Pantnagar and IARI, New Delhi and IIVR, Varanasi have collection of good number of promising lines of bitter gourd (Vidhi, 2022).

Breeding Objectives: According to Kasera (2012) the breeding objectives are 1) Breeding for Early fruiting, 2) Breeding to get High female to male sex ratio, 3) Breeding for Less ridged fruit surface, 4) Breeding for Thick fruits particularly suitable for stuffing, 5) Breeding for Fruit size variation as per consumer's preference (small-7.5–10 cm long, medium long– 10-15 cm, long– 15-20 cm and extra long– 20-40 cm), 6) Breeding for Immature seeds for longer period during green edible stage, 7) Breeding for High yield, and 8) Breeding for Resistance to red pumpkin beetle, epilachana beetle, fruit fly and mosaic virus. Mini Raj and Peter (2012) stated that breeding for self-staked varieties—varieties that are high yielding and early bearing—and development of lines resistant to fruit fly are a few of the major breeding objectives in bitter gourd. There is great scope to exploit heterosis in this crop. Evolving varieties suited for canning and dehydration is yet another objective. According to Vidhi (2022) the breeding objectives of bittergourd are as follows:

- Early fruiting
- High female to male sex ratio
- Fruit shape, size, colour and spininess as per consumers' preference:
  - Short, oval, spiny, green, 7-8 cm long,
  - Short, spindle, spiny, green, 15 cm long
  - Medium long, spindle, spiny, green, 20 cm long
  - Smooth, spindle, green, 20 cm long
  - Medium long, spiny, white, 20 cm long
  - Long, spiny, white, 30 cm long
  - Tough spines for long distance transportation
- Immature seeds for longer period during green edible stage
- High yield (a product of number of fruits and fruit weight)
- Resistance to powdery mildew, downy mildew, mosaic

BREEDING METHODS

Single plant selection, mass selection, pedigree method, and bulk population method are the common breeding methods followed for bitter gourd breeding. Heterosis is exploited in bitter gourd breeding as well. As this plant is monoecious, production of F_1 hybrids is simple and economical (Mini Raj and Peter, 2012). Single plant selection, mass selection, pedigree selection, and bulk population improvement are common methods are used widely in the bitter gourd improvement program. Recent discovery of gynoecious lines and their genetics will facilitate hybrid breeding (Behera *et al.,* 2020). Inbreeding, pure-line selection in segregating generations and heterosis breeding as described in other cucurbits, particularly bottlegourds are applicable to bittergourd (Vidhi, 2022). Breeders focus primarily on elite × elite crosses to capitalize on previous breeding successes. This has resulted in genetic uniformity among commercial cultivars,which could increase the overall risk to farmers due to pests and diseases. Trait- specific breeding pays rich dividends to commercial breeding programs. Systematic and comprehensive evaluations of the global collection of bitter gourd can providetraits for sustainable production and new genetic diversity (Dhillon *et al*., 2016). Use of a gynoecious inbred in hybrid development reduces the cost of F_1 hybridseed production and enhances seed purity. Breeders have developed gynoecious inbreds (DBGy-201, Gy263B, OHB61–5) with better combining ability that improved early and total fruit yield in bitter gourd hybrids (Ram *et al*. 2006). According to Kasera (2012) in India little attention has been paid for the genetic improvement of bitter gourd. The morphological characterization and assessment of the variability parameters are meager. Several methods usually are employed in tandem to accomplish breeding objectives. Single plant selection, mass selection, pedigree selection, and bulk population improvement are common methods used for bitter gourd enhancement. Pedigree selection typically is used after crossing two parents for the development of inbred lines with high, early yield borne on a unique plant habit, and with high-quality fruit.

Selection Method: Single plant selection and mass selection methods have been followed to develop high-yielding bitter gourd lines in India. Pusa do mausami, Preethi, Priyanka, Konkan Tara, Arka Harit, CO1 and Pusa Vishesh have been developed through single plant selection and selfing (Kasera, 2012).

Hybridization: The mating or crossing of two dissimilar plants or lines is known as hybridization. In plants crossing is done by placing pollen grains from one line or genotype, called the male parent on to the stigma of flowers of the other genotype, referred to as the female parent. The seeds as well as the progeny resulting from hybridization are known as hybrid or F_1 and it's advance generations are called segregating generations (Kasera, 2012). For crossing purposes, female flower buds ready to flower in next 1-2 days are covered by cotton pad wrapping/small paper bags. Likewise male flower buds ready to open next morning are also covered. Pollination is carried out by rubbing staminate flower anthers from freshly opened flowers against the stigma of the protected pistillate flowers. The crossed flowers are covered as above for few more days to avoid contamination/pollination from other plants brought by insects.

Tagging is simultaneously done by writing the parentage and date of pollination. In order to increase crossed fruit set, other open-pollinated fruits already set may be removed to avoid inhibitory effects of these fruits on further fruit setting (Vidhi, 2022). *M. charantia* × *M. balsamina* hybrids are difficult to obtain (Bharathi *et al*., 2012).

Bulk method: In bulk method, F_2 or the subsequent generations are harvested in mass to raise the next generation. At the end of bulking period, individual plants are selected and evaluated in F_8 generations and superior progenies released as a new cultivar. This method is also termed as mass or population method (Kasera, 2012).

Pedigree Method: Pedigree breeding is a method of genetic improvement of cross pollinated species in which superior genotypes are selected from segregating generations and proper record of ancestry of selected plants are maintained in each generation. It is generally used when both the parents that are used in the hybridization have good agronomic traits or well adapted. It is more commonly used for the improvement of polygenic traits. In this, individual plant are selected in F_2 for raising for F_2 families of each selection, and from F_3 onward selection is made between and within families. The selection continues until. F_6 or F_7 generation, when almost all families become homogenous. The genetic constitution of the variety developed by this method is homozygous and homogeneous, because it is progeny of single homozygote (Kasera, 2012).

Heterosis: Heterosis is the superiority of an F1 hybrid over both of its parents in terms of yield or some other character. Heterosis is manifested as an increase in vigor, size, growth rate and yield. Bitter gourd is a cross-pollinated crop, exploitation of heterosis (hybrid vigor) is an important aspect of its improvement. Heterosis in bitter gourd was investigated at the Indian Agricultural Research Institute, New Delhi, as early as 1943. Heterosic effect is likely attributable to earliness, first node to bare fruit (first pistillate flowering node), and total increased fruit number. Several hybrids developed by private and public sectors breeding efforts are cultivated in Asia, including China and India (Kasera, 2012).

Mutation Breeding: The genetic improvement of crop plants for various economic traits through the use of induced mutation (mutation that are induced by the treatment of mutagenic agents *viz.*; gamma rays, 5 B.U., E.M.S., etc.) is referred to as mutation breeding. One such bitter gourd cultivar, MDU 1, developed as a result of gamma radiation (seed treatment) of the landrace cultivar MC 103, was found to possess improved yield. Likewise, the white bitter gourd mutant Pusa Do Mausami' (white fruited type) was developed through spontaneous mutation from the natural population Pusa Do Mausmi' (green-fruited type) at the Indian Agriculture Research Institute (Kasera, 2012).

QUALITATIVE GENETICS OF BITTERGOURD

In bitter gourd the fruit colour (green vs white), seed colour (dark brown vs. whitish brown) and seed size (small vs. large) have been reported to be monogenically controlled with dominance of green over white colour fruit, dark brown over whitish brown seed and small seed size over large seed size, respectively. Rare occurrence of complete gynoecism has been reported at IIVR, Varanasi by Dr. D. Ram and his associates in bitter gourd. Inheritance was examined in gynoecious line (Gy 263 B). The F_2 and testcross data revealed that gynoecism in Gy 263B was found to be under the control of single recessive gene designated as gy-1 (Vidhi, 2022).

Varieties/Hybrids of Bitter Gourd

Bitter melon comes in a variety of shapes and sizes. The cultivar common to China is 20-30 cm long, oblong with bluntly tapering ends and pale green in color, with a gently undulating, warty surface. The bitter melon more typical of India has a narrower shape with pointed ends, and a surface covered with jagged, triangular "teeth" and ridges. It is green to white in color. Between these two extremes are any number of intermediate forms. Some bear miniature fruit of only 6-10 cm in length, which may be served individually as stuffed vegetables. These miniature fruit are popular in Bangladesh, India (common name 'Karela'), Pakistan, Nepal and other countries in South Asia. The sub-continent variety is most popular in Bangladesh and India (Long An, 2015). People in tropical parts of the world like Asia, South America and Africa cultivate bitter gourd. However, it is highly treasured in India and China specifically. It is a staple in the majority of their cuisine. The Indian variety has a narrower appearance with pointy ends and jagged, rough spikes on the rind. On the other hand, the Chinese type is typically long and covered with wart-like bumps. If you aren't aware of the magical benefits bitter gourd offers, check out the helpful information about these pods in the following sections (Shukla, 2022). "Pusa Do Mausami," "Arka Harit," "Priya," "Balsam Pear," "Coimbatore Long," and "Pusa Visesh" are a few of the high-yielding selections in bitter gourd (Mini Raj and Peter, 2012). Bitter melon comes in a variety of shapes and sizes. The cultivar common to China is 20-30 cm long, oblong with bluntly tapering ends and pale green in color, with a gently undulating, warty surface. The bitter melon more typical of India has a narrower shape with pointed ends, and a surface covered with jagged, triangular "teeth" and ridges. It is green to white in color. Between these two extremes are any number of intermediate forms. Some bear miniature fruit of only 6-10 cm in length, which may be served individually as stuffed vegetables. These miniature fruit are popular in Bangladesh, India (common name '*Karela*'), Pakistan, Nepal and other countries in South Asia. The sub-continent variety is most popular in Bangladesh and India (Long An, 2015). *Characteristics of Varieties /Hybrids of Bittergourd Developed in India (Vidhi, 2022; Vikaspedia, 2022)*

Pusa Do Mausami: This variety has been obtained through selection from local germplasm at IARI and released by the same organization. It is suitable for spring-summer and rainy both the seasons. The fruits attain edible stage in about 55 days from sowing. The fruits are dark-green, long (18 cm), medium thick, somewhat club shaped having 7-8 continuous ridges. At edible stage, 8-10 fruits weigh one kg. VK-1 (Priya). This variety came as a result of selection at Kerala Agricultural University, Vellanikkara in the local germplasm. It is characterized by extra-long fruits (40 cm) and heavy fruiting (about 50 fruits/plant). The fruits are white.

Arka Harit: This was developed through selection from local materials of Rajasthan at IIHR, Bangalore and also released by the same institute as back as in 1973. The fruits are spindle shaped, attractive, glossy green with smooth regular ribs and thick flesh. The yield potential is about 120 q/ha in 120 days.

Pusa Vishesh: It is a dwarf-vine variety suitable for planting at higher plant density than that of long-vined other varieties. The fruits are glossy-green, medium long, thick and suitable as vegetable type, for stuffing and dehydration. It has been released by IARI release committee New Delhi. It is particularly suitable for spring summer season in northern plains. It takes about 55-60 days to first harvesting.

Kalyanpur Barahmasi: This has been developed at CSAUAT-Vegetable Research Station, Kalyanpur, Kanpur. It is a vigorous creeper. Fruits are long, thin and tapering. Yield potential is 100-125 q/ha in about 120 days. It is reported to be tolerant to fruitfly and mosaic. It is recommended for UP. Kalyanpur Sona. This variety has been developed at CSAUAT-Vegetable Research Station, Kalyanpur. The vine is creeper with green foliage. Fruits are medium long, thick and suitable for stuffing. The yield potential is 110-125 q/ha in 120 day crop duration. It is also reported to be tolerant to mosaic and fruitfly. It is suitable for UP. This has been duly notified by the Central Seed Committee in 1996 after its release by the UP state variety release committee.

Pant Karela 1: This is a selection from inbreds of indigenous germplasm at Pantnagar released in 1999 by UP state variety release committee. Fruits are thick, 15 cm long. Yield is about 150 q/ha.

Coimbatore Green It is a local type selected at TNAU, Coimbatore. Fruits are extra-long, up to 45 cm, dark green weighing 300-400 g. Yield potential is 180 q/ha.

Coimbatore Long White: Fruits are extra-long (45 cm) and white.

Pusa Hybrid 1: Medium long (14 cm), attractive green fruits.

***Phule Green*:** It has been developed by pedigree method from a cross of Green Long x Delhi Local at MPKV, Rahuri. Fruits are dark green, 25-30 cm long and prickled. Yield potential is about 200 q/ha in 150-180 days.

Priya (VK1): Extra long green spiny fruits with white tinge at stylar end, average fruit length 39 cm, average fruit weight 235 g, productivity 24.5 t ha-1. Relesed from KAU.

Preethi (MC 4): Medium sized white fruits with spines, average fruit length 30 cm, average fruit girth 24 cm, average fruit weight 0.31 kg, productivity 15.0 t/ha. Relesed from KAU.

Priyanka: Large white spindle shaped fruits with smooth spines, thick flesh and less seeds. Average fruit length 25 cm, average fruit girth 20 cm, average fruit weight 0.30 kg, Productivity 28.0 t/ha. Relesed from KAU

CO.1: Fruits dark green with medium length (20-25 cm) and weight (100-120 g). Yield 14 t/ha. Released from TNAU.

Coimbatore Long Green: Extra long fruits (60 cm) with dark green colour. Released from TNAU.

MDU 1: Fruit weight 300-450 g. yield 15-18 t/ha. Induced mutant with long (30-40 cm) greenish white fruits, fruit length 30-40 cm, yield 30-35 t/ha. Released from TNAU.

COBgH 1: F1 hybrid developed by crossing MC 84 x MDU1. Fruits are light green in colour, plumpy with more warts, each weighs 200g.-300g. Yields 44.40 t/ha in 115-120 days. It is rich in momordicin (2.99 mg per 100g). Released from TNAU.

Konkan Tara: Fruits green, prickly, medium long (15-16 cm) and spindle shaped. Yield 24 t/ha..Released from Konkan Krishi Vidya Peeth, Dapoli.

***Punjab 14*:** Plants bushy and bear light green fruits with average weight of 35 g. Yield 14 t/ha..Released from Punjab Agricultural University, Ludhiana.

Hirkani: Fruits dark green, 15-20 cm long, spindle shaped with warts and prickles, yield 14 t/ha in 160 days. Released from MPKV, Rahuri.

Hybrids/ Land races of Bitter Gourd from Seed Companies

Hybrid bitter gourd cultivars are more popular with Indian farmers than open- pollinated (OP) cultivars. Indian consumers prefer green, shiny, and bitter fruits with spines. Cultivars of different market segments are characterized according to the length of the fruit: short segment (<10 cm), medium segment (10–20 cm), and large segment (> 20 cm). The Indian bitter gourd market is dominated by medium- and long-segment cultivars (Dhillon *et al*., 2016). Important hybrid cultivars developed in India include Palee and Parachi (East-West Seed), Amanshri (Nunhems), VNR 28 and VNR 32 (VNR Seeds), CT 108 (Chia Tai Seeds), Vivek F_1 (Sun Grow Seeds), Vishesh (Golden Seeds), Abhishek (Seminis), Arjuna, Pallavi, Raja and Parijat (Rasi Seeds),and US1315 (US Agriseeds). Common hybrids of bitter-gourd by private seed companies in India are Chaman. Nikita. Abhishek. Green Butaka, Hita, Ishila. Prachi, Palec, etc. In South east Asia, the varieties/hybrids are long, cylindrical, smooth skinned, light green or whitish in colour (Vidhi, 2022). Landraces still popular with Indian farmers include Faizabadi Karela, Green long, White long, Jaipur long, Katai, and Jhalari (Dhillon *et al*., 2016).

Uses: The fruit is used as vegetable as well as it can be used as a medicine for diabetics and vermifuge. Immature fruit is pickled, stuffed, stir-fried, and prepared in many other ways. The fruits, young shoots, and flowers are used for flavorings, the leaves as greens, and the pulpy arils as a sweet (Mini Raj and Peter, 2012). The leaves have a bitter taste but it is eaten in Gabon and Malawi. The fruit is edible and is consumed in various countries, including Ghana, Gabon, Sudan and Tanganyika. The root is considered edible in Sudan (Long An, 2015). Bitter gourd is used to prepare one of the tasty dry/curry item called "Bharwan karela" or "Stuffed bitter gourd". Bitter gourd is used to prepare fried curry; which tastes very simpler and can be easily eaten with rice as a lunch item. It is used to prepare one of the detoxifying drink called; Bitter gourd juice. It tastes very bitter but is extremely good. The young shoots and leaves are also eaten as a salad and used as the greens. You can use it in soups and herbal tea. You can cook it as a curry with yoghurt to balance its bitterness (Jaiswal, 2015). This is bitter in taste but has been used as food in many countries, including India, China, East Africa, Central and South America, and the Caribbean. It is also available in countries like the United States and United Kingdom. (Garg, 2016). Consumers prefer bitter gourd fruit at a physiologically immature or unripe stage. Immature fruits have a fresh bright appearance and the seed coats are creamy- white. Mature fruits have yellow flesh with red seed coats and usually split, rendering them inedible and unsalable. Consumer preferences for fruit color, shape, skin pattern, and size vary between and within countries. Fruits are used after cooking and delicious preparations are made after stuffing and frying. During periods of glut in market, fruits are sliced, partially boiled with salt and dried under direct sunlight and stored for months. This is used after frying (Vikaspedia, 2022).

NUTRITIONAL VALUE

In terms of nutritive value, bitter gourd ranks first among cucurbits, the most important nutritional contribution being vitamins and minerals, especially iron, phosphorus, and ascorbic acid (Mini Raj and Peter, 2012). Bitter gourd is very low in calories, providing just 25 calories per 100g. Nevertheless, its fruits are rich in phytonutrients like dietary fiber, minerals, vitamins and anti-oxidants. In addition, the vegetable is an also good source of niacin (vitamin B-3), pantothenic acid (vitamin B-5), pyridoxine (vitamin B-6) and minerals such as iron, zinc, potassium, manganese and magnesium (Kasera, 2012). It contains Dietary fibres; Vitamin A, B-Complex, B1, B2, B3, C, K; Calcium; Phosphorus; Iron; Magnesium; Zinc; Copper; and Folate (Jaiswal, 2015). Like its relative *M. charantia*, the plant contains a number of bioactive compounds, including sitosteryl glucoside, 5,25-stigmastadien-3β-yl glucoside, and 1β-hydroxyfriedel-6-en-3-one, and several cucurbitane-type triterpenoid derivatives (Long An, 2015). *Momordica charantia* contains several biologically active chemical compounds such as glycosides, saponins, alkaloids, fixed oils, triterpenes, proteins, and steroids. Although several biologically active chemical constituents have been isolated from different parts of the plant, including the leaves, fruit pulp, and seeds, it is not clear what part of the plant or what component of the fruit is responsible for the antihyperglycemic effect (Garg, 2016). Bitter gourd fruit is rich in beta- carotene, vitamin C, folic acid, magnesium, phosphorus, and potassium (Yuwai *et al*., 1991; Dhillon *et al.,* 2016a). Bitter melon (*Momordica charantia* L., Family: Cucurbitaceae) is traditionally used as a medicinal food in different systems of medicine. It has significant importance in providing basic nutrients and prevention of various ailments. It contains a variety of bioactive compounds including alkaloids, polypeptides, vitamins, and minerals. A diversity of bioactive compounds comprises two classes of saponins: Oleanane and Cucurbitane-type triterpenoids (Aeri and Raj, 2020). Fruits are considered as a rich source of vitamins and minerals and 88 mg vitamin C per 100 g (Vikaspedia, 2022). 100 grams of raw bitter gourd contains Calories – 16, Dietary Fiber – 2.6 g, Carbohydrates – 3.4 g, Fats – 158 mg, Water – 87.4 g, Protein – 930 mg (Shukla, 2022).

HEALTH BENEFITS

The potential for bitter gourd to modulate blood glucose has received the most attention from investigators searching for natural foods or compounds that may be useful in the treatment of diabetes. Different parts of the plant have been shown to possess hypoglycemic properties in animal models, cell-based assays, and a limited number of clinical trials. Bitter gourd can lower blood glucose in normal animals, in animals fed a high fat diet, and in streptozotocin (STZ)-, alloxan- and genetically induced animal models of diabetes. In addition to the animal and human studies, in vitro studies have proven quite useful in the determination of the components of MC responsible for its hypoglycemic effect. These cell-based studies have allowed for the elucidation of the mechanisms of action of bitter gourd on the liver, as well as in peripheral tissues. Another proposed mechanism of action of bitter gourd is through its direct effect on the β cells of the pancreas and on the intestinal absorption of dietary glucose and amino acids. bitter gourd has stimulatory effects on insulin secretion, but not glucagon secretion, through its direct action on β cells of the pancreas. An aqueous extract of MC fruit was found to be a potent stimulator of insulin release from isolated β-cell-rich pancreatic islets obtained from obese hyperglycemic mice (Lucas *et al*., 2010).

According to Kasera (2012) bitter gourd has two times the beta carotene of broccoli, two times the calcium of spinach, two times the potassium of bananas. It is thought to be good for the hepatic conditions and has been proven by scientists to contain insulin, act as an anti-tumor agent, and inhibit HIV-1 infection. Bitter gourd notably contains phyto-nutrient, polypeptide-P; a plant insulin known for lowering blood sugar levels. In addition, it composes hypoglycemic agent called charantin. *Charantin* increases glucose uptake and glycogen synthesis in the cells of liver, muscle and adipose tissue. Together, these compounds are thought to be responsible for reduction of blood sugar levels. Fresh fruits are an excellent source of folates, contain about 72 µg/100g. Folate helps reduce the incidence of neural tube defects in the newborns when taken by mothers during early pregnancy. Fresh bitter gourd is an excellent source of vitamin-C (100 g of raw fruits provides 96 mg). Vitamin-C, one of the powerful natural antioxidants, helps the body scavenge deleterious free radicals one of the reasons for cancer development. It is an excellent source of health benefiting flavonoids such as ß-carotene, α-carotene, lutein, and zea-xanthin. It also contains a good amount of vitamin A. Together; these compounds help act as protective scavengers against oxygen-derived free radicals and reactive oxygen species (ROS) that play a role in aging, cancers and various diseases processes. According to Kasera (2012) the green fruits are used as vegetable after cooking in many ways as fried, stuffed, dried and pickles. It is used as a digestive aid. Because of its bitterness, it helps to stimulate digestion. It is thus a good treatment for dyspepsia and constipation. Juice is an antidote for alcoholism. Fresh juice of leaves useful in early stages of cholera. Effective against eczema and psoriasis. People suffering from piles can use the fresh juice or apply a paste of bitter melon roots over the piles.

The bitter principle momordicine lowers blood glucose content in humans; this observation has aroused considerable pharmacological interest in the crop (Mini Raj and Peter, 2012). Traditionally *Momordica cochinchinensis* (gac) has been used as both food and medicine in the regions in which it grows. Other than the use of its fruit and leaves for special Vietnamese culinary dishes, gac is also used for its medicinal and nutritional properties. In Vietnam, the seed membranes are said to aid in the relief of dry eyes, as well as to promote healthy vision. Similarly, in traditional Chinese medicine the seeds of gac, known in Mandarin Chinese as *mù biē zǐ*, are employed for a variety of internal and external purposes (Long An, 2015). Pharmacological studies indicate possible action of extracts of the plant on several medical conditions. The water extract was reported to have hypoglycemic activity in diabetic rabbits but not in normal rabbits. The ethanol extract was reported to protect rats from isoproterenol-induced myocardial injury (Long An, 2015). In addition to its use as a vegetable, bitter gourd is often used in folk medicine in Asia to manage type 2 diabetes, a non-communicable disease that affects 347 million people worldwide, with 80 % of these living in low- and middle-income countries (WHO, 2016). For uses related to various ailments, including diabetes, the fruit has been used raw, ripe, or dried, or only the ripe seed from the fruit is used. The fruit has shown not only potent antihyperglycemic activity in various animal models and clinical trials but also a dose-related hypoglycemic effect at higher doses in normoglycemic rats (Garg, 2016). Cultivated fruits of Momordica charantia are widely used to treat diabetes in Asia and Australia. Despite their bitter taste, they are often included in regular diet due to their prophylactic properties. The fruit and its extract have been introduced in Europe as alternatives to conventional treatments for non-insulin-dependent diabetes mellitus. Charantin, a mixture of glycosides, mainly β-sitosterol-D-glucoside and stigmadine glucoside, is the active substance responsible for the fruit's hypoglycemic action (Garg, 2016). It is extensively used for culinary purposes. Bitter gourd's extracts are important for the treatment of a number of diseases and ailments in traditional and modern medicinal systems because of the abundance of insulin-like peptides, a mixture of steroidal sapogenins and alkaloids (Saglam Yilmaz and Khawar, 2020).

All parts of this plant, mainly the fruits and the seeds, contain more than 60 phytomedicines active against more than 30 diseases including cancer and diabetes (Behera *et al.,* 2020). It is used as a food, bitter flavoring, and medicine. Bitter gourd has a relatively high nutritional value due to high iron and ascorbic acid content. Indians have traditionally used the leaves and fruits as a medicine to treat diabetes, colic, and to heal skin sores and wounds. Bitter gourd is reported to possess antioxidant, antimicrobial, antiviral, and antidiabetic properties (Asna *et al*., 2020). It is used as a conventional treatment for diabetes. It works by decreasing islet cell necrosis and repairing damaged cells while also protecting functional islets. It also reduces adiposity and the resultant release of inflammatory factors that are released by adipocytokines such as tumor necrosis factor alpha (TNF-α). Treatment with M. charantia regulates hepatic enzymes which are responsible for the breakdown of lipids such as gluthionine S-transferase. A recent study involved MS patients who were treated with 4.8 g/day of lyophilized bitter gourd. After seven weeks, the subjects showed improved fasting glucose levels and waist circumference. Another investigation on bitter gourd showed average hypoglycemic effect and considerably decreased fructosamine levels in patients newly diagnosed with type 2 diabetes. The hypoglycemic effect of bitter gourd is lower than that of metformin, but a significantly higher efficacy was observed in comparison to rosiglitazone in worldwide management of type 2 diabetes (Shenoy *et al.,* 2022). According to Castro (2022) bitter gourd is full in vitamin C, thus may help collagen production and immune system boost. It is rich in fibers and B vitamins, essential for weight management and brain health. It is loaded with important antioxidants may increase eye health. It protects cells against damage. It is a good source of catechin, gallic acid and epicatechin, powerful antioxidant compounds that can help protect your cells against damage. It helps in weight loss because it is low in calories. One cup only contains 20 calories. It helps reduce blood sugar. Bitter gourd has been shown to improve several markers of long-term blood sugar control.

Momordica charantia (bitter melon, Mandarin Chinese) is native to Africa but has been used in Chinese folk medicine for centuries as a 'bitter, cold' herb, and has recently been brought into mainstream Chinese medicine as well as natural medical traditions around the world. Recent research has shown that the immature fruit might have some antibiotic, anticancer, and antiviral properties, particularly well suited for use in treatment of malaria, HIV, and diabetic conditions. The use of *Momordica* fruit is contraindicated (not advised as a course of treatment or procedure) in a number of conditions, especially pregnancy (Wikipedia, 2022). Bitter gourd fruits have medicinal value and are used for curing diabetes, asthma, blood diseases and rheumatism. Drinking fresh bitter gourd juice is recommended by naturopaths. Roots and stem of wild bitter gourd are used in many ayurvedic medicines (Vikaspedia, 2022). While people condemn bitter gourd for its bitter taste, it truly can sweeten our well-being. It is due to the virtue of its health-promoting and disease-preventing

phytochemical compounds. Bitter gourd is also beneficial for patients suffering from intestinal and stomach problems, diabetes, and more (Shukla, 2022). Several clinical studies evaluate the efficiency of bitter gourd for human health. The majority of these studies reveal that consuming bitter gourd is beneficial for human health. Most of us aren't very fond of bitter gourd due to its bitter taste. However, once aware of the plentiful health benefits, we will probably change our mind (Shukla, 2022). Dried bitter gourd slices and bitter gourd capsules are are also available (Fig.5 & 6).

According to Shukla (2022) the health benefits of bitter gourd are as follows:

Bitter Gourd for Weight Loss: Since bitter gourd is bitter, it has components that prevent your body from absorbing extra sugar. Therefore, it helps lower and maintain blood sugar levels in your body. Moreover, it increases the number of beta cells in your pancreas responsible for secreting insulin in your body. When the insulin levels in your body are regulated, the blood sugar levels ultimately decrease, resulting in weight loss. Bitter gourd contains vitamin C, potassium, magnesium, iron, and reasonable amounts of protein and fibre. All these keep you feeling full throughout the day, preventing you from munching at odd hours. In addition, fibre helps curb hunger. The low amounts of carbohydrates and fats help prevent excess fat build up in the body and ensure that your food digests properly. Recent reports suggest that bitter melons enhance the conditions leading to obesity and hyperlipidemia or blood with too many fats (Shukla, 2022).

Fig. 5. Dried bitter gourd slices

Fig. 6. Bitter gourd capsules

Bitter Gourd Promotes Good Gut Health: Regular consumption of bitter gourd has a positive impact on gut health. It treats intestinal disorders like constipation and stomach ache. In addition, it is equally beneficial for Irritable Bowel Syndrome (IBS) as it helps kill parasites that enter the digestive system. Moreover, it contains antioxidants that help stimulate digestive enzymes and support digestion. Due to its natural laxative property and high fibre count, doctors recommend bitter gourd for maintaining good digestive health. According to a microbiological study, bitter gourd works on gut microbiota structure or the assemblage of microorganisms (Shukla, 2022).

Bitter Gourd Helps Manage Diabetes: Doctors and nutritionists prescribe bitter gourd to diabetic patients. It is one of the most crucial health benefits of bitter gourd known to all. It contains three active substances with anti-diabetic properties. The active substances (polypeptide-p, vicine, and Charanti) have insulin-like properties and blood glucose-lowering effects. These compounds work together or individually to help lower blood sugar levels. Moreover, bitter gourd contains a lectin that helps reduce blood glucose concentrations by suppressing appetite and acting on the peripheral tissues. According to experts, lectin is responsible for triggering the hypoglycemic effect. It means that the blood sugar levels are down. The flesh and seeds are both beneficial in this aspect. Consuming bitter gourd juice daily in the morning on an empty stomach can help you keep your diabetes under control. Remember, it works wonders for people with type 2 diabetes. It occurs when the pancreas doesn't produce enough insulin for blood absorption. In the case of type 1 diabetes, you should consult your doctor before consuming it (Shukla, 2022).

Bitter Gourd Boosts Immunity: Bitter gourd is a rich source of vitamin C that comes with plenty of antioxidant properties. Antioxidants are necessary for our body as it helps in the multiplication of the immune cells and white blood cells (WBCs). It strengthens the immune system and helps in preventing allergies. The recommended daily intake (RDI) of vitamin C is 98.5 mg, which bitter gourd easily fulfils. Research to check inflammation responses in mice with sepsis suggests that this plant food provides medical benefits for numerous conditions (Shukla, 2022).

Bitter Melon Purifies Blood and Cleanses Liver: The antimicrobial and antioxidant properties of bitter gourd help remove toxins. As per studies, it can help wipe out all kinds of intoxication settled in your liver. Thus, bitter gourd heals many liver problems and cleanses your bowel. It also aids the proper functioning of the bladder. According to experts, if you are hungover, consuming bitter gourd juice can help you reduce alcohol intoxication, thereby making you feel active (Shukla, 2022).

Bitter Melon Protects against Cancer: Free radicals are the primary cause of cancer. In addition, they can affect the way our body functions. Thus, keeping your body free of free radicals is essential. Free radicals are a by-product of our metabolism. Their count increases with smoking, pollution, and stress. Bitter gourd contains lycopene, lignans, carotenoids, and reasonable amounts of vitamin A, zeaxanthin, and lutein. In addition, it includes primary antioxidants and nutrients. All these help fight free radicals. As a result, it ultimately reduces the formation of tumours in your body. According to a study, bitter melon has anti-carcinogen and anti-tumour properties, which prevent prostate, breast and cervical cancers (Shukla, 2022).

Bitter Melon Regulates Cholesterol: High cholesterol levels may result in fatty plaque buildup in the arteries. It makes your heart work harder to pump blood. As a result, the risk of cardiovascular diseases increases. Several studies suggest that bitter gourd may reduce "bad" cholesterol levels and regulate "good" cholesterol to support overall health. In addition, bitter gourd is a good source of potassium, magnesium, and calcium, positively affecting the heart (Shukla, 2022).

Bitter Gourd Helps Treat Obesity: Bitter gourd qualifies as a weight-loss food due to its basic yet remarkable nutrient profile. For example, 100 grams of raw bitter gourd contains only 16 calories, 0.15 grams of fat, 0.93 grams of protein and 2.6 grams of fibre. Thus, it ensures that you feel satiated without adding extra pounds to your weight. The nutrients help boost the overall metabolism, and the fibre content keeps you full for hours. Thus, it aids in healthy digestion and avoiding binging on junk and unhealthy snacks. The best way to consume bitter gourd for obesity is by drinking raw juice. It also checks blood sugar levels which are necessary for managing weight. Finally, it activates insulin to prevent the storage of sugar as fat (Shukla, 2022).

Bitter Melon Adds Lustre and Shine to Hair: Bitter gourd promotes hair growth and supports hair health. Components like protein, zinc, and vitamin C in the bitter gourd help keep hair healthy and strong. Applying bitter gourd juice to the hair can help you retain its sheen and lustre. In addition, it ensures that the hair roots strengthen and problems like split ends and hair fall are eliminated. It also treats hair greying, roughness, dandruff, and itchiness (Shukla, 2022).

Bitter Melon Beautifies the Skin: Vitamin C plays a vital role in keeping the skin wrinkle-free and preventing premature ageing. As we know, bitter gourd is a rich source of vitamin C content. It also has other nutrients that aid collagen production, responsible for skin smoothness and elasticity. Furthermore, it reduces skin blemishes and acne, helps treat psoriasis and eczema. In addition, it protects the skin from the sun's harmful UV rays. Research proves that bitter melon is essential for treating photo-oxidative damage or skin wrinkling and melanogenesis (melanin production). And melanin determines your hair colour (Shukla, 2022).

Bitter Melon Keeps the Eyes Healthy: Doctors and health experts say that bitter gourd helps prevent vision-related problems such as poor eyesight and cataracts. Bitter gourd is rich in vitamin A and beta-carotene, healthy for the eyes. Moreover, it is a good remedy for treating dark circles as well (Shukla, 2022).

Bitter Melon Heals Wounds: One of the most commonly known properties of bitter melon is healing wounds. It accelerates the production of growth factors in the affected area. In addition, It induces proliferation, which plays a critical role in wound healing. Bitter melon also increases the oxygenation of the wound by accelerating capillary circulation. In addition, its antioxidant and antimicrobial effects enable the wounds to contract and close. It also speeds up the epithelialisation process, covering the denuded epithelial surface and the tension of the injury (Shukla, 2022).

Bitter Melon Energises the Body: Regular consumption of bitter gourd in the diet boosts the body's stamina and energy levels. In addition, it improves sleep quality and eliminates sleep-related disorders like insomnia (Shukla, 2022).

Bitter Melon Clears Kidney Stones Naturally: Kidney stones are excruciating to pass. They are hardened formations of calcium phosphate or calcium oxalate. Including bitter gourd in the diet helps them break down naturally. It also avoids the production of kidney stones by reducing the high acid content. It improves cardiac health too (Shukla, 2022).

According to Jaiswal (2015) the Health benefits of Bitter gourd are as follows:

Good for headache: Take 10-12 ml juice of Bitter gourd leaves. Mix it with cow's ghee. Now, apply this paste on the forehead. It cures a headache (Fig. 7).

Fig. 7. Bitter gourd juice

Treats Eye disorders: Bitter gourd is extremely beneficial in the case of night blindness and haziness. Take a rusting iron vessel and rub the juice of its leaves and black pepper in it. Collect the solution and apply it as eyeliner in the ways. Also, apply it around the eyes, it treats many types of eye disorders too.

Helpful in case of Vomiting: Extract the juice of its leaves. Give 10-12 gm of the juice with a little amount of vinegar and rock salt mixed in it. It cures Vomiting and purgation related disorders.

Enhances Galactagogue: Boil 20 gm of its leaves. Strain the solution and give it to the lactating woman. It increases the production of milk and also purifies the blood.

Treats Arthritis: Give 10-15 ml of Bitter gourd juice to the patient regularly. Or, give its fruits with mustard seeds and salt mixed in it. It is very beneficial in curing Arthritis.

Good for Diabetes: Give 10-12 gm juice of its fresh fruits regularly. In the diet of a diabetic patient, include cooked bitter gourd. It is extremely helpful. Give 3-6 gm of its powder with water or honey. It helps to activate the pancreatic cells and enhances the production of insulin.

Treats Jaundice: Take 10-15 ml of juice of its leaves. Mix it with powdered black myrobalan. It is beneficial in curing Jaundice.

Useful in Paediatric Nausea: Take 6 gm juice of Bitter gourd leaves. Mix a little amount of turmeric in it. It causes vomiting thus resulting in the cleansing of the stomach.

Cure for Intestinal worms: Extract the juice from 10-12 Bitter gourd leaves. Give it to the patient. It should be given daily; once a day. It kills the worms in intestines.

Treats Skin disorders: Take the whole plant, cinnamon, black pepper and oil of wild almonds. Grind all these together and apply on the affected area. It cures itching and such related skin disorders. A paste of its root is helpful in curing small boils, acne and eruptions.

Helpful in Paediatric Pneumonia: Extract the juice of bitter gourd and slightly warm it. Give 10-12 ml of the juice with a little amount of pure saffron. Give this dosage thrice a day.

Treats Fever due to cold: In the case of seasonal fever or fever due to cold. Give 10-15 ml of Bitter gourd juice with a little amount of cumin powder in it. Give this to the patient thrice a day.

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