



REVIEW ARTICLE

A review on the diversity of Melon

M Lija* & S Suhara Beevy

Department of Botany, University of Kerala, Kariavattom 695 581, India

*Email: lijaomana@gmail.com

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ABSTRACT

The species *Cucumis melo* L. (Melon) is a polymorphic taxon encompassing many botanical and horticultural varieties. Melon fruits exhibit substantial variability in their form, shape, skin characters, flesh color, flesh thickness, sweetness, seed cavity, seed size etc., which reflects in the market value of melon. This existing diversity in melon germplasm leads botanists to propose different classifications at the specific and infraspecific levels. The majority of classifications are based on morphological and molecular characteristics. Morphologic traits such as flower and fruit characteristics (sex expression, fruit size and shape, fruit skin color, pH, flesh color, taste, aroma, sugar composition, seed size and shape) were used in the past centuries for melon diversity analysis. Later on, scientists correlate these phenotypic and biochemical traits (pH, Total Soluble Solids, Ascorbic acid content, Titratable acidity) with genotypic variability by molecular tools. Molecular tools generally used for melon diversity analysis are RAPD, RFLP, AFLP, SSR markers and Single Nucleotide Polymorphism (SNP). This article emphasizes the progress of studies in the species *Cucumis melo* L. and its varieties since 1753. Particular attention has been paid to collect data regarding different horticultural groups of the species, and a recent infraspecific classification of the species has also been outlined. Even though the modern molecular techniques provide new insight to melon classification still there is an existing disparity in these classifications, which could be visible to the scientific world.

Introduction

Cucumis melo L., commonly known as melon, is a tropical plant species that belongs to the family Cucurbitaceae. According to FAO 2019 (1), the world production of melon is 32 million t from 1.14 million ha of land. It was 8.8, 13.5, 19.8, 27.3 million t in 1980, 1990, 2000 and 2011 respectively and major melon-producing countries are China (17.1 million tons), followed by Turkey, Iran, Egypt and India (2). The genus *Cucumis* consists of 52 species with two geographical centers of origin, such as Asia and Africa and it is a diploid crop with $2n = 2x = 24$ chromosomes, showing considerable variation in fruit sizes and shapes (3–5).

Systematic Position of *Cucumis melo* L.

Kingdom - Plantae

Phylum - Magnoliophyta

Class - Angiospermae

Category - Fabrids

Order - Cucurbitales

Family - Cucurbitaceae

Genus - *Cucumis*

Species - *Cucumis melo**

*APG 1V System of Classification.

The plant is a softly hairy annual. Vines are monoecious or andro-monoecious, 1.20–3.50m long. Root system large and superficial. The stem is densely pubescent, ridged, or striate. Leaves are orbicular or ovate to reniform, triangular or pentagonate, shallowly 3–5 lobed; leaf 8–12 cm long with midrib length of 8 cm or greater; margin undulating-wavy; petiole 4–10 cm long; tendrils simple. Flowers are bright yellow; female flowers 3.5 × 2.6 cm, solitary, male flowers 4.6 × 2.2 cm, in 4–5 per axil; calyx 5-lobed, 6–8 mm long; sepals ficiform, subulate or leaf-shaped, covered with dense, long hairs; corolla deeply 5-partite, petals round, 2 cm long; stamens 3, free, connectives of anthers prolonged; pistil with 3–5 placentas and stigmas. Fruits normally cylindrical-oval with faded markings or green, mature fruit weight 2.25–4 kg, size 36–62 × 16–24 cm, flesh usually yellow-peach-pink, strong external and internal musky aroma, blunt at the distal end; seed creamish-yellow 0.9–1.0 × 0.3–0.4 cm.

Botanically fruits of both melons and cucumber are described as fleshy berries, but they have been harvested at different physiological stages such that in cucumbers, fruits are an unripe berry, whereas, in melons, these are ripe berries (8, 9). Matured melon fruits detach from the plant naturally by making an abscission layer on the stem. The cultivated varieties of melon include both sweet and non-sweet "dessert" forms. The non-dessert forms (e.g., culinary melon, oriental pickling melon etc.) are consumed as raw, pickled, or cooked (10), but sweet dessert (e.g., snap melon, musk melon etc.) forms can be used in various dessert preparation.

Nutritional Value of melon

Melons carry a vast amount of photochemicals which are capable to fight against human diseases. Almost all cucurbit fruits are significant source of vitamin C, Provitamin A, toxic folic acid, phenolic phytochemicals, dietary fibers, minerals, cucurbitacin. Among these chemicals such as cucurbitacin, lithium and zinc helps in cancer prevention, fighting depression, prevention of ulcers and removal of dandruff, stimulating immune system (11–13). In commercial cultivars, the cucurbitacin level is negligible. However, the pharmacological and ethno botanical properties of melons are due to cucurbitacin (14). In addition to this, high dietary fibre in melon make it an ideal choice to avoid dehydration. As per the studies conducted by Food and Drug Administration, USA on Musk melon and Honey dew melons, the varieties were not only good source of Potassium and Vitamin C but also low with Fat, Sodium and calories. They also reported that among the two varieties, musk melon is an excellent source of Provitamin A or beta Carotene (13).

Historical background on melon cultivation

Linn' in 1753 termed the genus name '*Cucumis*' and described five species of cultivated melons in *Species Plantarum* (15). Miller coined the word '*Melo*,' but he neither described any species nor transferred any species (16, 17). Later in 1859, Naudin united all these five species into a single species, *Cucumis melo* and its cultivated varieties as var. *acidulous* (18). Later, a simplified version of Naudin's taxonomy into a single wild variety, *Cucumis melo* var. *agrestis*, six cultivated ones, *momordica*, *cantalupensis*, *flexuosus*, *indorous*, *conomon* and *dudain* (19, 20). Again there are classification on east and west melons into five varieties *momordica*, *acidulous*, *conomon*, *makuwa* and *chinensis*, all of which belong to the subspecies *C. melo* ssp *agrestis* (21, 22).

Based on archaeological records (seeds), illustrations, and analysis of the available text, it could be predicted that melon cultivation has been started in China 3000 year BC, in India in 2000 BC and in Egypt 1500 BC (23–29). India has a long history of melon cultivation and is considered a secondary centre of genetic diversity of cultivated melon. In India, Mughal rulers introduced cultivated melon from Central Asia (30). Columbus introduced melon to the new world on his first travel which was looking like watermelon. Later, Americans adopted this crop and started cultivation (31).

The most ancient records on cultivated melon appeared in Egyptian mural paintings (32). Pangalo studied a live collection of 3000 specimens of melons and proposed a multilevel taxonomy based on homologous series (22, 33). Then he subdivided four *C. melo* varieties in the homologous series into two homologous subspecies, *cultus* or cultivated types and *agrestis* or wild types, and each subspecies again divided into "types." He also reported that sweet melons were not known in the Roman period and were imported from Persia or Caucasus by travellers (15).

The pattern of melon evolution and divergence is still a question to the scientific world. Melon is of African origin, but the centre of diversity is from Turkey to Japan (34). A distributional map of important melon cultivation areas are given in the Fig 1. Cytological studies of melon germplasm based on low chromatin content, two nucleolar organizer, low chiasma frequency shown that non dessert melons are more primitive than dessert forms. But species like *C. hystrix* chakr. (2n=24) is native to Asia (35, 36) and it's morphological and biochemical characters similar to *C. sativus* and its chromosome number is equal to *C. melo*. This evidence indicates that *C. hystrix* is a possible bridge between these two species (37). *C. melo* was considered the most developed ancient cultivated species among the three species and through many changes, it would evolve into the existing elite forms (11, 23, 38, 39).



Fig. 1. A world distributional map of major melon growing area.

Molecular diversity studies on melon

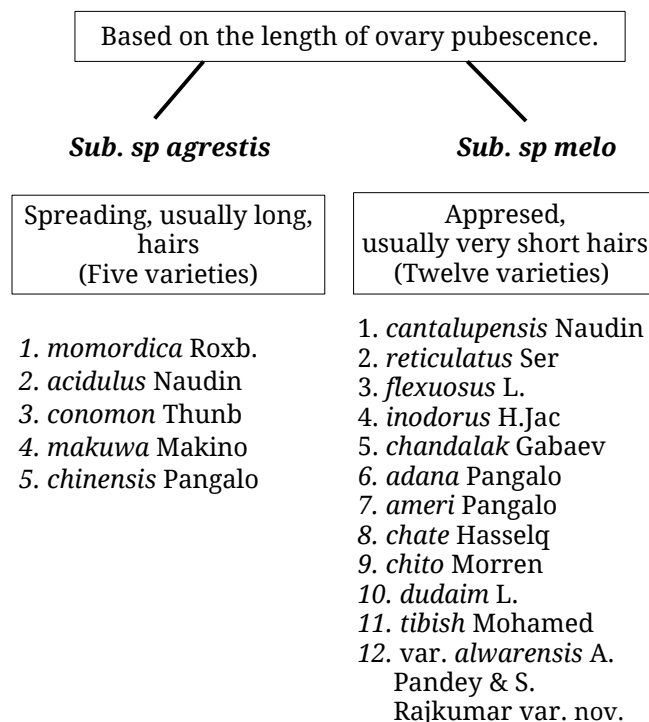
The phylogenetic relationship between various groups of cultivated melon and its genetic diversity was studied by analysis of morphological characters (40, 41), cytological characters (42) and molecular polymorphism by DNA markers. DNA markers such as isozymes (41, 43), restriction fragment length polymorphisms (RFLPs) (44), random amplified polymorphic DNA (RAPD) (15, 45–49), simple sequence repeats or microsatellites (SSR) (45, 50, 51, 53, 55, 56), Amplified fragment length polymorphism (AFLP) (53) and SNP (Single Nucleotide polymorphism) by genotyping by sequencing (54, 55) etc have been extensively used to measure genetic diversity in

melon germplasm. There had been conducted a comprehensive study on 54 wild and cultivated melon types using RAPD and inter-SSR markers which leads to the identification of the two melon subspecies, *melo* and *agrestis*, as proposed (56). These reports show a clear-cut genetic demarcation between subsp. *agrestis* and subsp. *melo* and it was defined by (19, 21, 57). It was analyzed AFLP of ninety-nine accessions of melon (*Cucumis melo* L.) from East and South Asia revealed its genetic relationship between East and South Asian melon (53). However, SSR markers have been used in a relatively limited narrow array of melon germplasm. The genetic variability studies performed with SSR markers in 27 accessions of melon pointed out their genetic relationships which could be further investigated for their classification and origin (51). The genotyping-by-sequencing (GBS) is considered as a simplest approach to discover SNPs in highly diverse crop species (58). Based on this, assessed 143 melon accessions of 15 horticultural groups in two subspecies, subsp. *melo* and subsp. *agrestis* (54). Recently, 164 genome-wide SNP markers were analyzed in the Oriental melon which leads to differentiate the varieties into ten clear groups. This result shows that SNP markers with high validation rate and marker-trait associations serve as a useful tool for varietal identification, genetic diversity studies (55).

Melon (*Cucumis melo* L.), one major cucurbit throughout the world, has intense diversification and significant physiological, molecular and morphological variations from its cultivar sub-group level (15, 18, 19). Various infraspecific classifications have been proposed on the crop based on these variations. One of the important morphological characters which would consider for the classification of this species is ovary hairiness and based on this, they have divided the species into two subspecies, such as *C. melo* ssp. *melo* and *C. melo* ssp. *agrestis* (40, 56, 57). Further, this subspecies were classified into 16 taxonomic groups or varieties, which leads to a quadrinomial nomenclature (eg: *C. melo* ssp. *agrestis* var. *momordica*) (21) and as per this classification, *C. melo* ssp. *agrestis* includes five melon types (groups of cultivars) *momordica* Roxb. (snap melon), *acidulus* Naudin, *conomon* Thunb., *makuwa* Makino and *chinensis* Pangalo (pickling melons) and (distributed in India to the Far East); *C. melo* ssp. *melo* comprises 11 types *cantalupensis* Naudin, *reticulatus* Ser. (cantaloupe, muskmelon), *flexuosus* L. (snake melon), *inodorus* H.Jac. (Winter melon or Casaba melon), *chandalak* Gabaev, *adana* Pangalo, *ameri* Pangalo (Asian melons), *chate* Hasselq. (Cucumber melon), *chito* Morren (Mango melon), *dudaim* L. (Pocket melon) and *tibish* Mohamed (distributed in Central, Western India, Africa, Europe, Western Asia and America) (58). Later, this scheme was adapted to the International Code for Cultivated Plants with five groups in ssp. *agrestis* and eleven groups in ssp. *melo* (60-64). Nevertheless, in the earlier studies, Wild melons have been included in a separate tribe referred to as '*agrestis*' (18). However, morphological and molecular analyses pointed out that the wild types show resemblances with the paraphyletic *agrestis* and *melo* subspecies sensu Kirkbride (64). A schematic

Schematic Representation of Infraspecific classification

Cucumis melo L.



representation of infraspecific classification of melon is mentioned below.

An infraspecific classification on *C. melo* cited 18 groups belonging to 2 subspecies: subsp. *melo* and subs. *agrestis* (Naud.) Pangalo. Subspecies *agrestis* includes ten var. *momordica* (Roxb.) Duthie et Fuller., *acidulus* Naud., var. *chito* (Morren) Naud., var. *agrestis* Naud., var. *chate* (Hasselq.) Sageret., var. *conomon* (Thunb.) Makino., var. *dudaim* (L.) Naud., var. *texanus* Naud., var. *makuwa* (Makino), var. *chinensis* and eight varieties in subsp. *melo* consist of var. *cantalupensis* Naud., var. *reticulatus* Ser., var. *flexuosus* (L.) Naud., var. *inodorus* H.Jacq., var. *chandalak* Pangalo., var. *adana* Pangalo., var. *ameri* Pangalo. and var. *tibish* Mohamed (65) and which has been recently revised (66). A potential variety of cultivated vegetable melon was reported from the north-western parts of India, which is locally named Arya (*Cucumis melo* subsp. *melo* var. *alwarensis* A. Pandey & S. Rajkumar) (67). Morphological and molecular characterization of the variety shows similarity with var. *flexuosus* (snake melon) in ovary pubescence and shelf life; hence it has been included in the subsp. *melo*.

Seed size can also consider an essential character to distinguish different subspecies of the melon. Varieties such as *conomon* and *agrestis* with seed lengths shorter than 9 mm were classified as subsp. *agrestis*, whereas large-seed type melon group *cantalupensis* and *flexuosus* with seed length more than 9 mm were classified as subsp. *melo* (41). Another study concluded that var. *acidulus* and var. *makuwa* belong to oriental melon because of their thin pericarp short duration, tiny seed and reduced shelf

life (68). Works had been conducted morphometric analysis on the melon germplasm in the humid tropics of south India and revealed that the collected germplasm belongs to two groups, *C. melo* var. *momordica* and *C. melo* var. *acidulous* (69, 70). There were similar type of study in Kerala landraces of melon and their uses and concluded that considerable variability exists in the fruit characteristics of varieties. This study also pointed out that the landraces belong to two varieties, *acidulus* and *momordica* (71).

Understanding and identifying the inter and infraspecific forms of melon is an unsolved problem to the botanist worldwide. In order to tackle this problem, every minute characteristic of the varieties are equally important. Therefore, here is an attempt to share some of the common pomological characteristic features (fruit shape, flesh colour, rind colour and ripening behaviour) of different varieties of melon, with particular reference to its common name and the most common cultivated places are listed below.

Snap melon

Snap melon (*Cucumis melo* var. *momordica* (Roxb.) Duthie & Fuller) is an indigenous crop to India, popularly known as "phut" or "phoont," which means to split (72) (Fig. 2). It is a locally grown dessert melon in Kerala, known as Pottuvellari, and is cultivated in Thrissur, Ernakulam and Malappuram districts. The large-scale cultivation of the variety is confined to Uttar Pradesh, Rajasthan, Haryana, Punjab and Bihar in India and prevalent in arid and semi-arid regions (73). This crop is cultivating as an intercrop with cotton, maize and sorghum in this region. China is considered the world-leading producer of snap melon.

Ripe fruits of snap melon consumed as dessert while immature fruits generally used as a vegetable.



Fig. 2. Snap melon (*Cucumis melo* var. *Momordica* Roxb.) Duthie & Fuller).

In recent times, the juice of snap melon is gaining popularity as a refreshing drink due to its cooling effects (74). Hence, it could be used as a cleanser for the skin and first aid treatment for burns and abrasion. The fruit is stomachic and flowers are expectorant and emetic. Seed contain 12.5% to 39.1% oil. This edible and medicinal fruit is also a good summer drink since it reduces heat from the body.

Culinary melon

Culinary melon (*Cucumis melo* var. *acidulus*. L. Naudin), commonly known as sambar vellari, pickling melon, preserving melon etc., which is endemic to humid areas of tropical southern India and cultivated in Tamil Nadu, Kerala, Karnataka and Andhra Pradesh (Fig. 3). Brazil is the world-leading producer of culinary melon (75). Fruits are oval, smooth, orange in color, flesh white, firm crisp with no aroma and with long shelf life. The tender fruits are used for salad and sambar preparation.



Fig. 3. Culinary melon (*Cucumis melo* var. *acidulus*. L. Naudin).

Oriental pickling melon

Oriental pickling melon (*C. melo* var. *conomon* Thunb.) is the most primitive domesticated melon. Varieties such as *conomon* (pickling type), *makuwa* (dessert type) and *chinensis* are considered East Asian cultivated melon (19) (Fig. 4). Variety *conomon* and var. *makuwa* have been cultivated in Korea and South China (76). At the ripening stage, fruits of these varieties are smooth-skinned with sweet and fragrant pulp, but the unripe fruits are eaten as raw, cooked or pickled. Seed is used for the preparation of juice against dyspepsia. It was hypothesized that the origin of vars. *makuwa* and *conomon* is India and these varieties were introduced into China by the 'Silk Road' from the west (77-79). They also assumed that the origin of this melon is from wild melon (var. *agrestis*) in China (80).



Fig. 4. Oriental pickling melon (*C. melo* var. *conomon* Thunb.).

Chinese melon

Chinese melon is divided into two types based on the thickness of the fruit skin. Thin-skinned melon is

named Group *conomon*, thick-skinned as Hami melon ("Hami Gua" in Chinese) (Fig. 5). The landraces of Chinese melon are classified as var. *chandalak* Pang Greb (extra early Guardian melon), var. *cassaba* Pang Greb (round fruits with three or five carpels), var. *ameri* Pang Greb (summer melon) and var. *zard* Pang Greb (winter melon) (81). Among these varieties, *zard* and *cassaba* are categorized as var. *inodorus* (group *Inodorus*), whereas varieties were *chandalak* and *ameri* as independent varieties based on fruit shelf life (19).



Fig. 5. Hami melon.

Winter melon

Winter melon (*C. melo* var. *inodorus* H.Jac.) is a locally cultivating melon variety in the Island of Sicily in the Mediterranean Sea (Fig. 6). This variety includes honeydew melons, casaba and the Crenshaw melon. These varieties got significant importance in the economy of southern Italy. On the other hand, the fruits of *Cucumis melo* var. *inodorus* (honeydew melon) are non-climacteric types. Melon cultivation in Italy is an average of 21000 ha, of which about 40% is *inodorus* melon (82).



Fig. 6. Honeydew melon.

Cantaloupe

Cantaloupe (*Cucumis melo* var. *cantalupensis* Naudin) is a lightly ribbed gray-green skinned fruit with sweet and flavorful flesh (82) (Fig. 7). Variety *inodorus* and var. *cantalupensis* are the most common growing

melon varieties in the USA, Europe, Asia and Mediterranean countries. Charentais is a type of cantaloupe widely grown in Europe and the USA. Every year approximately 6400 ha of this region give the productivity of 60000–70000 tones of this crop (83). The fruits of this variety can be taken as either fruit salad or dessert.



Fig. 7. Cantaloupe (*Cucumis melo* var. *cantalupensis* Naudin).

Musk melon

Musk melon (*Cucumis melo* var. *reticulatus* Naud.) has fruit with a "net-like" (reticulated) peel (Fig. 8). It is a round melon with firm, moderately sweet flesh and orange in color. Fruit gorgeous Juicy flesh is mainly used for dessert preparation. Fruits of *Cucumis melo* var. *cantalupensis* Naud. and *Cucumis melo* var. *reticulatus* Naud. are a climacteric type with an aroma and quick softening nature. Nevertheless, non-climacteric melons such as winter melon, oriental pickling melon, etc., possess a low-level aroma, pale-green flesh and slow softening. Hence, these melon varieties are typically more durable than climacteric varieties (64).



Fig. 8. Musk melon (*Cucumis melo* var. *reticulatus* Naud.).

Snake melon

Snake melon (*Cucumis melo* L. var. *flexuosus* (L.) Naud.) Or Armenian cucumber is considered one of the oldest horticultural crops in the world (62, 80) (Fig. 9). Landraces of var. *flexuosus* (known locally as "Fakous Baladi," in Arabic) have got the common name as "snake melon" because of their twisted, slender and bent fruits (19). It is a critical horticultural, rain-fed crop in the rural communities of Palestine and traditionally cultivated in the Mediterranean area. Fruits and flowers are edible. Fruits are used for salad preparation and stir fry (84).



Fig. 9. Snake melon (*Cucumis melo* L. var. *flexuosus* (L.) Naud.).

Arya

Arya (*Cucumis melo* subsp. *melo* var. *alwarensis* A. Pandey et S. Rajkumar var. nov.) is a locally cultivating vegetable melon from the Alwar districts Rajasthan. Its large sub-globose, cylindrical fruits are rich in vitamin C and are used in salad, sambar and dessert. Mature fruits have smooth pericarp and long shelf life like snake melon, but the aroma of the fruits is like snap melon or the typical musk melon (67).

Pocket melon

Pocket melon (*Cucumis melo* var. *dudaim* (L.) Naudin), commonly known as 'Queen Anne's pocket melon' or 'fragrant melon.' Fruits of this variety are around or slightly oval shape with velvety skin and small reddish-yellow ochre stripes (65). The unique exotic musky fragrant of the fruits is generally considered a mix of pineapple, cantaloupe and a hint of jasmine. The velvety rind of this melon is lovely and its pulp is whitish, loose and edible. These are widely cultivated from the Caucasus to Afghanistan and Turkey for aromatic or ornamental purposes. Due to its lovely musky smell, these melons were carried in the pockets of Queen Anne in the Victorian period as a body fragrance. Hence, the name 'Queen Anne's pocket melon' (85).

Cucumber melon

Cucumber melon (*Cucumis melo* L. var. *chate* (Hasselq.) Filov) is a traditionally cultivating melon in the area of Salento (Apulia region) of south Italy. This crop is locally called 'meloncella,' and its taxonomic position is *C. melo* ssp. *melo* convar. *adzhur* Greb. ex Mansf. & Greb. var. *chate*. There are two varieties of 'Meloncella'; one has pale-skinned fruits and the other is dark green. Fruits are oblong, tender, crispy and covered with soft hairs. Its flavor is fresh and delicate than cucumbers (*C. sativus*). One plant may produce more than 30 fruits, and each fruit weighs about 200–300 g. The unripe fruits are eaten raw, like salad, with the first dishes. They have low sodium content and soluble solids. Therefore, it is easily digestible and suitable for a hypo caloric and hypoglycemic diet (86).

Mango melon

Mango melon (*Cucumis melo* var. *chito* (Morren) Naud.), commonly called mango melon or peach melon (Fig. 10). It is a drought-tolerant annual crop. The color, flavor and texture of the fruits are similar to mango or peach. Hence, the common name (88). This variety is widely distributed in Central America and the Caribbean Islands. According to Naudin, the *chito* group represents feral melons that are not cultivated (18). Round small and yellow fruits of this variety are used for dessert preparation and the seeds are tiny with a gelatinous sheath.



Fig. 10. Mango melon (*Cucumis melo* var. *chito* (Morren) Naud.).

Seinat

Seinat (*Cucumis melo* var. *tibish* Mohamed) is a locally grown melon variety in Sudan. This crop is unknown to its neighboring countries and is cultivated for its edible seeds. Seeds of this variety are a rich source of protein and essential amino acids. Hence, it is used as a fortifier in a variety of food items (88). The native people of Sudan eat roasted seeds as time pass (89).

Conclusion

Melon is a worldwide growing profitable crop. Much about melon fruit biology and crop cultivation is known. However, these fruits exhibit considerable variability in their shape, skin characters, flesh color, flesh thickness, sweetness, seed cavity, size etc. Hence, it is a significant hurdle for botanists to classify them

at the subspecies level and provide an appropriate systematic position by analyzing their morphological and molecular characteristics. Diversity studies are inevitable to estimate and establish genetic correlation and better parental combinations for crop improvement programmes. The analysis of different melon diversity studies conducted worldwide suggests that fruits of var. *acidulus* and var. *conomon* could store for 8-9 months without losing their freshness. This long storage trait of the fruits could be exploited better in modern cultivars with low shelf life. The evaluation of snap melon germplasm from various parts of India shows that most of the accessions have high fruit acidity and pest resistance genes to combat different types of pests and diseases. These traits could also breed uniquely flavored melon cultivars and strengthen crop disease resistance against different pests and pathogens.

Future Prospect

Continuous and progressive research in melon diversity studies reveals that morphological and molecular characterization is inevitable to distinguish the varieties within the species or cultivars within the varieties. Molecular markers such as SSR and SNP are more suggestible in melon diversity studies because these techniques reveal the significant number of polymorphisms within genes of unknown varieties, leading to paternal analysis and cultivar identification. Since almost all melon varieties produce edible fruits, the development of elite varieties with better fruit qualities through molecular breeding or transgenic technology can only meet the global demand shortly.

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Authors' contributions

LM reviewed the literature, collected and compiled the data, drafted the manuscript. SB edited the manuscript and finalized it.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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