Chrysanthemum

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S. K. Datta, Y. C. Gupta (eds.), *Floriculture and Ornamental Plants*, Handbooks of Crop Diversity: Conservation and Use of Plant Genetic Resources,
https://doi.org/10.1007/978-981-15-3518-5_4

Abstract

The autumn-flowering garden *Chrysanthemum* (*C. morifolium* Ramat.) is an important flower crop throughout the world. It has earned tremendous popularity as a flower for the garden and as a cut flower for interior decoration or for greenhouse or conservatory display. The genus constitutes a large polyploid complex ranging from 2x to 22x, besides a number of aneuploids. The genetic diversity of chrysanthemum plays a very important role in developing new and novel desired forms through breeding and selection. All the present-day colorful varieties have been developed through complex interspecific crosses among elemental species, open pollination, indiscriminate intervarietal hybridization, spontaneous and induced mutation, and selection and management of chimera. The possibilities for creating different forms and improving chrysanthemum are infinite, and a breeder will always have future goals to work toward. This chapter will provide maximum information generated in India on different aspects along with important publications.

Keywords

Chrysanthemum · Germplasm · Genetic diversity · Breeding · Characterization · New varieties

19.1 Introduction

Chrysanthemum (*chrysos*, golden; *anthos*, flower) is one of the most interesting ornamental groups of plant in the world. The history of origin of chrysanthemum is very interesting and debatable among scientists. The history of the spread of chrysanthemum from its native place to the rest of the world and its development from wild daisy-like flowers to present-day magnificent cultivars make a fascinating reading. It is spread over temperate regions and in many parts of the globe. The present number of varieties in the world is reported to be above 2000, and in India, there are about 1000 varieties. Chrysanthemum has earned tremendous popularity as an ornamental flower for the garden and as cut flower for interior decoration or for the greenhouse or conservatory display. Its wide popularity is due to its large number of cultivars with respect to growth habit, size, color, and shape of bloom. As a short-day plant, it naturally flowers in the autumn and winter. Now, programmed blooming of chrysanthemum all year round is possible by environmental manipulations. Chrysanthemum has its admirers and enthusiasts all over the world for its use both as a commercial flower crop and as a popular exhibition flower. Chrysanthemum flowers vary greatly in shape, size, and color. All these variations have occurred due to the interplay of genetic factors, meaning thereby that the genetic resources have played a key role in bringing to the chrysanthemums their present fame and glory. All the present-day colorful chrysanthemum varieties have been developed through complex interspecific crosses among elemental species, open pollination, indiscriminate intervarietal hybridization, spontaneous and induced mutation, and selection and management of chimera. The main agencies responsible for varietal improvement are individual enthusiasts, nurserymen, and breeders working in research institutes and agricultural universities. This chapter will cover the information

on research activities related to the history of origin, geographical distribution, enrichment and characterization of germplasm, their utilization in breeding program, and development of new and novel varieties through hybridization, selection, in vivo and in vitro mutagenesis, standardization of agro-technology, disease management, post-harvest physiology, programmed blooming, tissue culture, molecular techniques, etc.

19.2 Botany

The *Manual of Cultivated Plants* (Bailey 1949) and the *Dictionary of Gardening* (Chittenden 1951) list *Chrysanthemum morifolium* as the valid name for the varieties of chrysanthemum we grow today. *Chrysanthemum* belongs to the family Compositae, the most phylogenetically advanced dicotyledonous family (Hemsley 1889; Popham and Chan 1950), which constitutes a large polyploid complex ranging from 2x to 22x, besides a number of aneuploids. The recognizable feature of the family is that a large number of flowers are arranged on flattened axis to form a compact floral head which looks like a single bloom. The blooms of Compositae appear on capitulum inflorescence. The capitulum or head consists of a large number of small florets in very close formation. Two kinds of florets, i.e., ray florets and disc florets, are present in a bloom. Ray florets are large, attractive, colorful, and of various shapes which give beauty to the head, whereas disc florets are smaller and centrally placed. The difference between the two kinds of florets at a glance is generally that the disc florets are short while the ray florets are usually quite long. The ray florets are unisexual with only female parts, while the inner disc florets contain both male and female reproductive elements. The chrysanthemum bloom type depends mainly upon the relative number of the two kinds of florets, their shape, and the direction of growth. At present, there are about 200 species in the genus *Chrysanthemum*, among which the modern autumn-flowering perennial *Chrysanthemum morifolium* Ramat. is the most important (Carter 1980). The name *Chrysanthemum morifolium* has been changed to *Dendranthema grandiflora* (Heywood and Humphries 1977; Kitamura 1978; Anderson 1987). Reclassification of the *Chrysanthemum* by botanists has been based on cytology, cypsela anatomy and morphology, embryology, hybridization, and phytochemistry.

It is native to the Northern Hemisphere, chiefly Europe, and Asia, with a few in other areas. Many authorities claim that it originated in China (Carter 1980). Many species believed to have taken part in its development have been mentioned by various workers as *Chrysanthemum morifolium*, *C. sinense*, *C. indicum*, *C. japonicum*, *C. ornatum*, *C. satsumense*, *C. boreale*, *C. nipponicum*, *C. arcticum*, *C. sibiricum*, *C. rubellum*, *C. parthenium*, and *C. coronarium* (Ramatuelle 1792; Sabine 1822; Hemsley 1889; Niwa 1936).

19.3 Geographical Distribution

Chrysanthemum is known to have been cultivated for over 3050 years, probably originating about 500 BC. Confucius, a great Chinese philosopher, knew its blooms and described it in his work *Li-Ki* or *Ninth Moon* as "the chrysanthemum with its yellow glory"; other references referred them as "the golden flower." T'ao-Yuan-

Ming (AD365–427) was said to be mainly responsible for many early improvements in cultural methods. Chinese poets were writing in praise of the chrysanthemum, while replicas of chrysanthemums in their original form have been discovered on some fifteenth-century Chinese pottery, emphasizing their long-standing popularity (c.f. Jim Smith, NCS Yearbook 1984, Rosse 1964; Kyle 1952). The available records on history of chrysanthemum cultivation and their spread in different countries are as follows:

China – Chrysanthemums were first cultivated in China as a flowering herb as far back as the fifteenth century BC (c.f. History of the Chrysanthemum. National Chrysanthemum Society, USA). Those chrysanthemums were flowering herbs which have medicinal and aesthetic uses. Over 500 cultivars had been recorded by 1630 (c.f. *Chrysanthemum*. Flora of China. eFloras). Confucius described its yellow glory as early as in 550 BC. The credit for early remolding of the wild ancestors into much superior diverse forms also goes to the Chinese. The first white blooming chrysanthemum is also claimed by Liew Chieh Yuan of Peking to have been raised by T'ao Hungching during 452–532 AD (Cumming 1964). Tao Yuanming (AD365–427), a Chinese chrysanthemum specialist, is responsible for many early improvements in cultural methods. The ancient Chinese name for chrysanthemum is "Chu." The Chinese City of Chu-Hsien (which means Chrysanthemum City) was so named to honor the flower (Woolman 1957).

Japan – Seeds of chrysanthemum reached Japan from China via Korea as early as in 386 AD (Cumming 1964). It is believed that the cultivated chrysanthemum must have been brought from China to Japan after they had attained some degree of development in the era of Tempyo which is also called as the Nara period (710–794 AD) (Niwa 1936). Chrysanthemum was declared as the National Flower by Emperor Uda in the year 910 AD, and a 16-petaled single large chrysanthemum called "Ichimonji" was adopted as the imperial crest during the twelfth century. However, at present, chrysanthemum is the symbol of Royalty in Japan. Chrysanthemum underwent wonderful transformation representing widest range of variability (Nakajima and Young 1965).

Europe – The first mention of the chrysanthemum in Europe was made by botanist Bregnius in 1689, though it was 100 years later before the plant began to be cultivated in this continent, when Frenchman Pierre Louis Blanchard brought from Macao what was for a long time known as "The Old Purple." Eventually plants of this stock reached Kew, and a description of the new flower was featured in the *Curtis's Botanical Magazine* in 1796 (Kyle 1952). One Japanese cultivar was introduced in Holland in 1688. Jacob Bregnius, a Dutch botanist, described six Chinese cultivars being grown in Holland in 1690 (Niwa 1936; Cumming 1964). It was not much popular in Holland. In 1690, H. van Rheede described a Holland-grown type from India called "Gool-doodi." A French merchant from Marseilles named Pierre Louis Blanchard brought three cultivars home from China in 1789. Only one of these survived and was named "Old Purple," the first named cultivar to grow in the western world. Eventually this cultivar reached Kew Gardens, and its description was featured in the *Curtis's Botanical Magazine* of 1796. In 1827, seed

was successfully produced in Europe by a retired French officer, Captain Bernet, and as many previous attempts by both English and French gardeners had failed, this date is of great historical importance in the chrysanthemum world. It is also on record that the first English raiser was Mr. Wheeler of Oxford in 1832 (cf. Jim Smith, History of the Chrysanthemum, NCS Yearbook 1984). In France, though its value was appreciated, it primarily remained a cemetery flower with a preference for white and purple. In England, the emphasis was on exhibitions, the first being held in 1843 at Norwich. Here, its popularity was steadily increased, and the National Register of Names of Chrysanthemum issued by the National Chrysanthemum Society of England listed more than 5000 cultivars.

France – French breeders accepted and appreciated chrysanthemum for commercial exploitation. Favorable climate helped to develop late-blooming types. White, violet, and purple varieties were imported by merchant A. Blanchard from China to Marseilles, and purple became very popular for gardens in 1789. Eight more frilled-type varieties were imported from Chinese during 1799–1808. Early and more better varieties were developed by Captain Bernet during 1826–1836. Several interesting varieties with new color and form were raised by Dominique Perfuse during 1836 from seeds given to him by Captain Bernet. Robert Fortune brought "Chusan Daisies" and large reflexing type from China in 1864 and popularized among the growers. Extremely early blooming group was introduced in 1890 by Simon Deleaux from crosses of Japanese importations (c.f. Kyle 1952).

USA – The first "dark purple" chrysanthemum was imported from England by scientist John Stevens in the United States in 1798, and it was followed by many more cultivars from China. The growing of chrysanthemum became commercialized in America in the shortest period. Different forms, such as pompon, decorative, anemone, and spider, received much attention here. Instead of big size and novelty in color, the main qualities sought-after were sturdy growth, long vase life, and higher yield. The National Chrysanthemum Society of America was founded in 1890, consisting exclusively of commercial growers, at New York. The society organized the first exhibition in 1902 at Chicago.

India – It is difficult to say since when its cultivation has begun in India as no historical literature is available on chrysanthemum. In Marathi literature, its first written mention seems to be in Dnyaneshwari (1290 AD) (Chap. 15, shloka 20). As already mentioned earlier, a cultivar from India has been reported to be grown in Holland in 1690 under the name 'Gool-doodi' which points toward the fact that chrysanthemum was in cultivation in North India in the seventeenth century. It is interesting to know that in Hindi, chrysanthemum is still called "Gul-daudi." In North India, chrysanthemum is primarily grown for decorating the landscape either in the ground or in pots. Contrarily, in southern part of the country, it is mostly grown in farmer's fields for supply to the market as loose flowers for garland, for hair decoration by the ladies, and for offering to god. While yellow-colored flowers are preferred in the South, in the North, various hues of red, purple, yellow, and white are found to be grown in abundance.

19.4 Origin

The origin of chrysanthemum is at the best hypothetical as there is no proper experimental proof and/or genetic evidence. Nonetheless, it is now generally accepted that modern, large, double, and exquisitely flowered cultivars owe their origin to relatively small, single, and not so attractive types. This great transformation is the result of centuries of natural cross-pollination and selection by keen growers and also by indiscriminate intervarietal hybridization by a galaxy of breeders and natural and induced mutations.

The chief mechanism in the cytogenetical evolution of garden chrysanthemum has been enumerated by Nazeer and Khoshoo (1982) as outbreeding, spontaneous, and intentional hybridization coupled with mutation, chromosomal differentiation, and repatterning and polyploidy. According to available literature, the modern chrysanthemums are the result of some 2500 years of continuous repeated cycles of hybridization and selection from several species of chrysanthemum that grew wild in China and Japan. After over 1000 years of development of cultivated chrysanthemum, these were exported from China to Japan about AD 750. Japanese started improvement of Chinese variety by cross-fertilization with the then existing wild Chinese varieties. Japanese hailed it as their National Flower in AD 797. Slowly the flower was first introduced to Holland in about 1668, to France in about 1789, and to England in 1795. Robert Fortune brought chrysanthemum at the Royal Horticultural Society from China in 1846 and from Japan in 1862.

The first English seedlings were raised in 1835 by Short and Freestone. John Salter established a nursery at Versailles in France in 1838 where he produced a number of seedlings, the two most notable being 'Annie Salter' (medium reflexed decorative, yellow) and 'Queen of England' (large pink incurve) introduced in 1847. John Salter started his improvement work on chrysanthemum at a nursery in Hammersmith, London, and isolated quite a number of sports from 'Queen of England'. A new seedling ('William Penn') was grown at the Pennsylvania Horticultural Society in 1841. Pottery dating back to the fifteenth century BC depicts the flower as we know it today. Respect for this flower ran so deep; a city was named after it: Chu-Hsien or Chrysanthemum City. In ancient China, almost all parts of the chrysanthemum had medicinal use. The chrysanthemum made its way to Japan around the eighth century AD, and the emperor adopted a single chrysanthemum as his crest and official seal. National Chrysanthemum Day is celebrated in Japan since 910 AD. Chrysanthemum is a hybrid species which has developed as a result of complex interspecific crossing among the elemental species for over and over a period of more than 2500 years. Literature survey indicates that the following elemental species have played very important role to build up the present status of chrysanthemum: *C. boreale*, *C. carinatum* (tricolored blooms), *C. coronarium* (native to South Europe, yellow and white blooms), *C. cinerariifolium*, *C. coccineum* (white, pink, and red), *C. frutescens* (white and soft yellow flowers), *C. indicum* (native of China and Japan, supposed to be one of the ancestral species involved in the evolution of modern florist's chrysanthemum, yellow flowers), *C. japonicum*, *C. maximum* (white and yellowish blooms), *C. ornatum*, *C. satsumense*, *C. sibiricum*, *C. sinense* (native of China, blooms white),

C. parthenium (flower white or pale yellow), *C. balsamita* (flower yellowish with some white rays), *C. maximum* (white perennials), *C. nipponicum* (native of Japan, white daisies), *C. rubellum* (England, pink to rose red), *C. cliginoseem* (white large daisies), *C. zawadskii* (species from Galicia and Siberia, rose pink daisies), *C. alpinum* (native to high Alps, daisies of glossy white), *C. arcticum* (Arctic regions, white or pink), *C. mawii* (pink daisies, white with pink reverse), *C. weyrich* (pink flowers), *C. carinatum* (tricolor Chrysanthemum, native to Morocco, purple or reddish rings with yellow and white base), *C. segetum* (corn chrysanthemum or corn marigold; native to Europe, Africa, and Asia; deep yellow or whitish blooms), *C. frutescens* (white or soft yellow daisies), *C. indicum* (native to India/China, tiny yellow blooms), *C. hortorum* (not a valid species, but all garden chrysanthemums have an occasion been grouped here), and *C. sibiricum* (this acted like a blood transfusion on the worn-out strains of *Chrysanthemum* when it was used for breeding in the early 1930s, single flowers, white aging to carmine pink). Exploitation of genetic resources of some more wild species like *C. oreastrum*, *C. hydrargyrum*, *C. zawadskii*, *C. chanetii*, *C. naktongense*, *C. mongolicum*, *C. argyrophyllum*, *C. rhombifolium*, *C. vestitum*, *C. dichrum*, *C. glabriusculum*, *C. lavandulifolium*, *C. foliaceum*, *C. nankingense*, *C. potentilloides*, and *C. maximowiczii* has been reported (Zhao et al. 2009; Datta 2013).

19.4.1 Domestication

Garden chrysanthemum has a long history of domestication. China is the primary center of origin, and Chinese have been growing improved forms for the last 3000 years. Two elemental species, *C. indicum* L. and *C. morifolium* Ramat. (*C. sinense* Sabine), played the major role in the development of garden forms. The original cultivars were likely single- and many-flowered. There has been a transformation of the corolla of individual florets into numerous forms during domestication for a long time. The first experimental hybrid was recorded in 1827, and the first bud sport arose in 1832 (Darlington 1973). The main improvement of chrysanthemum cultivars has been achieved in the gardens of China, Japan, Europe, and America through conscious and unconscious selection. Garden chrysanthemum reached various places in the form of seedlings or seeds. New cultivars have arisen from these stocks through further hybridization and bud sports. Indiscriminate intervarietal hybridization followed by selection was the main evolutionary factor (Nazeer and Khoshoo 1982).

19.5 Classification

The International Chrysanthemum Society and different National Chrysanthemum Societies have classified chrysanthemum based upon bloom structure. The commonly accepted classification of garden chrysanthemum is based on bloom shape and size and relative number of the two kinds of florets (ray florets and disc florets), their shape, arrangement, and direction of growth. They are mainly classified under two categories: large-flowered and small-flowered. Large-flowered chrysanthemums

are further classified into 13 classes and small-flowered ones into 10 classes (Datta 1996). Examples for each are as follows:

(i) Large-flowered: Class 1. *Regular Incurve* – Ray florets are narrow to broad and very smoothly incurved in a regular pattern to form a perfect ball (Fig. 1a). The average bloom size varies from 10 to 15 cm (4″–6″). Disc not visible. *Examples* include 'Gairik', 'Shin Mei Getsu', 'Casa Grande', 'Kokka Soun', 'Snow Ball', 'S.S. Arnold', 'Autumn King', 'Chandrama', 'Sonar Bangla', 'R Venkatraman', 'Dream Castle', 'Bharat Ratna', 'Queen of Tamluk', 'Belur Math', 'Super Giant', and 'Adventure'. Class 2. *Irregular Incurve* – Ray florets are usually broad, smooth, incurved, and arranged in an irregular manner (Fig. 1b). The bloom size is very large, and the breadth and depth of the blooms are almost equal. The disc florets are entirely covered by the upper florets. The bloom size varies from 15 to 20 cm (6″–8″). *Examples* include 'Audrey Shoesmith', 'Hommand Philips', 'J.S. Salesbury', 'Kiku Biyori', and 'Mountaineer'. Class 3. *Skirted Incurve* –The lower florets, mostly the basal florets, bend downward in an irregular fashion to give a skirted shape. The bloom size varies from 15 to 20 cm (6″–8″). *Example* includes 'Dream Castle'. Class 4. *Incurving* – Ray florets are incurved upward in an indefinite manner. The bloom is not a compact ball due to

Fig. 1 Chrysanthemum flower types. Figure 1**a**. Regular incurve (Sonar Bangla). Fig. 1**b**. Irregular incurve (S.L. Andre Faurd). Fig. 1**c**. Incurving (Pink Cloud). Fig. 1**d**. Reflex (Alfred Wilson). Fig. 1**e**. Irregular reflex (Miss Maud Jeferi). Fig. 1**f**. Reflexing (Dee). Fig. 1**g**. Intermediate (Thaiching Queen). Fig. 1**h**. Quilled (Red Quill). Fig. 1**i**. Spider (Icicles)

loose fitting arrangements of florets (Fig. 1c). *Examples* include 'Classic Beauty', 'Pink Cloud', 'White Cloud', 'Scarlet Waltz', 'Gusman Red', 'Hanayome Sugata', 'Dr. S. Mukherjee', 'Leading Lady', and 'Hommand Philips'. Class 5. *Reflex* – Ray florets are narrow to broad and bent backward and downward. Inner florets remain incurved at the early stage concealing the disc florets of the bloom. Outer florets turn outward away from the central tuft. Blooms look globular but may be somewhat flattened. The average bloom size is 15–20 cm (6″–8″). The center or disc of the flower is not visible. On the basis of arrangements of ray florets, this class is further subclassified into (a) *regular reflex* (Ray florets are bent back and downward in a regular arrangement (Fig. 1d).), (b) *irregular reflex* (Ray florets are bent downward in a twisted and irregular way (Fig. 1e).), and (c) *reflexing* (Ray florets are like aster and have a tendency to reflex. The bloom appears flat shape (Fig. 1f).). *Examples* include 'Imperial', 'Dee', 'Mrs. A.I. Miller', 'John Webber', 'Julios Brinas', 'President Viger', 'Rose Day, 'Star of India', 'Hope', 'Mrs. Roager Thompson', 'Ashok Pillar', 'Mrs. Eleston', 'Kansya', 'Kasturba Gandhi', and 'Beatrice May'. Class 6. *Intermediate* – This class represents blooms intermediate between "incurved" and "reflex." Ray florets are narrow to broad and may be short. Few outer ray florets are partially incurved, but lower ray florets are reflex. Inner florets are incurved. Disc concealed. Centers may be slightly flattened or depressed. The bloom shape gives a globular effect (Fig. 1g). The bloom size is 15 cm (6″) or more. *Examples* include 'General Petain', 'Mrs. W.A. Reid', 'T-1', 'Cloth of Gold', and 'Sun Flight'. Class 7. *Ball* – The ray florets are straight and densely packed. These radiate uniformly in all directions to give the bloom a ball/ovoid/roundish shape. *Examples* include 'W-23', 'Pride of Madford', 'Nigeria', and 'Red Jack'. Class 8. *Quilled* – The ray florets are tubular and elongated with tips open or closed (Fig. 1h). The thickness of the tube varies from thin to medium to thick. *Examples* include 'W-11', 'Red Quill', 'Green Sensation', 'Tribhuban', and 'Pradhan's Pride'. Class 9. *Spider* – The florets (same as Class 8) are large, tubular, and elongated. Tips may be open or closed, but in either case, they are coiled or hooked. The rays may either fall or spread (Fig. 1i). *Examples* include 'Sunder Calcutta', 'Geetanjali', 'Achievement', 'Innocence', 'Carnation Gold', 'Icicles', 'Tokyo', 'Senkyo Emaki', 'Florida', 'Manick', 'Senkyo No Rya', 'Miss Universe', 'Valiant', 'M-30', 'Flirtation', 'Kogen No Hoshii', 'Diamond Jubilee', and 'T-8'. Class 10 – *Spoon*. The ray florets are tubular with spatula-like open tips. The size of open portion varies. Disc visible (Fig. 2a). *Examples* include 'Pink Casket', 'M-24', 'Crimson Tide', 'Carnation', and 'Puspahanas'. Class 11. *Anemone* – The ray florets are ligulate or quilled. Here, the disc is noticeably developed with florets. Disc usually hemispherical and raised (Fig. 2b). *Examples* include '007', 'Cloud Bank', and 'Red Admiral'. Class 12. *Single* – Ray florets are long, elongated, and strap-like (Fig. 2c). The number of whorl of florets is restricted up to four. The disc is conspicuously visible. *Examples* include 'Potomac', 'Joan Helen' and 'Surja'. Class 13. *Semidouble* – Ray florets are long, elongated, and strap-like. The number of whorl of florets is more than five. Disc conspicuous. *Examples* include 'Ronald' and 'Crimson Tide'.

(ii) Small-flowered: Class 1. *Anemone* – Disc florets are well developed and prominent. Ray florets may be flat, twisted, and quilled (Fig. 2d). *Examples* include 'Nirmod', 'Venus', 'Pink Cushion', 'Violet Cushion', 'Season', 'Ace',

'Perfect', 'Gaity', 'Dainty Maid', 'Mercury', 'Rosa', 'Maise', 'Gem', 'Modella', 'Harbinger' and 'Smita'. Class 2. *Button* – Florets are short rayonate-like and hemispherical. Florets radiate in all directions. Blooms are small and compact. 2–3 cm (about 1 inch) in diameter. *Examples* include 'Liliput', 'Bull Finch', and 'King Fisher'. Class 3. *Single Korean* – Ray florets are strap-like. Bloom flat and disc well visible. Ray florets are arranged in five or less whorls. *Examples* include 'Tune Full', 'Pat', 'Alpana', 'Dolore', 'Sharad Bahar', 'Sharad Shobha', 'Sharada', 'Sharad Seema', ' Prabha', 'Sharad Singar', 'Sunset', 'Kirti', 'Ragini', 'Luoy', 'Margery', 'Pilgrim', 'Pat', 'Fantasy', and 'Vinaya'. Class 4. *Double Korean* – Florets are the same as Class 3. The number of whorls of ray florets is more than five (Fig. 2e). Disc visible. *Examples* include 'Jyotsna', 'Khushrru', 'Flirt', 'Lalkila', 'Tara', 'Lilith', 'Priya', 'Purity', 'Criterion', 'Man Bhawan', 'Red Gold', 'Fatima', 'Lalpari', and 'Sonali'. Class 5. *Decorative* – Florets are the same as Class 4. Here, the disc is not visible due to developed ray florets. Ray florets regular or irregularly reflexed (Fig. 2f). *Examples* include 'Megami', 'Sharad Mala', 'Jayanti', 'Sujata', 'Jubilee', 'Nilima', 'Sonali Tara', 'Puja', 'Jaya', 'Suneel', 'Ajoy', 'Illini Cascade', 'Pink Gin', 'Jawra', 'Ratna', and 'Shabnam'. Class 6. *Pompon* – Ray florets are short, broad, and very systematically and uniformly arranged to

Fig. 2 Chrysanthemum flower types. Figure 2**a**. Spoon (M-24). Fig. 2**b**. Anemone. Fig. 2**c**. Single (Potomac). Fig. 2**d**. Anemone (Nimrod). Fig. 2**e**. Double Korean (Lilith). Fig. 2**f**. Decorative (Jayanti). Fig. 2**g**. Quilled. Fig. 2**h**. Stellate

give bloom a compact hemispherical shape. Width and breadth almost equal. Ray florets may be incurved or reflexed. Disc normally covered or inconspicuously open. *Examples* include 'Horizon', 'Apsara', 'Nanako', 'Cotton Ball', 'Birbal Sahni', 'Purple Star', and 'Maharaja'. Class 7. *Semi-quilled* – The ray florets are tubular up to certain length of the floret from the base and then open at the tip. Open-tip portion may be flat, reflexed, or incurved. Disc open. Examples include 'Jean', 'Alison', and 'Garnet'. Class 8. *Quilled* – Ray florets are elongated and tubular like a quill. The tips of florets may be open but not developed (Fig. 2g). *Examples* include - 'Fraiar', 'Munchausen', 'Q-3', 'Donald', 'Rita', 'Snow Crystal', 'Space in 83', and 'Green Nightingale'. Class 9. *Stellate* – Florets are like Class 3, but both sides of ray florets are reflexed downward. Florets may or may not be twisted. Disc flat with short florets (Fig. 2h). Examples include 'Laura', 'Heloise', 'Red Star', 'Harvest Home', 'Stella', 'Morning Star', and 'Gordon Tailor'. Class 10. *Cineraria* – Blooms are flat Korean type with diameter not more than 3 cm (about 1.2″). Examples include 'Phyllis', 'Jessie', 'Kashturi', 'Bindya', and 'Charmis'.

19.6 Species and Cultivars

(i) *Species*: The number of species under the genus *Chrysanthemum* varies from 100 to 200 (Niwa 1936; Carter 1980). Some important species of chrysanthemum are *Chrysanthemum boreale*, *C. carinatum* (tricolor), *C. coronarium* (garland chrysanthemum, yellow and white blooms), *C. cinerariifolium* (grown in temperate regions for making an insecticide called pyrethrum), *C. coccineum* (grown in temperate countries from seeds, blooms with white, pink, and red colors and look like anemone chrysanthemum, perennial), *C. frutescens* (white and soft yellow flowers), *C. indicum* (it is supposed to be one of the ancestral species involved in the evolution of modern florist's chrysanthemum, yellow flowers), *C. japonicum* (found to be growing in the Pacific coastal region of Japan), *C. maximum* (popular cut flower bearing white and yellowish blooms, perennial), *C. morifolium* (florist's chrysanthemum), *C. ornatum* (syn. *C. marginatum*, allied to *C. indicum* and *C. sinensis*), *C. rubellum* (it is exceptionally sturdy and used by breeders for its hardiness), *C. satsumense*, *C. sibiricum* (this is said to be one of the parents of Korean hybrids evolved in early 1930), *C. sinense* (this is supposed to be one of the sources (with *indicum*) of today's florist's chrysanthemum, native of China, and bears blooms with white ray florets), *C. maximum*, *C. pacificum*, *C. segetum*, *C. aphrodite* Kitam., *C. arcticum* L., *C. argyrophyllum* Ling, *C. arisanense* Hayata, *C. chalchingolicum* Grubov, *C. chanetii* H. Lév., *C. crassum* (Kitam.) Kitam., *C. cuneifolium* Kitam., *C. daucifolium* Pers., *C. dichrum* (C.Shih) H. Ohashi & Yonek., *C. foliaceum* (G.F.Peng, C.Shih & S. Q.Zhang) J.M.Wang & Y.T.Hou, *C. glabriusculum* (W. W. Sm.) Hand.-Mazz., *C. horaimontanum* Masam., *C. hypargyreum* Diels, *C. integrifolium* Richardson, *C.* × *konoanum* Makino, *C. lavandulifolium* Makino, *C. leucanthum* (Makino) Makino, *C. longibracteatum* (C.Shih, G.F.Peng & S.Y.Jin) J.M.Wang & Y.T.Hou,

C. maximoviczii Kom., *C. miyatojimense* Kitam., *Chrysanthemum* × *morifolium* (Ramat.) Hemsl., *C. morii* Hayata, *C. naktongense* Nakai, *C. ogawae* Kitam., *C. okiense* Kitam., *C. oreastrum* Hance, *C. parvifolium* C.C.Chang, *C. potentilloides* Hand.-Mazz., *C. rhombifolium* (Y.Ling & C.Shih) H.Ohashi & Yonek., *Chrysanthemum* × *shimotomaii* Makino, *C. sinuatum* Ledeb., *C. vestitum* (Hemsl.) Kitam., *C. yantaiense* M.Sun & J.T.Chen, *C. yoshinaganthum* Makino, *C. zawadskii* Herbich, and *C. zhuozishanense* L.Q. Zhao & Jie Yang.

Cultivars: The number of chrysanthemum cultivars is incredibly large with more than 15,000 listed in Japan only. The National Chrysanthemum Society of Britain lists over 6000 cultivars (Machine and Scopes 1978). In India, too, the number would easily cross 500 marks. The exact number will vary because every year new varieties are being developed throughout the world, but they are not documented at one place. Different countries have started more and more breeding work and developing new varieties regularly. Lists of some selected cultivars grown widely throughout the world color-wise are the following:

Spray Cultivars: *white*, 'Artic', 'Bonnie Jean', 'Cloudbank', 'Divinity', 'Elegance', 'Hurricane', 'Japanerin', 'Memento', 'Nimbo', 'Polaris', 'Schnesstern', 'Snow-don', 'Super White', 'White Illini Springtime', 'White Marble', 'White Sands', 'White Spider', 'White Taffeta'; *yellow*, 'Agenta', 'Celebrate', 'Golden Crystal', 'Golden Hurricane', 'Golden Polaris', 'Golden Sands', 'Golden Vedova', 'Golden Winner', 'Jubilee', 'Souvenir', 'Sunbeam', 'Super Yellow', 'Yellow Agenta', 'Yellow Bonnie Jean', 'Yellow Divinity', 'Yellow Galaxy', 'Yellow Horim', 'Yellow Illiini Springtime', 'Yellow Marble', 'Yellow Nimbo', 'Yellow Snowstar', 'Yellow Spider', 'Yellow Tuneful'; *pink*, 'Belair', 'Bluechip', 'Blue Winner', 'Dolly', 'Illini', 'Springtime', 'Riviera Spider', 'Taffeta', 'Vedova'; *pale pink*, 'Pink Marble', 'Pollyanne', 'Snapper'; *red*, 'Crackerjack', 'Red Fandango', 'Red Galaxy', 'Red Nero', 'Red Tuneful'; *bronze*, 'Belreef', 'Bronze Nero', 'Bronze Rosado', 'Flame Belari', 'Galaxy', 'Tuneful'; *light bronze*, 'Apricot Marble', 'Apricot Winner', 'Dramatic', 'Orange Aglow'; *purple*, 'Fandango', 'Flamenco'; *salmon*, 'Coral Marble'.

Standard Cultivars: *white*, 'Giant Indianapolis White', 'Improved Mefo', 'May Shoesmith', 'Beauty', 'Snow Ball', 'William Turner', 'Innocence', 'Gen. Petain', 'Valiant', 'Green Goddess', 'Ajina White', 'Premier'; *yellow*, 'Bright Golden Anne', 'Bright Yellow May Shoesmith', 'Rivalry', 'Yellow Fred Shoesmith', 'Chandrama', 'Kikubiori', 'Mountaineer', 'Super Giant', 'J.S. Lloyd', 'Triumphant', 'Evening Star', 'Melody Len'; *pink*, 'Cassandra', 'Deep Champagne', 'Pink Champagne', 'Promenade', 'Regal Anne', 'Ajina Purple', 'Pink Cloud', 'Pink Turner'; *red*, 'Crimson Anne', 'Red Anne', 'Red Resilient', 'Working Scarlet', 'Alfred Wilson', 'Alfred Simpson', 'The Dragon'; *bronze*, 'Bronze Princess Anne', 'Resilient'; *light bronze*, 'Gay Anne'; *purple*, 'Purple Anne'

Pot Cultivars: *white*, – 'Altis', 'Bonnie Jean', 'Mountain Snow', 'Neptune', 'Snow Crystal', 'White Anne', 'White Popsie', 'Windsong'; *yellow*,

'Armelle', 'Golden Crystal', 'Mountain Peak', 'Pride', 'Reaper', 'Spic', 'Stargold', 'Yellow Bonnie Jean', 'Yellow Delaware', 'Yellow Hector', 'Yellow Illini Spinwheel', 'Yellow Mandalay', 'Yellow Paragon', 'Yellow Popsie', 'Yellow Tuneful'; *pink*, – 'Always Pink', 'Dark Maritime', 'Deep Louise', 'Deep Popsie', 'Illini Trophy', 'Judith', 'Proud Princess Anne', 'Princess Anne Superb', 'Regal Anne', 'Rose Hostess', 'Royal Trophy'; *pale pink*, – 'Distinctive', 'Maritime', 'Wedgewood'; *red*, – 'Crimson Anne', 'Cromson Torch', 'Red Torch', 'Rory, Rufus', 'Working Scarlet'; *bronze*, 'Bronze Princess Anne', 'Copper Hostess', 'Gay Louise', 'Glowing Mandale', 'Mandalay', 'Rascal', 'Red Anne', 'Sparking Mandale', 'Tuneful'; *light bronze*, 'Bronze Popie', 'Dramatic', 'Gay Anne', 'Orange Aglow', 'Orange Bowl'; *purple*, 'Cerise Magnum', 'Purple Anne', 'Royal Purple'

It is difficult to mention the exact number of varieties available in India. New varieties are being developed by different research institutions, universities, amateur growers, etc. through selections, breeding. and induced mutations. A tentative list of varieties is mentioned.

CSIR-National Botanical Research Institute, Lucknow, India, is maintaining the following chrysanthemum cultivars (Datta 1998):

Large-flowered chrysanthemum – White: 'Beatrice May', 'Beauty', 'Bharat Mata', 'Casa Grande', 'Dee', 'Dorrige Queen', 'Frosty Whisker', 'General Petain', 'Green Goddess', 'Green Sleeves', 'Gypsy Queen', 'Icicles', 'Imperial', 'Jet Snow', 'John Webber', 'June Bride', 'Kasturba Gandhi', 'Kokka Soun', 'Maudjafferies', 'Mrs C Tolly', 'Nightingale', 'Pennylane', 'Purnima', 'Shamrock', 'S S Arnold', 'Snow Ball', 'Snow Don', 'Tokyo', 'Valiant', 'White Cloud', 'White Snow', 'White Sport of Pink Cloud', 'Willium Turner', 'Woolman Century', 'White Sport of Pride of Madford'. *Yellow*: 'Autumn King', 'Betty Barnes', 'Bhima', 'Bob Pulling', 'Chandrama', 'Cossak', 'Diamond Jubilee', 'Duskey Queen', 'Ella Dalby', 'Mahabi', 'Evening Star', 'Florida', 'Garden State', 'J S Salisbury', 'Kiku Biori', 'Kokka Yamata', 'L C Philips', 'Mountaineer', 'Mrs J A Miller', 'Mr Roger', 'Thompson', 'Mrs Nancy', 'Ferneaux', 'Pitamber', 'Queen of Tamluk', 'Rohinhood', 'R Venkatraman', 'Senyo No Rya', 'Sheila Morghan', 'Shin Mei Getsu', 'Sonar Bangla', 'Super Giant', 'Surya', 'Tamra', 'Thiokinga', 'Yellow Reflex', 'Yellow Rayonette', *Red*: 'Alfred Wilson', 'Arjuna', 'Black Hawk', 'Bicolour Incurved', 'Crimson Tide', 'Dorrige Velvet', 'Dragon', 'Gusman Red', 'Party Time', 'R.M. Quittenton', 'Red reflex', 'Leviathan', 'Mrs W A Reid', *Mauve*: 'Ajina Purple', 'Allahabad Reflex', 'Angeles Belle', 'Belur Math', 'Cover Girl', 'Coronation Pink', 'Edith Cavel', 'Fish Tail', 'Hope', 'H Townsend', 'Incurve Dwarf', 'Julius Brinas', 'Kenroku Kangiku', 'Kingford Smith', 'K N Modi', 'Kunchit', 'Mahatma Gandhi', 'Otome Zakura', 'Pink Brocade', 'Peacock', 'Pink Cloud', 'Pink Casekt', 'Pink Intermediate', 'Pink Rayonette', 'Pink Turner', 'Potamac', 'President Viger', 'Pride of Jamshedpur Raja', 'Royal Pinch', 'Royal Purple', 'Satish Modi', 'Scater's Waltz', 'Senkyo Emaki', 'Shefali', 'Spoon', 'Sport of H, Towensend', 'Tata Century',

'Taiho Tozan', 'Violent Queen', '(M45)', '(M-61)'. *Terracota*: 'Achievement', 'Alfred Simpson', 'Appart', 'Autum Blaze', 'Bhai- Bhai', '(T-10)', 'T-1', 'Captain Kettle', 'Chengis Khan', 'Dignity', 'Distinction', 'Gambit', 'Gen-Carpenter', 'Goliath', 'Heather James', 'Jane Sharp', 'Miss Universe', 'Mrs Helmipot', 'Orange-Fair Lady', 'Paul, Ronaldo', 'Sancho', 'S L Andre', 'Spider Bruno', 'Thiching Queen', 'Red Fair Lady', 'Red Quill'

Small-flowered chrysanthemum – Summer season cultivars: 'Himanshu', 'SU-1', 'Jwala', 'Jyoti', 'Su-3', 'Su-4', 'Phuhar'. *September–October blooming cultivars*: 'Ajay', 'Sharda', 'Sharad Kiran', 'Sharad Shobha', 'Vijay', 'Vijay Seedling'. *October blooming cultivars*: 'Arunima', 'Sharad Kanti', 'Sharad Mukta', 'Sharad Sandhya', 'White Dwarf (OO-8)'. *October–November blooming cultivars*: 'Chakra', 'Double Korean', 'Hemanti', 'Lalpari', 'Makhmal', 'Megami', 'Mohini', 'Nanako', 'Sharad Har', 'Sharad Mala', 'Tricolour', 'White Prolific', 'Yellow Prolific (NN-14)'. *November-December blooming cultivars*: 'Archana', 'Apsara', 'Birbal Deep Pink', 'Cotton Ball', 'Jayanti', 'Jubilee', 'Kundan', 'Ping Pong', 'Ratna', 'Yellow mutant of Ratna'. *December–January blooming cultivars*: 'Ratna', 'Button', 'Gauri', 'Gulal', 'Jaya', 'Khumaini', 'Lalima', 'Lilith', 'Mauve Spoon', 'Nilima', 'Puja', 'Purplish Red', 'Sunayana', 'Sunil', 'Vasantika', '(X-1)'. *Dwarf (no pinch no stake mini cultivars)*: 'Akita', 'Appu', 'Apurva', 'Arun Kumar', 'Arun Singar', 'Bindiya', 'Bronze', 'Cameo', 'Haldighati', 'Hemant Singar', 'Mahendra Singar', 'Mini Queen', 'Minihar', Orange, Pancho, Peet Singar, Pink Princess, 'Rangoli', 'Red', 'Red Anemone', 'Sengoku Ban', 'Sharad Singar', 'Shizuka', 'Suhag Singar', 'Shveta Singar', 'Swarn Singar', 'White Dwarf', 'White Pincushion', 'Yellow Charm'. *Decorative*: 'Alankar', 'Astral', 'Iiar', 'Jwara', 'Kalyani', 'Kanpur Yellow', 'Navneet', 'Pink', 'Renukoot', 'Seedling', 'Shyamal', 'Sonalitara'. *Stripped* 'S': 'Countees stripes', 'Duke', 'Karanfool', 'Kiran', Surekha. *Spoons* 'S': '(T-1)', '(T-3)', '(T-4)', '(T-5)', '(T-6)', '(T-7)', '(T8)', '(T-14)'. *Cultivars a*: 'Dainty Maid', 'Executive', 'Gaity', 'Perfecta', 'Venus', '(AA-4)', '(AA-9)'. *Cultivar b*: 'Angela', 'Anjali', 'Aura', 'Blaze', 'Coy', 'Gem', 'Lady-Roberts', 'Lord-Roberts', 'Marble', 'Marshal', 'Modella', 'Murcury', 'Rosa', 'Sukhai', 'Topaz', 'Vandana', '(A-8)'. *Cineraria* 'c': 'Bronze', 'Charmis', 'Philips', 'White Seedlings', '(C-5)'. *Cushion* 'E': 'Basanti', 'Fairy', 'Freedom', 'Himani', 'IIHR Selection', 'Kaumuduni', 'Kumkum', 'Processor', 'Harris', 'Seedling', 'Shanti', 'Snow White'. *Cultivars* 'F': 'Harvest Home', 'Laura', 'Stella'. *Cultivar* 'I': 'Molly', 'Fanny', '(I-3)', '(I-4)'. *Cultivar* 'Y': 'Pink', 'Rani', 'Sindoori', 'Sport of Y-1'. *Single Korean* 'N': '(N-1)', '(N-2)', '(N-3)', '(N-4)', '(N-6)', '(N-7)', '(N-8)', '(N-9)', '(N-10)', '(N-11)', '(N-12)', '(N-14)', '(N15)'. *Quilled* 'Q': '(Q-1)', '(Q-2)', '(Q-3)', '(Q-4)'. *Double Korean*: 'Aparajita', 'Batik', 'Cissie', 'Fatima', 'Flirt', 'Hindalco', 'Juno', 'Jyotsna', 'Khurso', 'Lalpari', 'Lalquila', 'Man Bhawan', 'Priya', 'Red Gold', 'Shabnam', 'Tara', 'White' (Korean Double), '(O-6)', '(O-21)', '(O-2)'. *Pin Cushion*: 'Malika', 'Mayur'.

The following new varieties of chrysanthemum have been developed through conventional breeding at CSIR-NBRI, Lucknow, and in some other ICAR institutions and universities in India: *CSIR-NBRI*: 'Ajay', 'Appu', 'Apsara', 'Apurva',

'Apurva Singar', 'Arun Kumar', 'Arun Singar', 'Bindiya', 'Birbal Sahani', 'Dhawal', 'Diana', 'Gauri', 'Gulal', 'Guldasta', 'Haldighati', 'Hemant Singar', 'Himanshu', 'Jaya', 'Jayanti', 'Jubilee', 'Jwala', 'Jyoti', 'Jyotsna', 'Kargil 99', 'Kaumudi', 'Kiran', 'Kirti', 'Kundan', 'Lal Kila', 'Lalima', 'Lalpari', 'Lilith', 'Maghi', 'May-Day', 'Mayur', 'Meghdoot', 'Mini-Queen', 'Mohini', 'Mother-Teresa', 'NBRI Pushpangadan', 'NBRI Khoshoo', 'NBRI Kaul', 'NBRI Himanshu', 'NBRI Little Orange', 'NBRI Little Hemant', 'NBRI Little Kusum', 'NBRI Little Pink', 'NBRI Yellow Bud Sport', 'Neelima', 'Niharika', 'Nirmal', 'Pancho', 'Peet Singar', 'Phuhar', 'Priya', 'Prof. Harris', 'Puja', 'Ragini', 'Rangoli', 'Sadbhavna', 'Shanti', 'Ratna', 'Sharda', 'Sharad Kanti', 'Sharad Kumar', 'Sharad Mala', 'Sharad Mukta', 'Sharad Sandhya', 'Sharad Shobha', 'Sharad Singar', 'Shizuka', 'Shyamal', 'Suhag Singar', 'Sujata', 'Suneel', 'Sunayana', 'Suparna', 'Surekha Yellow', 'Surya', 'Swarn Singar', 'Sweta Singar', 'Tushar', 'Vandana', 'Vasantika', 'Vijay', 'Vijay Kiran', 'Vinaya', 'White Charm', 'White Profile', 'Y2K', 'Yellow Charm', 'Yellow Prolific', 'NBRI Yellow Bud Sport'. *Indian Institute of Horticultural Research, Bengaluru*: 'Arka Ganga', 'Arka Pink Star', 'Arka Ravi', 'Arka Swarna', 'Chandrakant', 'Chandrika', 'Indira', 'Kirti', 'Nilima', 'Pankaj', 'Rakhee', 'Ravikiran', 'Red Gold', 'Yellow Star', 'Yellow Gold', 'Usha Kiran'. *Punjab Agricultural University, Ludhiana*: 'Anmol', 'Baggi', 'Gul-E-Sahir' [yellow], 'Royal Purple', 'Yellow Delight', 'Autumn Joy', 'Garden Beauty', 'Winter Queen'. *Tamil Nadu Agricultural University, Coimbatore*: 'CO.1', 'CO.2', 'MDU'. *Dr. YSPUHF, Nauni, Solan*: 'Solan Mangla'

Some outstanding chrysanthemum cultivars have originated in India through spontaneous mutations. The most notable varieties are 'Kasturba Gandhi' (white) developed from 'Mahatma Gandhi' (mauve), 'Sonar Bangla' (yellow) from 'Snow Ball' (white), 'White Cloud' (white) form 'Pink Cloud' (pink), 'Sharda' (yellow) from 'Sharad Shobha' (white), 'Queen of Tamluk' (yellow) from 'Casa Grandi' (white), 'R Venkatraman' (yellow) from 'S S Arnold' (white), 'William Turner' (white) from 'Pink Turner' (pink), 'J S Lloyd' (yellow) from 'William Turner' (white), 'White Ball' from 'Pride of Madford', etc. In addition to these promising varieties, a large number of new varieties have been developed in India through sports.

Mutant varieties developed in India: *CSIR-NBRI*, Lucknow – 'Agnishikha', 'Alankar', 'Anamika', 'Aruna', 'Asha', 'Ashankit', 'Basant', 'Basanti', 'Batik' (Fig. 6d), 'Colchi Bahar' (Fig. 6i), 'Cosmonaut' (Fig. 6f), 'Gairik', 'Hemanti', 'Himani', 'Jhalar', 'Jugnu', 'Kanak', 'Kansya', 'Kapish', 'Kumkum', 'Kunchita', 'Lalima Head Shape', 'Lalima Tubular Mutant', 'Lohita', 'Man Bhawan', 'Navneet' (Fig. 6g), 'Navneet Yellow', 'Nirbhaya', 'Nirbhik', 'Pingal', 'Pitika', 'Pitamber', 'Purnima' (Fig. 6c), 'Raktima', 'Rohit', 'Shabnam' (Fig. 6e), 'Shafali', 'Sharad Har', 'Sheela', 'Shweta', 'Surekha Yellow', 'Sonali' (Fig. 6h), 'Subarna', 'Tamra', 'Taruni', 'Tulika'

19.7 Cultural Practices

(i) *Pot culture*: Well-drained sandy loam of good texture and aeration, with a neutral or slightly acidic pH (6.5–7.0) and a high organic content, is the ideal soil for chrysanthemum culture (Datta 1996).

For pot culture of small-flowered chrysanthemum soil/F.Y.M./leaf mold (1:2:2 v/v) is very suitable. Small amount of bone meal/super phosphate (2 tablespoon) is added sometimes with the compost. Proper vegetative growth at the early stage is most important. Feeding mixture, rich in nitrogen and potash content, should be applied regularly. Phosphorus is used as basal dressing. Small amount of oil cake is added over the soil in the pot at the early stage, and it is allowed to dissolve slowly by normal irrigation process. Application of liquid manure is started when the root system is well established. Fresh cowdung and oil cake are allowed to rot in a container in water. This decanted solution is applied to plants once a week as watering. Liquid manure (5 g potassium nitrate and 5 g ammonium nitrate dissolved in 10 liters of water) is applied twice at fortnight interval during September. The top portion (about 2 cm) of each pot is filled during the end of September by a compost mixture made up of neem cake/F.Y.M./soil/wood ash (1:4:8:4 part). Two doses (at fortnight interval) of liquid manure (as mentioned above) are applied at the time of flower bud initiation. Immediately after that, two doses (once a week) of another liquid fertilizer mixture (potassium nitrate 30 g + urea 5 g dissolved in 10 liters of water) are applied.

(ii) *Sterilization*: It is one of the most important operations for chrysanthemum culture. Old earthen pots are first cleaned with the help of a piece of cloth or jute and then dipped in 2% formalin solution and sun dried. Coarse sand is a very good medium for planting cuttings for rooting. The sand is sterilized by heating over an iron pan for half an hour. It may also be sterilized by using 2% solution of formalin. The compost containing of a mixture of leaf mold, cowdung manure, and soil is properly sprayed 2% formalin, mixed properly, and covered with alkathene sheet for about a week.

(iii) *Field preparation*: The field is ploughed twice or thrice, and 15–20 tons of F.Y.M. per acre are applied at the time of preparation of beds. Rooted suckers are planted at 30 cm (12″) distance. Fertilizers at the rate of 25 Kg nitrogen and 40 Kg each of P_2O_5 and K_2O per acre are applied for better performances. Application of urea at the rate of 30 kg per acre at color showing stage is recommended.

(iv) *Preparation of pots*: For maintaining proper drainage system, the drainage hole at the bottom of pots should be loosely covered first with broken pieces of earthen pots before filling compost. The drainage hole should never be clogged with compost and should be checked frequently.

(v) *Irrigation*: Chrysanthemum requires frequent and thorough watering before monsoon. Proper drainage system should be maintained both in beds and in pots as these plants are very sensitive to excessive water. There should not be waterlogging in beds and also on the pots during rainy season. If the water accumulation is due to clogging of drainage hole and faulty potting mixture, checking of drainage hole and changing of old potting mixture by new potting mixture are recommended. Excess water accumulation causes serious damage to the plant roots.

(vi) *Pinching*: Pinching is one of the most important operations in chrysanthemum culture. Soft vegetative shoot tips half to 1 inch long are removed. It is done with thumb and forefinger, although knives, scissors, etc. can also be used. Pinching gives the plant an appreciable shape and most essential for small-flowered chrysanthemum. Pinching is performed both in suckers and in cuttings. Two types of pinching, i.e., soft pinching (top soft tips of the shoot with 2–3 open leaves) and hard pinching (longer portion up to hard shoot), are performed.

(vii) *Suckers*: Rooted suckers are planted in field during January for stock plants. For vigorous and profuse branching, regular pinching is performed in these plants. These stock plants may be used both for preparation of cuttings and as potted plants for flower show and other displays. The first pinching is performed in April, second pinching in May, and third pinching in June. After third pinching, cuttings are taken from these mother plants. Fourth pinching is performed during August, and the final pinching of stock plant is completed by the middle of September.

(viii) *Cuttings*: Suckers are planted in open beds in January, and all care is taken for their vigorous growth and profuse branching by frequent pinching. Terminal shoot cuttings (7–13 cm or 3–4″ long) are taken from these stock plants in June. 15–20 cuttings may be available from a healthy well-grown plant. Cuttings are prepared during June to August. The cuttings may be planted in 10–25 cm (4″–10″) pots, flat thalis, or rectangular wooden box (10–13 cm or 4″–5″ deep) filled with sterilized coarse sand. The basal portion (10 mm or less than half inch) of cuttings are dipped either in Seradex/Keradex (rooting hormone) or in any other rooting hormone (1000 ppm solution of indolebutyric acid) for better rooting. Before planting, 3–4 basal leaves of each cutting are removed, and the lower portion of cuttings are treated with some copper fungicide to avoid fungal growth. The container, after planting cuttings, should be kept in semi-shade for about 2 weeks to avoid hot sun. Watering is done once or even twice a day as per weather condition.

(ix) *Disbudding and Dis-shooting*: These operations are mostly performed for large-flowered and decorative-type chrysanthemums. Disbudding operation is an important factor in the maintenance of high-quality product. Many of the varieties are disbud or standard types, in which the largest terminal bud is reserved and all axillary buds are removed. For disbudding of spray varieties, only the large apical bud is removed, and the axillary buds are allowed to develop. When growers want to develop three blooms per plant or one bloom per plant, these operations are most essential. For taking three blooms per plant (June-planted cuttings), the first pinching is done in August. Three lateral strong shoots are allowed to grow and others are removed. Disbudding starts in October when all but the central buds on each lateral shoot are removed. Lateral buds and side shoots are removed at their early stage of growth from time to time. For taking one bloom per plant (June-/July-planted cuttings), no pinching is done. Only the main stem is allowed to grow.

Disbudding and dis-shooting of undesirable lateral buds and shoots are done as in the case of three-bloom type.

(x) *De-suckering*: During the vegetative growth phase, plants grow upward. New suckers continue to develop from the base of plants. For proper and vigorous growth of plants, suckers are removed from time to time.

(xi) *Staking*: Staking is necessary to keep plants erect and to maintain proper shape of plants and bloom. Growers need only one stake for single bloom and three stakes for three blooms per plant. In small-flowered, 5–8 stakes are used for profuse blooming.

19.8 The Art of Training

(i) *Standard*: Large-flowered chrysanthemums are trained as standard for better shape of the plants and attractive extra-large flower producing 1–3 blooms per plant. Suckers are planted in January. The plants are transplanted several times in bigger pots and finally into 25 cm (10″) pot in August. These plants bloom in November–December. These plants are normally very tall and need care throughout the year. According to recent cultural methods for developing better standards, plants are developed from cuttings in July. It avoids unnecessary care of plants for about 6 months.

(ii) *Sen Rin Tsukuri*: It is a Japanese style of chrysanthemum culture whose literal meaning is "growing thousand blooms." The plant is designed to a geometrical shape (6–10 concentric circles in stepped manner), and it is trained in such a way that about 200–300 blooms, and even more, are formed per plant having an approximate height of 153–183 cm (56 ft.) and a diameter of 183–244 cm (6–8 ft.). Varieties with vigorous growth habit in all directions, long internodes, flexible stems, etc. are suitable for this. Suckers are planted in December in 15 cm (6″) pots filled with the compost made of leaf mold/light clay/charcoal powder (10:2:1). Second potting is done into 20 cm (8″) pots during the end of February in a potting mixture of cowdung manure/leaf mold/light clay + bone meal (4:2:2 + 1 tablespoon). Two tablespoonful of oil cake is added on the top of each pot for vigorous growth. The first pinching is performed when the plant attains a height of 20–25 cm (8″–10″). Plants are shifted in bed in March for more vigorous growth. The bed is well manured with rotten farm yard manure, bone meal, and oil cake. The planting distance is 92 cm (3 ft.). The main stem is made vertical with the help of a strong bamboo stake. The lateral shoots which come out after first pinching are made horizontal with the help of hooked wire inserted in the pot. Pinching is continued for profuse branching till the end of June. The new branches are trained in desired direction. Liquid cowdung manure and oil cake are added to accelerate the growth rate. Disbudding is done from October to maintain only one terminal bud. The plant is finally shifted into the container. The lifting of plant from bed to container is a very important operation and should be performed with great care to maintain proper beauty of plant. The plant should be lifted without

damaging the ball. The final pot size may be 31 cm (12″). When the plant is well established in pot after lifting, the plant is given the final shape. Now the structure is made by splitting bamboo around the plant. The shape of the structure may be given according to choice, but the most popular shape is hemisphere or dome-shaped. Then branches and individual buds are tied at definite places so as to give the plant a particular uniform shape. Before lifting of plant from bed and the time of final tying, the branch irrigation is stopped for 2–3 days so that the branches become soft and more flexible.

Suitable varieties: 'Beauty', 'Maud Jefferies', 'John Webber', 'Evening Star', 'Shin Mei Getsu', 'Allhabad Reflex', and 'Raja'

(iii) *Bush Form*: It is a specific cultural practice for small-flowered chrysanthemum where the plant is given a bush appearance by specific pinching and training. Blooms are arranged compactly to give an effect of a floral carpet. Korean, anemone, button, charm, stellate, decorative, quilled cultivars having profuse branching habit are the most suitable. First soft pinching is started in March when the plant attains about 20 cm (8″) height. The lateral primary branches are again soft pinched, and the process is continued till September. For maintaining uniform spreading, bamboo stakes are used around the periphery and tied the plants with a ring of wire.

(iv) *Pot Mums*: One cutting is planted in one pot which grows tall, and the lower portion of stem looks naked. 5–7 cuttings are also planted at equal distance around the periphery of a pot (20–25 cm or 8″–10″) during June/July. Optimum conditions are provided for proper vegetative growth of plants for 2 months till the initiation of flower bud. The compost mixture of clay/F.Y.M./leaf mold (1:2:2) has been found to be very good for proper growth of plants. Top dressing with neem cake about a month after potting is very useful. Liquid manuring with fertilizer mixture during early September is recommended for vigorous growth. The height of plants of pot mums is mostly uniform. In no-pinch pot mums, the number of flowers are almost as many as there are plants, i.e., 5–7, and the flowers are bigger in size. If larger number of flowers are desired, the branching is encouraged by soft-pinching.

Suitable varieties: 'Beatrice May', 'Kasturba Gandhi', 'General Petain', 'Otome Zakura', 'Pink Cloud', 'Pink Casket', 'Fish Tail', 'Jack Straw', 'Evening Star', 'Goldie', 'John Reid', etc.

(v) *Cascade Form*: Cascade form plants give the excellent look effect of a water fall in blooming stage. Cascades may be small, medium, and large size. Varieties with both long and short internodes, thick flexible stem, profuse branching, and prolific blooming habit and specially anemone and Korean types are suitable. Selected varieties are planted in the bed during March in a slanting position (60° angle). A strong bamboo stake is inserted in the soil at the same angle. The plants are dug out from bed with large balls in July and planted in a large pot at 45° angle. Bamboo frames of desired shape and design are prepared. The main stem and branches are tied to the frame at several places. The frame is bent gradually downward by applying pressure taking care that the main stem is not broken or cracked. The operation should be done very

carefully and slowly step-by-step so that the plant acquires a horizontal shape by the end of August. The bending process is continued for the next 2 months (September–October). Pinching is the most critical technique in the formation of cascade. Pinching is started at the height of 15–25 cm (6″–10″) from the ground, and the process is continued till September. Both soft and hard pinching are performed. October is the most crucial period when bud initiation starts. One should keep regular vigilance to plants, and buds should be arranged systematically by bending and trying to cover the entire structure.

Suitable varieties: 'Perfecta', 'Modella', 'Jaya', 'Aparajita', 'Mayur', and 'Flirt'

(vi) *Coniform*: The plant shape is made conical by special training. The most suitable varieties are those which produce profuse lateral branching from the base of the main branch upward. Staking and pinching are most important for giving a perfect coniform shape. A strong vertical bamboo stake is used from the very beginning to keep the main stem erect. The first pinching is performed during late March, and the last pinching is most important step which is performed in four stages during September. The plant is divided into four regions – lower, middle, upper, and tip. The branches at lower portion (1/third height) are pinched first. The middle portion is pinched after interval of another 3–4 days. The tip is pinched at the end after another 3 days. For support to the branches, additional bamboo stakes are used to maintain a perfect "coniform" plant. The first lateral shoots from the top are removed. The second lateral shoots are allowed to grow upward. Subsequently other lateral shoots which develop late are pinched selectively. The longer shoots are at the base and shorter at the upper level.

(vii) *Fan Form*: It looks like a hand fan and small-flowered chrysanthemums are suitable. It looks flat, round, and vertical made of split bamboo. The bamboo structure is fixed in between the two identical plants planted close to each other in 25 cm (10″) pot. All the branches of both plants are tied to the bamboo structure to give the plants a flat shape. Both soft and hard pinching start during the end of February and continues up to September. The central portion of the plant is made first by hard pinching. The area surrounding the central portion is pinched after 3–4 days. The pinching date should be calculated in such a way that the last pinching is performed by the middle of September (Datta 1996).

19.9 Protected Cultivation

Protected cultivation has been taken up extensively for the year-round production of chrysanthemum. Greenhouse cultivation has been adopted in many countries for commercial exploitation of cut flowers. Low-cost polyhouse model has been developed in some countries using bamboo poles or GI pipes covered with white/yellow HDFE sheets. Low-cost greenhouse model has also been created by using mild-steel tubes and ultraviolet stabilized polythene sheet. Cooling and exhaust systems do not cost much. It may be mentioned that highly sophisticated greenhouses are used in

case of commercial production of high-quality flowers, but in case of nursery, low-cost greenhouse is ideal.

19.10 Postharvest Managements (Harvesting, Grading, and Packaging)

Harvesting is done in the morning hours at appropriate stage, and hand cutters are used for this purpose. The correct stage of harvesting depends on the cultivar, marketing, and other facilities available to a grower. Single cultivars are harvested when the maximum number of flowers is open, but before the pollen grains are shed from the outer row of the disc florets. Anemone cultivars are harvested before the central cushion in the topmost flower is fully developed, whereas decorative types should be harvested when the petals in the center of the topmost flower are almost fully developed. In standards, harvesting is generally done when outer ray florets ceased to elongate. Pot mums are sent to the market when flowers are about half to full open (Machine and Scopes 1978). The stems after cutting are stripped off leaves (one-third) and collected in buckets containing cold water at 15–18 °C. The buckets are kept in cold rooms at 10 °C for cooling for a minimum duration of 2 h. The water contains a biocide to prevent the growth of microorganism. Silver nitrate at the concentration of 25 ppm has been found to be most effective biocide for chrysanthemums (Kofranek 1980). The bud opening solution is used at the marketplace, and 200 ppm 8-HQC and 2% sucrose are ideal for bud opening. Bud opening solution containing 2.5–3.0% sucrose, 25–30 ppm silver nitrate, and 75 ppm citric acid has been suggested. BAP has been reported to be one of the limiting factors in opening of immature buds. Sucrose (5%) in combination with biocide ($AgNO_3$, 25 ppm + citric acid, 75 ppm.) substantially increases bud size and vase life.

Cut flowers are graded into several grades depending on stem length, spray type, color and diameter of flowers, weight, number of flowers, etc. For pot mums, there is no standard grade. Plants should be bushy with good growth, 2.0–2.5 times as tall as their pots, having a minimum of 15 flowers and free from pests and diseases. A plant having 20–25 good-quality flowers would be more desirable. Normally, corrugate fiberboard (CFB) material is used for preparation of packing box. The dimensions of packing box vary on the number of stems. The CFB box is lined by spreading an adequately large sheet of tissue paper along the cartoon walls. The stems are placed horizontal layer by layer and in an alternating pattern using tissue paper between the layers. The top layer is covered with the tissue paper. The tissue paper is just moistened with water. The boxes are closed using self-adhesive BOPP tape. The boxes are stacked in cold rooms or air-conditioned vans as the case may be.

Chrysanthemum flowers show visible senescence symptoms after 12–15 days. Florets/petals primarily determine the commercial longevity of flowers. Knowledge on flower senescence is very important, and majority of work on flower senescence focused on ethylene sensitive plants. Chrysanthemum is an ethylene-insensitive plant, and experiment has been conducted to study the physiological, biochemical, and genetic processes that occur during floret senescence. Reactive oxygen species

(ROS) concentration and lipid peroxidation increase from young floret stage to the senescent stage. Activities of superoxide dismutase (SOD), ascorbate peroxidase (APX), peroxidase (POD), and catalase (CAT) show uniform increases from young floret through to the mature stage and thereafter decline. Lipid peroxidation and membrane damage are involved in flower deterioration. Variation in oxidative stress and the antioxidant enzyme activity in the florets of chrysanthemum during senescence have been studied. Among the SOD isoforms, Fe-SOD and Cu/Zn-SOD were induced during the onset of senescence. Similarly different isoforms of APX and glutathione reductase (GR) also appeared during the senescence process. The capacity of the antioxidative defense system increased during the onset of senescence, but the imbalance between ROS production and antioxidant defenses ultimately led to oxidative damage. It has been proposed that a decrease in the activity of a number of antioxidant enzymes that normally prevent the buildup of free radicals can at least partially account for the observed senescence and cell death in chrysanthemum florets (Chakrabarty et al. 2007).

19.11 Manipulation of Growth/Flowering and Vase Life

A wide range of growth substances and chemicals have been used to regulate growth and flowering in chrysanthemum. GA_3 shows marked variation in response to growth and development depending on the time of application and stage of growth. Considerable encouragement of floral initiation has been observed after **s**praying of β-sitosterol and lanosterol (100 ppm) and glycocholic acid (500 ppm). Branching and plant height can be increased by spraying BA (40 ppm) and PBA (200 ppm) and morphactin, respectively. Flowering can be delayed using ethephon and CEPA ((2-chloroethyl)phosphonic acid, 100 ppm). Vegetative growth and flower yield are increased by spraying GA_3, ascorbic acid, and IAA alone and in different combinations:

(i) **Growth retardation**

A number of growth retardants have been identified to restrict stem elongation and to develop well-shaped pot plants. *SADH* (Alar, B-nine 2000–4000 ppm) reduces stem length, and stems are thicker and stronger. Application at 250 ppm 3 weeks after the start of short days increases flower life. *PHOSFON* (300–750 g/m^3) is used mainly for potted plants, and the rates may vary depending on cultivar, potting compost material, and season. It reduces cell division which effect on growth due to shortening of internodes. Higher doses delay flowering and reduced flower size. It reduces apical dominance, to encourage branching, to improve petal color, and also to develop resistance to disease and drought (Machine and Scopes 1978; Sachs and Kofranek 1963). *Paclobutrazol* is a gibberellin biosynthesis inhibitor which suppresses internode and long-term growth, dwarfing, and delay in flowering properties (Kher 1973; Gilbertz 1992). A number of other chemicals like CCC (chlormequat) at 1.25%, Amo-1618, EI-531 (α-cyclopropyl α-4-methoxyphenol-5-

pyrimidin methanol) as a single spray at 150 ppm, ancymidol, pp. 333, etc. have been found effective to reduce stem length (Sachs and Kofranek 1963; Barrett and Bartuska 1982).

(ii) **Vase life**

The use of proper preservative solution throughout the period of postharvest handling is very important to prolong the life of cut flowers. Dipping of stem for a very short period (5 s) in 1200–4800 ppm silver nitrate has been suggested. Addition of 2% sucrose to silver nitrate is beneficial which increases the vase life from 12 days to 20 days. The type of preservative used is very critical because of 8-HQC that even at level as low as 150–200 ppm can cause stem discoloration and 1–3% sucrose may result to foliar chlorosis and/or necrosis. Sodium dichloro-S-triazinetrione (SDT) in combination with sucrose is equally effective as silver nitrate and sugar. The flower stems should be placed into the preservative solution as soon as possible after harvesting or removing them from storage.

(iii) **Effect on flowering and programmed blooming**

Blooming season of chrysanthemum could be extended slightly by traditional methods like late planting and delayed pinching. Being a short-day plant, flower bud formation in chrysanthemum can be prevented by reducing the length of continuous night below critical level through artificial light, and the plants remain vegetative till the long day.

Chrysanthemums are classic short-day plants with blooming controlled by the relative length of the day and night. Since chrysanthemums are considered a short-day (SD) plant, the plants show vegetative growth under long days and flowers under short days. Most cultivars begin to develop flower buds when days are less than 12 h long. When the night gets longer than 9 h, chrysanthemums begin to set flower buds. The blooming period under traditional culture is short, few weeks or month, depending on the geographical location of growing area. Each chrysanthemum variety has its specific photoinduction requirement, i.e., the number of lights and continuous long dark periods (short days) required by its plant for coming into bloom after it has attained maturity. A combination of day and night is termed as one photoperiod. Varieties require differential photoperiod ranging from 8 to 15 weeks for coming into bloom. A variety requiring 8 weeks for photoinduction period is said to belong to 8-week response group. The term "response group" refers to the number of weeks to flowering from the commencement of short days in a night temperature of 15.6 °C in light conditions near to those prevailing for natural flowering (October and November). The varieties have been thus classified into eight groups, i.e., 8, 9, 10, 11, 12, 13, 14, and 15 weeks' response group, depending on their respective photoinduction requirement. A succession of chrysanthemum of some choicest varieties is obtained by planting, pinching, lighting, and shading the plants according to a definite plan. By manipulating the planting date and the light inside the greenhouse, the grower can coordinate the response of several varieties as per

specific flowering dates and marketing requirements. The success of year-round blooming has been based on sound business thinking. With planned scheduling, now salable chrysanthemum flowers can be produced every day of the year (Datta and Gupta 2012; Kher 1969, 1972, 1976).

19.12 Chrysanthemum Trade

Chrysanthemum stands third in the world cut flower trade and first in Japan and China, third position in Germany, and second position in the United Kingdom. Chrysanthemums are produced in almost all major flower-producing regions of the world, with major area being in Japan followed by the Netherlands, Colombia, Italy, and Spain. Standard (Inga, Lilac Eleonora, Boris Becker, Rivalry, Tom Pearce, Fred Shoesmith, Migoli, Astro, Pandion, Alee Bedser), Spray (Spider White, Spider Yellow, Super White, Bosshardt Majoor, Glance, Starmark, Green Peas, Gold Peas, Statesman), and Santinis (Fatima, Kermit, Stallion, Delilah) are the main commercial types for international market. Spray-type chrysanthemums are of much demand in the market. White color dominates the chrysanthemum sales followed by yellow, purple, and pink, and top-selling varieties belong to the Reagan family, followed by spiders.

19.13 Diseases

Chrysanthemum suffers from different diseases which severely damage the plant at various stages of growth. Researchers, nurserymen, gardeners, and amateurs have reported their views about the symptom and control of different diseases in different journals, books, bulletins, monographs, newspapers, etc. The literature on diseases and control measures of chrysanthemum are very rich:

(i) *Wilt* - Wilt is the most serious and destructive disease of chrysanthemum. The word “wilt” may be used in conjunction with other words as the name of specific diseases. It may occur due to a number of different diseases and disorders or even just a lack of water. Wilting may cause rot of the root or the base of the stem. Yellowing and browning of leaves is the first symptom, which causes the death of the base of the plant upward. Infected plants are stunted and often fail to produce flower.

Symptom: Different fungal species responsible for wilting are *Fusarium* sp., *Verticillium* sp., *Pythium* sp., *Phytophthora* sp., *Phoma* sp., and *Rhizoctonia* sp. *Verticillium dahliae* is mainly found in greenhouse soil and enters the plant through roots, later invading the vessels of the stem and cutting off the water supply. Fungus disease occurs in some specific soil when the vegetative growth of plant ceases and the bud development begin. Lower leaves turn yellow, and the lower portion of the stem turns black and deep brown due to *Fusarium* wilt. Collar rot or root rot disease causes damping off of

cuttings in the rooting bench. In warm humid condition, root rot wilt will occur in beds and plants wilt suddenly. The foliage margin first turns yellow, then the whole leaf becomes brown, and gradually the entire plant wilts due to fungal disease "Seidwetz disease" caused by *Verticillium alboatrum*. The symptoms of *Verticillium* wilt develop in two ways. First, the plant may be stunted, with interveinal yellowing of lower leaves associated with browning of the petioles. Second, more severe symptom develops with general wilting leaves turning brown but often attached to the plants. Vascular tissues may be brown and discolored although wilting may not occur until the flower buds are developing. Unsterilized or poorly sterilized soil encourages *Phoma* root rot (*Phoma chrysanthemicola*). Plants become stunted, often with chlorotic lower leaves which may eventually show necrotic areas (spotting). The necrotic areas spread slowly and the entire leaf is affected; ultimately, the whole plant will wilt and die. *Phytophthora* and *Pythium* species can invade sterilized soil and infect root. *Pythium* species infect cuttings in the rooting bench causing damping off at the base of the stem. Spores of these fungi are readily produced in wet soils and rapidly invade other plants, especially those with damaged roots. *Rhizoctonia solani* may infect roots but is more frequently found attacking the base of stems of young plants. *Sclerotinia* rot caused by *Sclerotinia sclerotiorum* is uncommon and rarely causes serious losses. Light brown lesions develop on stems which become covered with fully fungal growth. *Verticillium albo-atrum* wilt disease is the most destructive which causes conspicuous yellowing and browning of the leaves. Infected plants are stunted and often fail to produce flowers. The fungus is soil-borne and enters through the roots later invading the vessels of the stem and cutting off the water supply. Other two wilt diseases are caused by *Fusarium oxysporum* var. *tracheiphila* and *Pythium aphanidermatum*, respectively. Infection results in plugging of xylem vessel elements with gum and pectinaccous materials, hypertrophy, and hyperplasia of xylem parenchyma cells, abnormal activity of the vascular cambium derivatives, formation of cavities within tissue, and eventual colonization of phloem and cortex parenchyma cells which result in their collapses. The collapse and necrosis of these cells result in black streak appearing on the stems of severely wilted plants.

Control: Disease can be greatly reduced by growing new plants developing from tip cuttings of apparently healthy plants. The soil must be properly sterilized. The affected plants should be immediately destroyed. Regular steam sterilization and use of thiram or dusting with PCNB are good measures for control. Avoidance of overwatering, steam sterilization of beds, and good soil condition for proper air circulation to keep the plants dry will help to avoid the disease. Drenches of carbendazim (25–30 gm/100 ltr) and thiram (150 gm/100 ltr.), dusting quintozene (13 gm/m^2), and spraying or dipping in benomyl (240 gm/100 ltr.) have been found to protect young plants. High lime and nitrate nitrogen fertilizer treatments, together with benomyl drenches for control of *Fusarium* wilt and soil drenches with

Dexon or Truban have been recommended for excellent control. The use of Basamid (dazomet) in different propagation media composed of two methyl bromide compounds can control *Fusarium* wilt disease. Faltap (0.2%) and Capfat (0.3%) reduce collar and root rot disease severity significantly caused by *Phoma chrysanthemicola*. A wild-type isolate of *Trichoderma viridis* (T-1) and a benomyl-resistant biotype (T-1-R9) alone or in combination with *Aspergillus ochraceus* reduces disease by at least 50%. Application of *Aspergillus*, *Paecilomyces*, *Penicillium*, *Trichoderma*, and *Bacillus* spp. cultures on solid media is found to protect chrysanthemum from infection by *Rhizoctonia solani.*

(ii) *Rust*

Symptom: Rust is a troublesome disease in chrysanthemum. The symptom of rust, caused by *Puccinia chrysanthemi*, develops as blister-like swelling, which breaks open and discharge masses of brown, powdery spores. Severely infected plants became very weak and fail to bloom properly. The rusts may be carried on stocks and thus introduced into greenhouses. Rust pustules from undersides of the leaves discharge brown spores. White rust of chrysanthemum due to *Puccinia horiana* and is observed, and its relation to temperature has been noted. Infection of leaf petioles, stem, petals, sepals, and bracts is usually associated with sori formation. Mass infection leads to total necrosis of leaves, absence of flowering, and premature plant death.

Control: Early removal of infected leaves, better ventilation, supply of water directly to the pots without wetting the plants, and dusting of plants with sulfur have been recommended for control. Spraying the plants thoroughly with potash sulfide at the rate of half ounce to a gallon of water or a wettable sulfur spray can be used. Any good fungicides such as zineb, ferbam, phalton, captan, thylate, etc. can be used for its remedy. Spraying of oxycarboxin on plants infected with *Puccinia horiana* has been recommended. Plantvax (oxycarboxin) has been recommended for good control of white rust. Spraying of fungicides (propiconazole, triadimefon, benodanil, triadimenol, etc.) before appearance of disease symptoms has been recommended for control. Systemic fungicide (triforine, bitertanol, oxycarboxin, and propiconazole) are effective for control of white rust of chrysanthemum. Phytosanitary and cultural measures have been recommended to protect against infection. Weekly foliar spray of hexaconazole (at 50 g/ml) alone and/or in combination with captan (1:17.5) and with mancozeb (1:28) has been recommended for control of white rust.

(iii) *Leaf Spot*

Symptom: Two types of leaf spots are found in chrysanthemum. The one type of leaf spot is caused by *Septoria chrysanthemella*. In this case, the spots are at first yellowish and then become dark brown and black. Serious infection may result in premature withering of the leaves; the dead leaves hang to the stem for some time. The leaves curl and fall prematurely. The lower leaves are infected first. Numerous spores are found in the diseased area which are

long and slender and marked by crosswalls. There are other types of leaf spots in chrysanthemum, caused by *Cylindrosporium chrysanthemi*. The spores are dark brown with yellowish margins. Excessive nitrogenous feeding stimulates blotch. Several other fungi cause spots on this host. Most prevalent are *Alternaria chrysanthemi* and *Cercospora chrysanthemi*. This produces dark brown spots with yellowish margins.

Control: Handpicking and burning to destroy the infected leaves have been recommended as good practices for control. Spraying/dusting with sulfur compounds or Bordeaux mixture, lime sulfur or karathane, bavistin (carbendazim), benomyl (0.1%), chlorothalonil, fermate, captan, phaltan, maneb, tecto (thiabendazole), nanob, and zineb and avoiding wetting leaves while watering and mulching with peat moss are perfect for control. Acceptable control was achieved in the field with 80% difolatan (Captafol) W.P. and 50% Zincofol W.P. alternately or alternately with 50% Benlate (benomyl) or by alternatively 65% Neo Asozin with 80% Captafol.

(iv) *Viral Disease*

Virus-infected plants show varying amounts of distortion and loss of flower color and reduce flower size. Color bleaching occurs on red, bronze, and pink varieties producing streaks or flecks of white or yellow on the ray florets. The virus is mostly transmitted by aphids. The number of viral diseases affecting chrysanthemum is nearly 20, and some notable are *Chrysanthemum* stunt, tomato spotted wilt, tomato aspermy, *Chrysanthemum* flower distortion, *Chrysanthemum* mosaic, *Chrysanthemum* rosette, etc.

Plants should be destroyed as soon as the symptoms are detected. Heat therapy consisting of treating the plants at 37.2 °C for 4 weeks has been found effective in eliminating aspermy virus. Meristem culture after heat treatment produces virus-free cuttings. Aspermy, English stunt, and most mosaic viruses are controlled, while vein mottle, American stunt, and some mosaic viruses are not controlled by heat treatment. Control of thrips and weeds and use of cuttings from virus-free indexed stock can control viral diseases.

(v) *Pests* - The most common pests of chrysanthemum are aphids, hairy caterpillars, red spider mites, root cutting grub, thrips, and nematodes. Leaf miner is another pest very extensively reported from many countries.

(vi) *Aphids*: Aphids are greenish to black dot-like insects which suck the sap from growing stem tips and undersurface of laves, causing loss of vigor. They are also carriers of virus diseases, and they excrete honey dew which forms a substratum for fungal growth. *Myzus persicae*, *Macrosiphoniella sanborni*, *Brachycaudus helichrysi*, *Aphis gossypii*, *Aphis fabae*, and *Aulocorthum circumflexum* are the aphids attacking chrysanthemums.

The control measures include spraying with tobacco-soap decoction. Several insecticides, viz., malathion, parathion, pirimicarb, and aldicarb, smoking with 98% deltamethrin at 1 g/m^3 for 1 h and fumigation with phosphine for another

5 h, and spraying spores of a fungus *Verticillium lecanii* have been used to control aphids.

(vii) *Hairy Caterpillars*: It (*Diacrisia obliqua*) attacks the plants in rainy season and continues till winter. The pest is easily recognized by the presence of hair on their body. They multiply fast and have gregarious habit during early stage. As they eat up the leaves from the surface, papery skeletons are left which dry up. Manual collection and destruction in early stages can check heavy infestation. Spraying thiodon 35 EC or ecaulux 35 EC at 1.25 ml/l is recommended as a control measure.

(viii) *Red Spider Mites*: Mites (*Tetranychus urticae*) look red dot-like bodies on undersurface of leaves causing white specks in the early stages. They occur in hot season and damage leaves and buds which give a pale appearance.

Control: Soil application of systemic insecticide UC 21149; conventional acaricides, e.g., dicofol, tetradifon, and aldicarb; and sprays of demeton-S-methyl (22 g/100 l), diazinon (16 g/100 l) or quinomethionate (125 g/100 l), and cyhexatin (25 g/100 l) are recommended.

(ix) *Grubs*: Grub (*Holotrichia* sp.) is a troublesome pest which remains underground, particularly in shade under the trees. It cuts the underground portion of stem or roots causing sudden wilting of healthy plants during dry hot months. Soil application of aldrin, lindane, or thimet has been found effective against the grub. Tropical cut-worm (*Spodoptera littoralis*) attacks chrysanthemum cuttings which can be controlled by using 0.04% dieldrin emulsion.

(x) *Thrips*: Thrips are slender white to black insects which feed on growing point causing mottling and distortion of leaves and also leaf silvering due to separation of upper epidermal tissue from the rest of the leaf. The insects also damage flowers of summer blooming cultivars. Several insecticides, viz., malathion, lindane, metasystox and nicotine spray, deltamethrin, and phosphine, have been found effective. *Thrips tabaci*, *T. nigrophilosus*, *Frankliniella tritici*, and *Hercinothrips* sp. are thrips commonly attacking chrysanthemums.

As the insects pupate in soil, drenching with BHC (200 g/100 l) or diazinon (40 g/100 l) also helps in controlling their population.

(xi) *Leaf Miners*: *Phytomyza syngenesiae* and *Liriomyza trifolii* have been identified as major leaf miners in greenhouse grown chrysanthemum. The larvae of these insects make tunnels in lea and pupate at the end, leaving characteristic trails behind.

Liriomyza can be controlled by foliar treatment with methamidophos, cypermethrin, and permethrin but found methamidophos phytotoxic. Pyrazophos has been found to be effective in reducing the damage by *Phytomyza* leaf miner. Interplanting of *Vicia faba* (field bean) has been recommended as trap crop.

(xii) *Nematodes*: Nematodes travel up the plant in films of water, enter leaves through the stomata, and feed on them causing triangular brown and black patches between the veins, a characteristic of eelworm infestation. Lower leaves are attacked first. Nematodes damaging chrysanthemum are *Pratylenchus penetrans*, *Aphelenchoides ritzemabosi*, *Belonolaimus longicaudatus*, and *Meloidogyne incognita*.

The use of eelworm-free stock plants for propagation and sterilized compost, application of aldicarb (500 g/ha) before planting, and treating with parathion and mocap (O-ethyl S, S-dipropyl phosphorodithioate) can reduce the damage.

(xiii) *Biological Control*: Chrysanthemum is largely damaged by various pests like aphids, leaf-eating caterpillars of moths and butterflies, etc. Moths and butterflies lay their eggs on leaves, and newly emerging buds cause irreparable damage. The insecticides sprayed on the plants fail to kill them. The growth of the plant is also greatly affected by environmental pollutions like toxic gases, smoke, heavy dew drops, smog, dirt, etc. It is not practicable to spray chemicals and insecticides directly on flower and buds. The use of translucent paper bags or polythene bags to cover the buds and flowers has been suggested. It protects the buds and flowers from moths and butterflies and does not allow them to lay eggs on them. It also saves the buds and flowers from dirt, dust, smoke, dew, toxic gases, and other sources of pollution.

(xiv) *Variety selection*: Selection of resistant variety/strain through screening and breeding for resistance is very encouraging to combat diseases. Encouraging experimental results are available for screening varieties under greenhouse and natural condition resistance to *Puccinia horiana*, Japanese white rust, *S. chrysanthemella*, *Fusarium oxysporum* f. sp. Chrysanthemi, and *F. oxysporum* f. sp. *tracheiphilum* race l, collar and root rot disease, etc.

19.14 Chromosome Status

The genus *Chrysanthemum* constitutes a large polyploid complex ranging from 2X to 22X, besides a number of aneuploids (Dowrick 1952, 1958; Endo 1969; Nazeer and Khoshoo 1982, 1983; Miyazaki et al. 1982; Maoxue et al. 1983). The basic chromosome number of the genus is 9 with varying numbers of chromosome in different cultivars of the species with 2n = 36, 45, 53–60, 62–65, 67, 68, 72, and 75. The model number is 2n = 54(6X) followed by 2n = 55(6n + 1) and 53(6X-1). Nazeer (1981) reported the presence of one B-chromosome in four cultivars. The chromosome complement in most of the cultivars is composed of metacentric, submetacentric, and sub-telocentric chromosome. Telocentric chromosome in few cultivars has also been reported (Nazeer and Khoshoo 1983). The size difference of chromosomes is not much prominent. In tetraploid cultivars, the chromosomes range from 3.5 to 5.0 μm and hexaploid cultivars from 3.2 to 4.8 μm, whereas a smaller chromosome size 2.1–3.1 μm is reported in octoploid. Karyotypic heteromorphicity

is observed in the complement of almost all the taxa. The appearance of unusually long and/or small odd chromosomes in the complement may indicate unequal translocations or centric fusion. Nucleolar chromosomes are present in almost all the taxa and nucleolar or organizer appears as satellites. Meiotic analysis shows the presence of only a few multivalents accompanied by a very large number of bivalent which indicate segmental aneuploid nature of the taxa. Diploid-like meiotic behavior, characterized by predominant bivalent formation, is also noticed in some cultivars. There is a decrease in size of the chromosome with an increase in the grade of ploidy. DNA content among cultivars varies from 12.64 to 25.33 pg and shows a ratio of approximately 1:1.2:1.5:2 between tetraploid/pentaploid/hexaploid/octaploid (Nazeer and Khoshoo 1982). Chromosome pairing during meiosis has been studied in colchiploids *C. japonense* 6X and *C. boreale* 2X. In both species, chromosomes paired predominantly as bivalents, even though because of complete homology they possess the ability to pair as multivalents (Watanabe 1983). Detailed analysis of the chromosome compliment revealed that considerable reshuffling and structural alterations have taken place during the course of differentiation. The chief mechanism in the cytogenetical evolution of garden chrysanthemum has been enumerated as outbreeding, spontaneous, and intentional hybridization coupled with mutation, chromosomal differentiation, and repatterning and polyploidy.

19.15 Genetics

Ornamental plants are essentially cross-pollinated with considerable heterozygosity on account of attractive flowers with fragrance and/or nectaries. The variability in habit, height, vigor, period and quality of bloom, color, size and shape of flowers, and fertility is expressed under cultivation. Compared to the wild types, there have arisen a large number of shapes, colors, etc. in chrysanthemum. The useful aspect underlying the transformation in the genetic system accompanying the change in habitat, from wild to domesticated condition, has been one of the important factors contributing to the origin of new varieties.

Genetic studies showed that self-incompatibility was sporophytic and involved more than one locus (Fryxell 1957; Drewlow et al. 1973). Zagorski et al. (1983) detected on the basis of selfing and crossing in a complete diallel outcrosses in 11 garden chrysanthemums that at least three genes were responsible to govern self-incompatibility. Stewart and Derman (1970) worked out the complex nature of color inheritance on the basis of somatic-genetic analysis of the apical layers of 16 chimeral sports of the Indianapolis chrysanthemum cultivars. It has been clearly detected that a cultivar can be genetically one color in L1 and of another color in L2. As the sex cells arise from L2, a cultivar which is white in L1 and pink in L2 would have white color but breed as pink and vice versa. Genetic studies with special reference to both self-incompatibility and self-compatibility have been studied thoroughly in garden chrysanthemum (Drewlow et al. 1973; Mulford 1937; Ronald and Ascher 1975). Kawase and Tsukamoto (1977) made a thorough study with 57 cultivars and 2 wild species for investigating self-fertility. All the parental plants

in this experiment were self-incompatible which, however, varied with cultivating year or the flower head even for the same cultivar. Some parental plants exhibited a high degree of self-fertility. The inheritance of characters, cell sap anthocyanin, and chromoplast carotene in petal cells in a wide range of progenies from crosses has been studied. The presence of one gene A ensured anthocyanin production, while gene I inhibited carotene production. Yellow flowers were formed in the absence of both A and I while white flowers in the absence of A alone. The combination of A and I resulted in pink, carmine, bluish red flowers, whereas A without I resulted in bronze and brownish red flowers. Segregation of flower color was suggested by them to help in the identification of parental genotype. An extensive genetic approach was made in a large number of population to study the inheritance pattern of flowering behavior and floral characteristics (Jong 1989). He found 70% heritability of characters, like number of days to flower and number of flowers per plant, in 79 F_1 population from 15 parents. A significant general combining ability effect for days to flowering was noted. The progenies of parents that flowered early at 1 temperature were generally early at all temperatures at which plants were studied (12°, 13°, 15°, and 17 °C at night). He also studied the inheritance of flower doubleness and floret corolla shape in 70 F_1 population from 16 parents. Singleness was partially dominant over doubleness of type double X single (29% single, 58% semidouble, and 12% double). The percentage varied with parents. The anemone type was inherited as if it was single. Crosses between ligulate, tubular corollas produced ligulate, intermediate, and tubular types in various ratios depending on parents used. Flower doubleness and corolla shape were not linked.

19.16 Improvement

(i) *Breeding*: Breeding is the art and science of changing the genetics of plants in order to produce desired characteristics. Breeding of chrysanthemum is carried out in many countries by individual enthusiasts, gardeners, and farmers or by professional plant breeders at government institutions and agricultural universities, crop-specific industry, or research centers. New varieties of chrysanthemum are now being developed methodically through efficient, intelligent, and systematic work. It will not be possible to highlight all the breeding work going on in different countries. In general, common techniques followed everywhere for developing new varieties have been highlighted. Closely or distantly related varieties are crossbred to introduce traits/genes from one variety or line into a new genetic background. In breeding with heterozygous material, the breeder does not know exactly what genes have been introduced to the new cultivars.

(a) *Hybridization/selection*: Chrysanthemum is a hybrid species which is the result of repeated cycles of complex interspecific crossing among elemental species extending over a period of more than 2600 years. Chrysanthemum has developed considerable heterozygosity and the variability in habit, height, vigor, period and quality of bloom, color, size and shape of flowers, and fertility. Cross-breeding is one of the main methods to increase the

genetic variability, with which the plant breeder tries to combine the beneficial characters from different sources into one genotype. Cross-breeding has been utilized as one of the main methods to increase further genetic variability in chrysanthemum. Systematic efforts have been made at different research institutions and private nurseries to develop high-yielding variety, pot culture variety, cut flower variety, garland purpose, and exhibition type by selection, incorporating desirable genes through natural crossing or conscious selective crossing.

Under hybridization program, new varieties of chrysanthemum are developed by the following methods: (a) Seedlings, with promising desirable characters, are selected from natural cross-pollination that resulted in the development of many new varieties. (b) Parent varieties with desired characters are grown separately in the field for natural crossing. Seedlings from this crossing result into development of new varieties. (c) To avoid contamination, selected parent varieties are grown in pots, and they are kept separately under net. Seedlings with desirable character are selected from these crosses as new varieties. (d) Deliberate conscious/selective artificial cross-pollination between closely and distantly related individuals resulted in the development of many promising varieties.

Male and female parents with desirable characters are selected, and anthers of disc florets of female parent are clipped before anthesis. Disc florets are bagged with cellophane paper bag to avoid natural pollination. Long ray florets of female plants are cut to expose stigma. Pollen grains are collected from male parent and dusted on stigma of female parent. Seedling with superior characters over the existing parents are selected and multiplied as new variety. Promising varieties comprising novel commercial characters like attractive flower color and shape, no pinch no stake dwarfness, out-of-season blooming, cut flowers (attractive color, long erect stem, uniform bloom opening, tough florets, long vase life, and healthy leaves), pot culture (dwarf and compactness, profuse branching, uniform spreading of branches, simultaneous blooming habit, attractive color and good color retention quality, and healthy leaves), high yielding, garland purpose, exhibition type, chlorophyll variegation in leaves, showy decorative leaves, etc. have come out from systematic efforts of all abovementioned methods.

Selection through hybridization resulted in the development of more than 85 new promising varieties at CSIR-National Botanical Research Institute, Lucknow, India (mentioned above). Some promising varieties with attractive floral characteristics are mentioned:

(i) *Pompon Type*: Seedlings of Japanese pompon variety ‘Nanako’ were selected and further crossed among themselves resulting into development of promising high-quality pompon varieties most suitable for cut flowers by virtue of their attractive form, color, and good keeping quality [‘Apsara’ (Fig. 3a) (rosy flush on white background), ‘Vasantika’ (Fig. 3b) (yellow), ‘Birbal Sahni’ (white), ‘Kundan’ (Fig. 3c) (yellow), ‘Jayanth’ (Fig. 3d) (yellow), ‘Jubilee’ (orange), ‘Maghi’ (pink), ‘Shanti’ (Fig. 3e) (white), etc.].

(ii) *No Pinch No Stake Mini Chrysanthemum*: Year-round cultural operations and a lot of additional care like "pinching" and "staking" are required for all garden chrysanthemums which are expensive and time-consuming. Japanese varieties 'Akita' and 'Koben' were repeatedly crossed among themselves, and a series of dwarf varieties were selected and grouped under "mini chrysanthemum." These are unique genetic selections with dwarf, bushy, compact, round-shaped, profuse blooming habit which require neither "pinching" nor "staking." These can be grown in small container smaller than ice cream cup to 10–12″ pots. These have created a good awareness of "mini chrysanthemum culture" in the society. The mini varieties developed at CSIR-NBRI, Lucknow, India, are 'Apurva' (Fig. 4a), 'Appu', 'Arun Singer', 'Bindiya', 'Cameo', 'Haldighati' (Fig. 4b), 'White Charm' (Fig. 4c), 'Peet Singar' (Fig. 4d), 'Hemant Singar' (Fig. 4e), 'Pancho' (Fig. 4f), 'Mini Queen' (Fig. 4g), 'Diana' (Fig. 4h), 'Kusum' (Fig. 4i), 'Sweet Singar', 'Yellow Charm', 'Kargil'99' (Fig. 5a), 'Sadbhavna' (Fig. 5b), 'Y2K' (Fig. 5c), 'NBRI Mini Jessie' (Fig. 5d), 'NBRI Little Darling' (Fig. 5e), 'Mother Teresa' (Fig. 5f), 'Shanti', 'NBRI Iidiana', 'Orange Little Darling' etc. The variety 'Mother Teresa' got US patent (PP13,678). There are series of new selections for release as new varieties (Figs. 5g–k). These are the only varieties in chrysanthemum which can be utilized for multicolor culture in one pot and landscaping.

(iii) *Out-of-Season Blooming Varieties*: Normal blooming season of chrysanthemum in Northern India persists approximately 6 weeks. Conscious selective crossing among Japanese varieties 'Shin Fuzi', 'Bosetsue', 'Yuki Kaza', etc. and selections resulted in development of out-of-season varieties. Chrysanthemum can be grown almost round the year exploiting these genotypes by planting in the right time and right genotype ['Himanshu' (April–May/second flush in October); 'Jawala', 'May Day' (May–June/second flush in November); 'Tushar', 'Jyoti' (June–July/second flush in November); 'Meghdoot', 'Phuhar' (July–August); 'Sharad', 'Ajay' (September–October); 'Sharad Mala' (October); 'Sharad Singar' (October); 'Haldi Ghati' (October–November); 'Vasantika', 'Jaya' (December–January); 'Maghi' (January–February)].

(iv) *Development of chlorophyll variegated varieties*: Plants with chlorophyll variegated leaves look beautiful even when there is no flower. Chrysanthemum remains in vegetative growth almost 9–10 months in a year. Continuous efforts are being made at NBRI to develop suitable genetic strains with variegated leaves by conventional and induced mutation breeding methods. Six chlorophyll variegated varieties (DWS-2, DWS-12, DWS-15, B-16, B-17, and OO-2) have been selected through selections from conventional breeding and one from induced mutation. The intensity of variegation varies from variety to variety. Chlorophyll variegations of leaves of these varieties have become additional beauty which can be enjoyed throughout the year. All these chlorophyll variegated strains are being utilized in different hybridization and mutation breeding programs to develop more and more new attractive variegated varieties (Datta 2015).

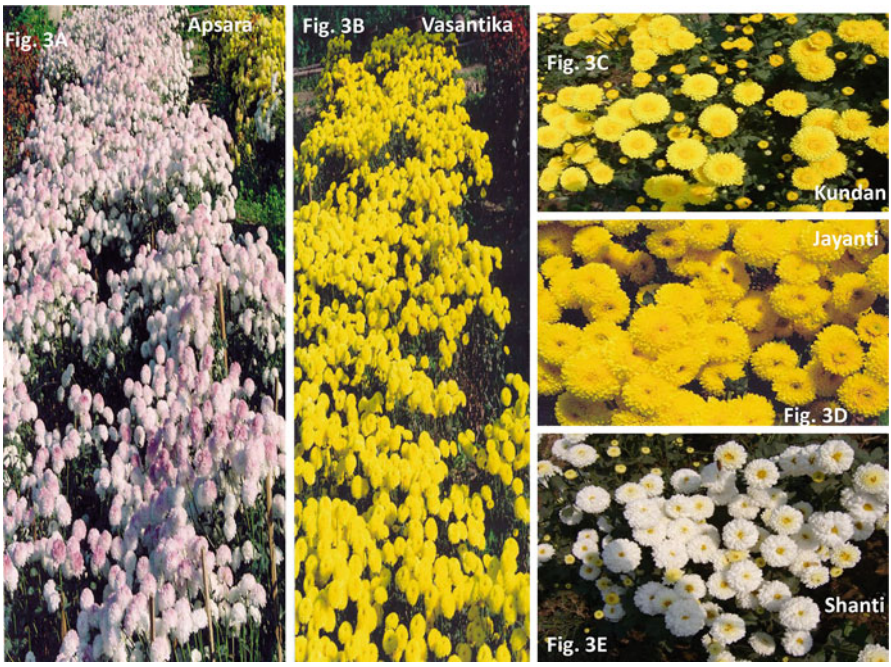

Fig. 3 Cut flower varieties developed through breeding. Figure 3**a**. 'Apsara'. Fig. 3**b**. 'Vasantika'. Fig. 3**c**. 'Kundan'. Fig. 3**d**. 'Jayanti'. Fig. 3**e**. 'Shanti'

(b) *Induced Mutation*: Extensive work on induced mutations has been done on *C. morifolium* Ramat. by a number of workers in different countries, and a wide range of physical mutagens (X-ray, gamma rays, fast neutrons, thermal neutrons, radioactive phosphorous) and chemical mutagen (ethylene imine, ethyl methane sulfonate, and colchicine) have been used for its improvement. Appreciable knowledge and literature have been generated on practical experiments for crop improvement using classical and modern (in vitro and management of chimera) induced mutagenesis techniques on different aspects like LD_{50} dose, radiosensitivity (with respect to influence of various factors including flower type, shape and color, chromosome number, INV, ICV, 2c DNA content, and chromosome number and chromosomal aberrations), selection of material (suckers/cuttings), methods of exposure to mutagens, determination of suitable dose of mutagen, combined treatment, recurrent irradiation, split dose, colchicine mutation, mutant genotype, detection of mutation, mutation frequency and spectrum of mutations, nature of chimerism, classical and modern methods for management of chimera, in vitro mutagenesis, isolation of mutants, etc. (Datta 2015). The details of utilization of induced mutations and its prospects and released mutant varieties have already been reviewed (Datta 1988, 1997, 2015; Broertjes and Van Harten 1988; Ahloowalia et al. 2004; Datta and Chakrabarty 2005).

Fig. 4 No pinch no stake mini chrysanthemum. Figure 4**a**. 'Apurva'. Fig. 4**b**. 'Haldi Ghati'. Fig. 4**c**. 'White Charm'. Fig. 4**d**. 'Peet Singar'. Fig. 4**e**. 'Hemant Singar'. Fig. 4**f**. 'Pancho'. Fig. 4**g**. 'Mini Queen'. Fig. 4**h**. 'Diana'. Fig. 4**i**. 'Kusum'

Approximately 280 mutant varieties have been developed throughout the world (FAO/IAEA, Vienna, Mutant Variety Database) which are mainly color mutations. More than 75 gamma ray-induced mutant varieties (mentioned above) have been reported from CSIR-NBRI, Lucknow, India (Datta 2015). Radiation-induced phenotypic variations including several interesting changes in flower form for novelties have been developed ('Tulika', 'Shabnam' (Fig. 6e), 'Cosmonaut' (Fig. 6f), etc.). Induction of tubular florets is one of the interesting observations in chrysanthemum. Complete tubular floret mutant can be induced in those cultivars where there is small tube at the base of each floret. Plants with chlorophyll variegated leaves look beautiful even when there is no flower. Chrysanthemum remains in vegetative growth almost 9–10 months in a year. Conventional breeding/selection resulted in the development of six chlorophyll variegated traits (DWS-2, DWS-12, DWS-15, B-16, B-17, and OO-2). The intensity of variegation varies among the traits. Two chlorophyll variegated varieties ('Kargil'99' (Fig. 5a) and 'Niharika') have been developed. Perhaps these are the first chlorophyll leaf variegated varieties of *Chrysanthemum* developed at NBRI for floriculture trade reported so far.

Colchicine for the first time has been used for development of new flower color in chrysanthemum. *Chrysanthemum* cv. 'Sharad Bahar' was purple, whereas the mutant ('Colchi Bahar', Fig. 6i) color was terracotta red. Colchicine treatment can

produce gene mutation (Colchi mutation (C-mutation)) instead of inducing polyploidy (Datta 2015).

(c) *Chimaera and Its Management*: Mutation is a single-cell event. Mutated cell is exposed to the so-called diplontic selection, that is, the competition between the mutated cell and the surrounding non-mutated ones. The mutated cell develops into a group of cell and finally into a cell layer. All the somatic mutations in flower color/shape induced after gamma irradiation appeared as chimera (Fig. 6a, b). The size of mutant sector varied from a narrow streak on a floret to entire floret, from few florets to whole flower head, and from a portion of a branch to entire branch. Isolation of mutant tissue is one of the most important operations in mutation breeding. Isolation of mutant tissue is not possible with the help of available conventional propagation technique when it is chimera of a flower and a huge number of such spontaneous and/or induced mutant tissues are lost. Standardization of in vitro technique has opened a new way for isolating new ornamental varieties through retrieval of chimeric tissues. A novel technique has been standardized for isolation of new chimeric flower color/shape mutants through in vitro direct shoot regeneration from ray florets and

Fig. 5 No pinch no stake mini chrysanthemum. Figure 5**a**. 'Kargil 99'. Fig. 5**b**. 'Sadbhavna'. Fig. 5**c**. 'Y2K'. Fig. 5**d**. 'Mini Jessie'. Fig. 5**e**. 'Little Darling'. Fig. 5**f**. 'Mother Teressa'. Figs. 5**g**–**k**. New Selections

Fig. 6 Chimera and induced mutants of *Chrysanthemum*. Figure 6**a**. Chrysanthemum flower bud chimera (original red and mutant yellow). Fig. 6**b**. Chrysanthemum flower chimera (original red and mutant yellow). Fig. 6**c**. 'Purnima'. Fig. 6**d**. 'Batik'. Fig. 6**e**. 'Shabnam'. Fig. 6**f**. 'Cosmonaut'. Fig. 6**g**. 'Navneet'. Fig. 6**h**. 'Sonali'. Fig. **i**. 'Colchi Bahar'

development of solid mutants through in vitro mutagenesis in chrysanthemum (Datta 2015).

(d) *Possibilities of Inducing Desired Flower Color Mutation*: Although mutation is a chance process, from the repeat experiments with the same and/or different cultivars of chrysanthemum, it has been determined that if white varieties are irradiated, the mutation will either be in flower shape or color (yellow). Red varieties, on the other hand, will produce either a completely yellow mutation or a mixture of red and yellow. If yellow varieties are irradiated, the mutation will be either different shades of yellow or white or mixture of yellow and white (Datta 2015).

19.17 Tissue Culture and Gene Transfer

Micropropagation is the practice of rapidly multiplying stock plant material to produce a large number of progeny plants. Most of the modern ornamental breeders follow the micropropagation techniques for large-scale propagation of ornamentals. Conventionally, chrysanthemums are propagated through suckers/cuttings. Some cultivars are easy to propagate, while others are very difficult to propagate mainly

due to low number of suckers and low survival rate of plants. Any new variety developed can be made available in the market at the earliest due to high rate of in vitro multiplication. In vitro techniques have been well established for multi-purpose use specially for rapid multiplication for commercial exploitation from almost all plant parts like nodal explant, stem tips, shoot apices, petal epidermis, petal, bud, protoplast, achenes, leaf discs, etc. Tissue culture of different explants has also been done after treatment with X-rays and gamma rays for in vitro mutagenesis (Datta 2015; Misra et al. 2010).

Explant Culture Ray florets were collected and washed thoroughly under running tap water for 15 min and for another 5 min with 5% aqueous solution of Godrej Liquid Cleaner or aqueous solution of Teepol. The explants were then quickly dipped in 70% ethanol and surface-sterilized with 0.1% $HgCl_2$ for 2 min followed by repeated rinsing with sterile distilled water. Florets of the original cultivar were cultured on MS medium (Murashige and Skoog 1962) supplemented with different combinations of 1-naphthaleneacetic acid (NAA) and 6-benzylaminopurine (BAP) + sucrose (3%) and Bacto4 agar (0.8%). All cultures were kept under a 16-h photoperiod (36 lmol/m2 ás) at 25 °C and 55 ± 60% relative humidity. The pH of the medium was adjusted to 5.6 before autoclaving at 121 °C for 15 min. All the regenerated shoots (2–3 cm in length) were transferred to half-strength MS medium containing 1.5% sucrose and 0.8% BactoAgar for root induction. Rooted plantlets were transferred to plastic pots containing soil and leaf mold mixture (1:3) and placed under high humidity for 1 week for hardening. After another 2 weeks of hardening, plantlets were transplanted in the field. In this system, we obtained up to 79.2% response with 16.6 number of shoots per responding explants on MS medium containing 0.2 mg/l NAA and 2 mg/l BA. Shoots were excised and easily rooted on MS medium without any growth regulators (Datta 2015).

Mutated ray florets collected from flower heads (after approx. 105 days of planting) were washed thoroughly in running tap water for 15 min and for another 5 min with 5% aqueous solution of Teepol (a liquid detergent) and then washed again in tap water. Florets were disinfected with 70% ethanol for 20 sec followed by surface sterilization with $HgCl_2$ solution (0.1%, w/v) for 2 min and then washed thoroughly in sterile distilled water. Individual whole florets were used as explants. They were cultured on MS medium (Murashige and Skoog 1962) containing 30% sucrose, 0.8% BactoAgar, and growth regulators. For cv. 'Purnima', different combinations of NAA (0, 0.2, 0.5, and 1.0 mg/l) and BAP or kinetin (0, 0.2, 0.5, and 1.0 mg/l) were tested, while in the case of cv. 'Colchi Bahar' only one combination (NAA 0.2 mg/l BAP 0.5 mg/l) was tested. Medium pH was adjusted to 5.6 before autoclaving at 121 °C for 15 min.

Ray florets were cultured on MS medium (Murashige and Skoog 1962) supplemented with 0.2 mg/l NAA, 1 mg/L BAP, sucrose (3%), and BactoAgar (0.8%). The medium pH was adjusted to 5.6 prior to autoclaving at 121 °C for 15 min. For rooting, 2–3 cm shoots were excised from explants and placed in rooting medium (MS + 0.2 mg/liter, NAA + 3% sucrose +0.8% ~ gar). All the cultures were

kept under a 16-h photoperiod (36 ~ molm2 S-I) at 25 ± 1 °C and 50–60% relative humidity. The rooted plantlets were then placed ·in potted soil [containing sand/soil (1:1)] and kept in humid chamber (with 80–90% relative humidity) for 15 days prior to their transfer to field.

19.18 Biotechnology

Biotechnology, the world's fastest-growing and most rapidly changing technology, has revolutionized research activities in the area of floriculture. Concentrated research in the molecular and cellular biology of important ornamental crops has resulted in the development of effective gene transfer procedures, with subsequent recovery of engineered plants. Isolation of desirable gene with floricultural properties, characterization, manipulation, and their transfer to desired variety have opened up novel routes to the development of improved ornamental plant varieties. Series of publications are available on standardization of regeneration protocol using different explants and *Agrobacterium*-mediated Bt II, GUS, PFG, hygromycin phosphotransferase, CHS, TSWV nucleocapsid protein, etc. Improvement of chrysanthemum through biotechnology has recently been reviewed (Teixeira da Silva 2004). Transgenic plants having genes of economic important characters have been regenerated (c.f. Datta and Chakrabarty 2005). White-flowered plants have been produced by successful isolation and introduction of CHS gene to a pink cv. Moneymaker (Courtney et al. 1994). Kunitake et al. (1993) studied the transformation in chrysanthemum through polyethylene glycol and electrophoretic transfection. Chrysanthemum is susceptible to infection by wild-type *Agrobacterium tumefaciens*. *Agrobacterium*-mediated Bt II gene has been transferred to leaf explants, and transgenic calluses have been regenerated. *Agrobacterium*-mediated NPT II as selectable marker gene and GUS as reporter gene have been successfully introduced into *D. morifolium* and *D. indicum* genotypes (Ledger et al. 1991). *Agrobacterium*-mediated transgenic (NPT II, GUS, and hygromycin phosphotransferase genes, delta endotoxin gene, nucleocapsid protein gene, flavonoid 3′5′hydroxylase gene) plants have been regenerated, and different problems related to transformation have been discussed by several workers (c.f. Datta and Chakrabarty 2005; Takatsu et al. 1999; Dolgov et al. 1995; Renou et al. 1993; Pavingerová et al. 1994; Fukai et al. 1995). *Agrobacterium*- and biolistic-mediated transformation procedure has been developed for nucleocapsid protein genes (Yepes et al. 1995).

19.19 Characterization

Characterization is the most important for correct identification of cultivars. It helps to understand the genetic diversity and to trace out the phylogenetic relationship, taxonomical status, preparation of catalogue, variation patterns, identification of desirable/novel genes, hybridization, registration, plant variety protection, farmer's

right, etc. Different workers have developed their own characterization system for chrysanthemum. The author did an extensive work on the characterization using classical and modern techniques. Different parameters of cytology, morphology, physiology, chemical and biochemical, DNA markers, etc. have been utilized for characterization. Such analysis will provide important information for preparation of checklist of chrysanthemum. This will be the most helpful not only for identification of varieties but also for selection of desirable characters for intervarietal breeding program (Datta 2015).

Under characterization program, a wide range of morphological characters, viz., plant height, plant spread (N–S), plant spread (E–W), branch number, leaf length, leaf width, petiole length, number of flowers/branch, number of flowers/plant, size of flower, size of floret, number of florets/flower head, moisture content, weight of flower, time of flowering, and type of flower, were taken into consideration. All morphological characters with special reference to floral characters are of much commercial importance for assessment of cultivars. A good amount of variety-specific morphological characters and desirable genes have been identified through characterization (Datta 2015). Chlorophyll (Chl. a, Chl. b, and total) contents in leaves were estimated both at vegetative and flowering stages. Chlorophyll content varied from cultivar to cultivar. It was interesting to note that chlorophyll content in all the cultivars increased at flowering stage.

Voluminous works have been done on chrysanthemum for characterization of normal varieties and mutant (spontaneous and induced) varieties. Induced mutations have developed a large number of flower color/type and chlorophyll variegated mutants worldwide in chrysanthemum. The author did comparative cyto-palynological, anatomical, biochemical, and DNA-based fingerprinting of original and mutant cultivars for better and clear understanding of the exact mechanism involved in the origin and evolution of somatic flower color mutation.

(i) **Cytological studies**

The study of mitosis was done by preparing slides by squash technique. First of all, fresh roots were pretreated in paradichlorobenzene and a pinch of aesculin for 5 min in −20 °C followed by 15 min at 4 °C and then fixed in the fixative propionic acid/alcohol (1:3). Roots were hydrolyzed in 1(N) HCl for 13 min and stained by usual Feulgen staining procedure (Datta 1997).

Original and all mutant cultivars showed $2n = 6x = 54$ chromosome number. Different types of chromosomal aberrations (bridge, fragment, laggard, early separation, clumping, exclusion, micronucleus, etc.) were observed during root tip mitosis in few cells. No mutant-specific abnormality could be detected. Ideograms showed that the mutants did not differ from their respective original cultivars in number of types of chromosomes and number of each type represented in them. The karyotype in the analyzed original and mutant cultivars was reasonably symmetrical. Cytological analysis clearly indicate that changes in flower color may be considered to have taken place through gene mutation but neither through change in chromosome number and aberration nor due to change in karyomorphology (Datta 1994).

(ii) **Micromorphological studies**

Flower petals were fixed and then mounted on SEM stubs using double-sided adhesive tapes after critical point drying. Subsequently the materials were sputter-coated with gold (200 Ao thickness), and scanning photomicrographs were taken in JEOL-JSM 35C Scanning Electron Microscope at 10 kV (Datta and Shome 1994).

The original and their respective induced mutant cultivars showed considerable variations in petal epidermal micromorphology particularly in cell boundaries, cell surface, striations, and papillae. The petal micromorphological characters can be utilized for identifying mutants (Datta 2015).

(iii) **Palynological studies**

Pollen grains are collected soon after anthesis. These are dusted on glass slides, washed in absolute alcohol, and mounted in malachite green-glycerin jelly. The pollen grains which are regular in shape and full and had uniform stain are considered as fertile, while those which are irregular in shape, empty, and hyaline are regarded as sterile. For the study of pollen grain morphology, pollen slides are made using the revised acetolysis method of Erdtman (1960).

Most of the chrysanthemum cultivars show regular size pollen grains, but few cultivars and their mutants had dimorphic pollen grains. The shape of endocolpium is variable; lalongate types are the most common, but lolongate, circular, square, and indiscernible types are also found. Exine surface pattern shows conspicuous changes. The base and tip of exine spines are variable in shape. The original exine surface, i.e., fosso-reticulate pattern with narrow muri and irregularly shaped lumina, changed to reticulate exine with broad muri and uniformly circular lumina in the "mutants." The tips of the spines changed from straight to bent. The reticulate undulated exine surface changed to a scrobiculate wrinkled surface. The punctata exine surface pattern of the original transformed to a scrobiculate pattern in the mutant (Datta 2015).

(iv) **Pigment analysis**

Chrysanthemum pigments have been studied by a number of workers using thin-layer chromatographic and spectrophotometric methods and categorized into a large number of chrysanthemum cultivars according to the presence or absence of different pigments.

For spectrophotometric analysis of phenolic compounds, 200 mg of florets were extracted in 50-ml methanol containing 1% HCl. The extracts were scanned from 200 to 800 nm region of wave length in Utltroscope 2000, Pharmacia Biotech (Datta 2015).

For the study of phenolic compounds by thin-layer chromatographic methods (TLC), mature leaves and petals were extracted in methanol containing 1% HCl. The chromatograms were developed on glass plates (6.3 X 10 cm) coated with silica gel emulsion. The plates were run 8 cm in a mixture of benzene/propionic acid/H2O (20:

40:10 v/v). They were then dried in air, and the spots were observed and marked under the necked eye and under UV. The plates were then sprayed with flavone reagent (diphenylboric acid ethanolamine complex) and again marked under UV. The color reaction of each spot and their Rf values were determined from six good chromatograms. These were then transformed into hRf (Rf X 100) values (Datta 2015).

Floret pigment analysis by thin-layer chromatographic and spectrophotometric methods of large number of mutants and original cultivars indicated that somatic flower color changes were due to both qualitative and quantitative changes in pigments as a result of mutations induced by mutagens in pigment biosynthesis pathway.

Chrysanthemum pigments have been studied by a number of workers using thin-layer chromatographic and spectrophotometric methods and categorized into a large number of chrysanthemum cultivars according to the presence or absence of different pigments. Several pigment compounds have been qualitatively characterized by thin-layer (TLC) and paper (PC) chromatography. Carotenoid and anthocyanin pigments were extracted from the flowers and analyzed both qualitatively and quantitatively. Series of carotenoids have been reported, but only a few have been identified, including lutein or xanthophyll, tetraxanthin, and flavoxanthin. Cultivars were classified into four basic groups according to analysis: (1) white, containing flavonols; (2) pink (pink to red-purple), anthocyanins, and flavonols; (3) yellow, carotenoids; and (4) (i) orange and (ii) red, anthocyanin, flavonols, and carotenoids. Anthocyanin compounds include cyanidin-3-glucoside (chrysanthemin) and its derivatives, malvin and ensatin. Four flavonoids – apigenin, acacetin, quercetin, and luteolin – have been identified (Kawase and Tsukamoto 1974, 1976, 1977).

(v) **Molecular characterization**

DNA-based markers provide powerful and reliable tools for discerning variation within crop germplasm, cultivar identification, and pedigree analysis and to study evolutionary relationships. DNA fingerprinting is used to analyze the various aspects of plant genus such as taxonomy, phylogeny, ecology, genetics, and breeding in interspecific or intraspecific level. These techniques include RAPD, RFLP, SSR, STS, SNP, VNTR, STR, SFP, and AFLP. The genetics of chrysanthemum are very complex. RAPDs, however, are a powerful tool to detect different molecular markers in hybrid populations of *Chrysanthemum* cultivars. Huge amounts of work have been done on molecular characterization of chrysanthemum from different laboratories. RAPD markers have been successfully used to distinguish between the radiation-induced mutants from original group in an early vegetative stage, sports, commercial varieties, and nonrelated cultivars. Because of the high level of polymorphism and clonal stability, RAPD fragments are useful for cultivar identification. The genetic variability among related *Chrysanthemum* species was too high to study genetic distances either among cultivars within chrysanthemum or among species related to chrysanthemum (Wolff and Peters-Van Rijn 1993; Wolff et al. 1994, 1995; Rumin et al. 2004; Trigiano et al. 1998; Martin et al. 2002; Wolff and Peters-van Rijn 1993; Scott et al. 1996).

The author and his colleagues selected large number of large-flowered, small-flowered, mini varieties, mutant varieties of chrysanthemum, and the objective of the study was to estimate the genetic relationship among the different cultivars with relation to their morphological and biochemical characteristics and geographical distribution. Special attempt was to investigate the molecular differences for better understanding of the origin and evolution of somatic flower color mutation.

DNA Extraction The total genomic DNA was extracted from young leaves of rose cultivars by CTAB procedure (Saghai-Maroof et al. 1984) with some modifications. Extraction in chloroform/isoamyl alcohol (24:1) followed by centrifugation twice at 14,000 g helped to remove polysaccharides. RNA contaminants in all the samples were digested with 100 mg/mL RNase A for 30 min at 37 °C, extracted once with phenol/chloroform/isoamyl alcohol (25:24:1). After ethanol precipitation, DNA was resuspended in 100 mL of TE (10 mM Tris–Cl + 1 mM EDTA) buffer (pH 8.0). The average yield was calculated by a spectrophotometer (Ultraspec 2000, Pharmacia Biotech), and DNA samples were stored at −20 °C. PCR Conditions 20 arbitrary decamer primers (Bangalore Genei, India) were used for polymerase chain reaction (PCR). PCR was performed in 20 mL reaction mixture containing 5 ng template DNA, 1 unit of Taq DNA polymerase, 100 μM dNTPs, 1.0 μM primer, 2.5 mM MgCl2, 10 mM Tris-HCl (pH -9.0), 50 mM KCl, and 0.01% gelatin. PCR amplification was performed using a PTC-100 Peltier Thermal Cycler (MJ Research, USA) using the following conditions, preheating of 4 min at 94 °C and 45 cycles of 15 sec at 94 °C, 45 sec at 36 °C, and 1.5 min at 72 °C, and elongation was completed by a final extension of 4 min at 72 °C. The final reaction mixture was cooled down to 4 °C. After amplification PCR product was resolved by electrophoresis in 1% agarose gel with l × TAE buffer. Bands were visualized by staining with ethidium bromide (0.5 μg/mL-1) under UV light and protographed. Only distinct bands were counted for data analysis and faint was not considered. The size of the amplification products was estimated from a 100 bp DNA ladder (Sigma). All the reactions were repeated at least twice, and only those bands reproducible on all runs were considered for analysis. DNA fragment profiles were scored in binary fashion with "0" indicating absence and "1" indicating presence of band. Genetic distance was calculated by Jaccard's coefficient (Jaccard 1908) which is as follows, $Sij = Nij/(Nii + Nij + Njj)$, where Sij is the similarity index between the ith and jth genotype, Nij is the number of bands present in both genotypes, Nii is the number of bands present in the ith genotype but absent in the jth genotype, and Njj is the number of bands absent in the ith genotype and present in the jth genotype. The similarity matrix was converted to dissimilarity matrix (1-Sij), and a dendrogram was constructed using the neighbor joining tree method using RAPDistance Package version 2.0 (Armstrong et al. 1998).

Variation between cultivars was high. The intervarietal and intravarietal taxonomic relationship of C. x *grandiflorum* was obtained. Moreover, the selected unrelated cultivars and mutants of chrysanthemum were distinguishable from each other through banding patterns obtained from RAPD. Cultivars, whether parent or

mutant, with different flower colors could be clearly distinguished. Some primer yielded extremely different banding patterns which help to identify mutant from its mother plants. It is, however, possible that some of the specific bands present for some of the mutants may code for flower color, but this can only be verified by using SCAR markers and cloning cDNA. The analysis of genetic similarity indices revealed low diversity within the radiomutants. High genetic distance among the different *C*. x *grandiflorum* parents and mutants provides the chance to introgress new and novel genes from the chrysanthemum gene pool (Chatterjee et al. 2005; Chatterjee et al. 2006a, b; Datta 2015). Data shows an estimation of genetic diversity which cannot be simply interpreted by classical morphological, cytological studies. Present experiment of estimation of genetic diversity is useful for the farmers for the breeding purpose to increase the heterosis of hybrids and introgress the new genes in the gene pool. These studies can be very effectively proof to be a technique for the development of mapping population for tagging of agronomically important traits. Difference in morphology is totally independent of geographical distance, negating a simple isolation by distance model. As all the selected cultivars are morphologically very similar, it is very difficult to identify them until the blooming season. DNA fingerprinting is the only solution to solve this problem. This RAPD profile serves as a way for identification of species-specific marker and also produces a reliable data to construct the phylogenetic relationship of the genus *Chrysanthemum* (Chatterjee et al. 2005).

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