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Breeding and genetic diversity in *Chrysanthemum morifolium* in India : A review

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ABSTRACT

Genetic diversity of any crop plays a very important role in developing new and novel desired forms through breeding and selection. Knowledge of diversity and its response to natural/human selection through hybridization is necessary for future breeding plan. All the present day colourful varieties of *Chrysanthemum morifolium* Ramat have been developed through complex interspecific crosses among elemental species, open pollination, indiscriminate intervarietal hybridization, spontaneous and induced mutation, selection and management of chimera. In floriculture industry there is always demand and necessity for new varieties. There is an urgent need for developing crop wise database. There is no record of total chrysanthemum varieties developed through classical breeding in different countries. Present article will provide maximum information generated in India on classical and mutation breeding on chrysanthemum along with important publications in chrysanthemum/floriculture by other research institutions/ universities.

Key words: Breeding, Chrysanthemum, Genetic diversity, New varieties

Inbuilt genetic diversity of any crop is explored by breeders to develop desirable genotype through repeated hybridization and selection. Breeders develop the most promising genotypes by selection procedure. It depends upon the genetic reservoir of the crop. Knowledge of diversity and its sensitivity to natural/human selection through hybridization is necessary. Nature of crop is very important in this regard. An attempt has been made to explore the genetic diversity of an important ornamental crop chrysanthemum. Range of phenotypic expression of genetic diversity in chrysanthemum can be recorded from existing varieties. Scientists/breeders working on chrysanthemum should develop a database of all the available varieties country wise. This will give a clear picture of genetic diversity for different phenotypic characters and their response in terms of segregation/expression to human selection pressure.

Today, commercial floriculture is the most profitable business and expanding rapidly all over the world. Science based techniques have given an impetus to the growth of this industry in various parts of the world. Floricultural production contains a wide variety of different types of plants and plant materials. The flower industry comprises the cultivation and trade of cut flowers, cut foliage, potted plants and bedding plants. The main cut flower is the chrysanthemum, followed by the carnation and the rose. The top ten cut flowers in Netherlands are rose, chrysanthemum, carnation, tulip, lily, freesia, gerbera, cymbidium, gypsophila, alstroemeria. *Chrysanthemum morifolium* Ramat is one of the most interesting ornamental group of plants in the world. 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. The unique position of chrysanthemum may be attributed to the great amount of variation in the flowers and plant characteristics as well as to their wide adaptability to varied agro-ecological conditions. The chrysanthemum flowers vary greatly in shape, size and colour. 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. Chrysanthemum stands third in the world cut flower trade and first in Japan and China, 3rd position in Germany, 2nd position in United Kingdom. A great deal of genetic variability is required in chrysanthemum to meet the demands of millions of its lovers who earnestly desire to have all sorts of shapes, colours and all plant forms. The primitive cultivars and wild relatives of chrysanthemum plants constitute a pool of genetic diversity which provides the raw materials for future breeding programme. The objective of creating new varieties is to combine in them constellation of characters by careful choosing of parents. All the present day colourful chrysanthemum varieties have been developed through complex interspecific crosses among elemental

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species, open pollination, indiscriminate intervarietal hybridization, spontaneous and induced mutation, 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. Being a cross pollinated crop, new varieties arise mainly as seedlings obtained either by natural or conscious cross-pollination. Farmers have been altering the genetic makeup of the crops since the practice of agriculture began. The main drawback of breeding experiments by private breeders is that they never disclose the parentage of new varieties. With advancement of genetic knowledge, plant breeders used what they knew about the genes of a plant to select for specific desirable traits to develop improved varieties. Conventional plant breeding has been going on for hundreds of years, and is still commonly used today. The genetic system of a taxon controls its heredity and variation and one of its important components is the breeding system. Breeding system exercise considerable influence on the genetical architecture and nature of its variability. Chrysanthemum and rose have been under investigation from this point of view and data are being generated about the range of genetic diversity for developing new forms.

New varieties of chrysanthemum are being developed throughout the world mainly through hybridization and induced mutagenesis. New varieties are also developed through sports. International Atomic Energy Agency, Vienna is maintaining a data base for new varieties developed through induced mutagenesis of all crops including chrysanthemum. But unfortunately, there is no record of total chrysanthemum varieties developed through classical breeding in different countries. There are several papers which report the new chrysanthemum varieties developed through different breeding methods. Present article will provide maximum information generated by the authors on classical and mutation breeding on chrysanthemum along with important publications in chrysanthemum/floriculture by other research intuitions/universities. Readers can collect more information from referred publications or from authors. Efforts have been made to highlight all the new chrysanthemum varieties developed in India exploiting all available techniques. Extensive research is going on chrysanthemum breeding at CSIR and ICAR institutions in India. National Botanical Research Institute (NBRI), Lucknow, India is one of the pioneer institutions under Council of Scientific and Industrial Research (CSIR) which has done a commendable work on chrysanthemum on both basic and applied aspects. Interdisciplinary research on chrysanthemum is going on under All India Coordinated Research Project on Floriculture at ICAR institutes with State Agricultural Universities.

The main research activities were enrichment and characterization of germplasm, their utilization in breeding programme, development of new and novel varieties through hybridization, selection, *in vivo* and *in vitro* mutagenesis, standardization of agro-technology, disease management, postharvest physiology, programmed blooming, tissue culture, molecular techniques, etc. (Datta 2015). CSIR-NBRI is maintaining a living germplasm of more than 300 chrysanthemum cultivars collected from all over India and abroad comprising almost all bloom types and colour which are being used as base line material for further increase of genetic variability and improvement through indiscriminate intervarietal hybridization, induced mutagenesis and selection (Datta 1998, Kher 1975, 1977). The realization of this fact led to introduction of 80 cultivars from Japan (Kher 1977). This is a reasonably wide base of germplasm from which appropriate gene combinations have been selected over the years. The commonly accepted classification of garden chrysanthemum is based on bloom shape and size and relative number of the two kinds of 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. CSIR-NBRI is maintaining 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, Nightangale, 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, (M-45), (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.

Sept-Oct 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).

Oct-Nov blooming cultivars: Chakra, Double Korean, Hemanti, Lalpari, Makhmal, Megami, Mohini, Nanako, Sharad Har, Sharad Mala, Tricolour, White Prolific, Yellow Prolific (NN-14).

Nov-Dec blooming cultivars: Archana, Apsara, Birbal Deep Pink, Cotton Ball, Jayanti, Jubilee, Kundan, Ping Pong, Ratna, Yellow mutant of Ratna.

Dec-Jan 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), (T-8), (T-14).

Cultivars a: Dainty Maid, Excutive, 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), (N-15).

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 Cusion: Malika, Mayur.

Hybridization/selection

Chrysanthemum is a hybrid species which is the result of repeated cycles of complex inter-specific crossing among elemental species extending over a period of more than 2600 years. A number of elemental species have been involved, viz. *C. boreale*, *C. carinatum* (tricoloured 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. coccineum* (flowers white, pink ,or red), *C. cinerariifolium*, *C. parthenium* (flower white or pale yellow), *C. balsamita* (flower yellowish with some white rays), *C. mayimum* (white perennials), *C. nipponicum* (native of Japan, white daisies), *C. rubellum* (England; pink to rose red), *C. uiginoseem* (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* (Asiatic regions, white or pink), *C. mawii* (pink daisies, white with pink-reverse), *C. Weyrich* (pink flowers), *C. carinatum* (tricolour 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 chrysanthemum have occasionly been grouped here), *C. sibiricum* (this acted like a blood transfusion on the worn-out strains of Chrysanthemum when it was used for breeding in the early 1930's, single flowers, white aging to carmine pink). Exploitation of genetic resources of some more wild species like *C. oreastrum*, *C. hypargyrum*, *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* have been reported (Shibata 2008, Zaho *et al*. 2009). The chrysanthemum has developed considerable heterozygosity and the variability in habit, height, vigour, period and quality of bloom, colour, size and shape of flowers, and fertility is expressed under cultivation. Cross-breeding has been utilized as one of the main method to increase further genetic variability. Systematic efforts were made at CSIR-NBRI and ICAR to develop high yielding variety, pot culture variety, cut flower variety, garland purpose, exhibition type by selection and incorporating desirable genes which had been missing among cultivars grown in India but found elsewhere in the world through natural crossing or conscious selective crossing.

Under hybridization programme, new varieties of chrysanthemum are developed by following methods :

(i) New varieties develop mainly as seedling selection collected from natural cross-pollination. Seeds of promising varieties are collected and seedlings with desirable characters are selected, multiplied and released as new variety.

(ii) Desirable varieties are selected as parent varieties and grown separately in field for natural crossing. Seedling selections from these crosses result into development of new promising varieties.

(iii) To avoid contamination, selected parent varieties are grown in pots and they are kept separately under net. Seedlings with desirable characters are selected from these natural crosses among selected parents as new varieties.

(iv) New varieties are developed through conscious/selective artificial cross-pollination. This classical breeding uses deliberate interbreeding (crossing) of closely or distantly related individuals to produce new varieties with desirable properties. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. 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 colour and shape, no pinch no stake dwarfness, out- of- season blooming, cut flowers (attractive colour, 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 colour and good colour 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 above mentioned methods. Selection through hybridization resulted in development of more than 95 new promising varieties at CSIR-NBRI, Lucknow, some promising varieties are mentioned below (Datta 1996a, Datta 1998).

Pompon type: Japanese pompon variety Nanako was selected as parent variety(Kher 1995a, 1995b). Seedlings from Nanako (Japanese) variety were crossed among themselves and seedling selections resulted development of promising high quality pompon cut flower varieties with attractive form, colour and good keeping quality (Apsara, Birbal Sahni, Jayanth, Jubilee, Kundan, Maghi, etc.).

No pinch no stake mini chrysanthemum: Japanese varieties Akita and Koben were used as starting parental varieties which were repeatedly crossed among themselves for subsequent generations and seedling selections resulted development of a series of mini chrysanthemum varieties (Apurva, Appu, Arun Singer, Bindiya, Cameo, Haldighati, Hemant Singar, Peet Singar, Sweet Singar, White Charm, Yellow Charm, Mother Teresa, Diana, Y2K, Sadbhavna, Kargil 99, Shanti, NBRI Indiana, Orange Little Darling × Yellow Nanako, NBRI Kusum, Yellow Haldighati × Yellow Sharad Kanti, NBRI Little Darling, White Charm × Jubilee bronze, NBRI Mini Jessie, Pink Cameo × Purple Jessie, etc.) Variety Mother Teresa got US Patent (PP13,678). These varieties are dwarf, bushy, compact, round shaped, profuse blooming habit which require neither 'pinching' nor 'staking'(Kher 1977, 1995a, 1995b).

Out-of-season blooming varieties: Blooming of chrysanthemum persists approximately six weeks in Northern India. Selective crossing among Japanese varieties (Shin Fuzi, Bosetsue, Yuki Kaza, etc.) resulted in development of out-of-season varieties [(Himanshu April-May/2nd flush in October, Jawala, May Day (May-June/2nd flush in November), Tushar, Jyoti (June-July/2nd 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)]. The Maghi variety was further included into induced mutagenesis programme and developed new colour range like Maghi White, Maghi Yellow, etc.

Following new varieties of chrysanthemum have been developed through conventional breeding at CSIR-NBRI, Lucknow and in some other ICAR institutions in India.

CSIR-NBRI: Ajay (1990), Appu (1982), Apsara (1977), Apurva (1987), Apurva Singar, Arun Kumar (1983), Arun Singar (1982), Bindiya, Birbal Sahani (1976), Dhawal, Diana (1999), Gauri, Gulal, Guldasta (1986), Haldighati (1988), Hemant Singar (1981), Himanshu (1982), Jaya (1980), Jayanti (1979), Jubilee (1980), Jwala (1981), Jyoti (1980), Jyotsna, Kargil 99 (2000), Kaumudi, Kiran, Kirti, Kundan (1980), Lal Kila (1980), Lalima (1990), Lalpari, Lilith, Maghi (1989), May-Day (1981), Mayur, Meghdoot (1982), : Mini-Queen, Mohini, Mother-Teresa (1997), NBRI Pushpangadan (2011), NBRI Khoshoo (2010), NBRI Kaul (2010), NBRI Himanshu (2009), NBRI Little Orange (2009), NBRI Little Hemant (2009), NBRI Little Kusum (2009), NBRI Little Pink (2009), NBRI Yellow Bud Sport (2011), Neelima (1980), Niharika, Nirmal, Pancho, Peet Singar (1981), Phuhar (1982), Priya, Prof. Harris, Puja, Ragini, Rangoli, Sadbhavna (2000), Shanti (2000), Ratna (1989), Sharda (1978), Sharad Kanti,' Sharad Kumar, Sharad Mala (1976), Sharad Mukta, Sharad Sandhya, Sharad Shobha, Sharad Singar (1977), Shizuka, Shyamal, Suhag Singar (1981), Sujata, Suneel (1991), Sunayana (1976), Suparna, Surekha Yellow (1992), Surya, Swarn Singar, Sweta Singar, Tushar (1982), Vandana, Vasantika (1980), Vijay, Vijay Kiran (2009), Vinaya, White Charm, White Profile, Y2K (2000), Yellow Charm, Yellow Prolific, NBRI Yellow Bud Sport (2011).

Indian Institute of Horticultural Research, Bengaluru: Arka Ganga (White with pink tinge 1999), Arka Pink

star(Pink 2009), Arka Ravi (Peach 1999), Arka Swarna (Yellow 1999), Chandrakant [1990, white], Chandrika [1994, white], Indira [1980, yellow], Kirti [1994, white], Nilima [purple], Pankaj [1994, pink], Rakhee [1980, yellow with red stripes], Ravikiran [1993, Greyed-red], Red Gold [1980, Greyish-Orange to golden-yellow], Yellow Star [1994, yellow].Yellow Gold (1992, Yellow with brick-red), Usha Kiran (2001, Yellow)

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 [1985, Canary Yellow], CO.2 [1985, Rhodamine purple], MDU [1985, Sulphur Yellow].

Dr YSPUHF, Nauni, Solan: Solan Mangla

To maintain the authentic record of all the chrysanthemum varieties, passport data of all the chrysanthemum varieties, available in India at different institutions and universities has been prepared.

National Botanical Research Institute, Lucknow: 300 varieties; Regional Plant Resource Centre, Bhubaneswar – 104 varieties, Dr Y S Parmar University of Horticulture and Forestry, Solan – 55 varieties, Maharana Pratap University of Agriculture and Technology, Udaipur – 39 varieties, Tamil Nadu Agricultural University, Coimbatore – 75 varieties, Birsa Agricultural University, Ranchi – 45 varieties, University of Agricultural Sciences, Bangalore – 23 varieties, Punjab Agricultural University, Ludhiana – 23 varieties, Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar – 40 varieties, Mahatma Phule Krishi Vidyapeeth, Pune – 28 varieties, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad – 22 varieties, Indian Institute of Horticultural Research, Hessaraghatta – 76 varieties (Datta 1998, Bhattacherjee *et al.* 2002).

Spontaneous mutation: Bud sports or spontaneous somatic mutations have played very important role in the evolution of many varieties throughout the world. Approximately 30% of the chrysanthemum cultivars originated as sports (Wasscher 1956). Some cultivars have given rise to a great number of sports such as Sweetheart, The Favourite (Anonymous 1961, Bowen *et al.* 1962) and Indianapolis (Yoder 1976). 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.

Induced mutagenesis: Extensive work has been done on *C. morifolium*. for its improvement through induced mutation by number of workers in different countries and a wide range of physical mutagens like *X-ray* (Broertjes 1979, Broertjes and Roest 1976, Broertjes *et al*. 1980, Dowrick and El-Bayoumi 1966a, 1966b, Jain *et al*. 1961, Jank 1957, Rana 1964), gamma rays (Datta 1998, 1988, Bowen *et al*. 1962, Dowrick and El-Bayoumi 1966a, 1966b, Broertjes and Van Harten 1988, Datta 1989,1990a, 1990b, 1992, 1994, 1997a, 1997b, 1997c, 2001, 2005, 2010, Banerji and Datta 1992, Datta and Gupta 1980, Bowen 1965, Fuji and Matsumura 1967, Weaver 1963, Love and Constantin 1965), fast neutrons (Broertjes et al. 1980, Love and Constantin 1965), thermal neutrons (Bowen 1965), radioactive phosphorous (Drelow and Widmer 1971) and chemical mutagen like Ethylene Imine (Bowen 1965), ethyl methane sulphonate (Bowen 1965) and colchicine (Weedle 1941, Datta 1990c, Datta and Gupta 1987) have been used for such studies. A good number of ornamental mutant varieties have already been commercialized. Appreciable knowledge and literature have been generated on practical experiments for crop improvement using classical and modern induced mutagenesis techniques on different aspects like radiosensitivity, selection of material, methods of exposure to mutagens, determination of suitable dose of mutagen, combined treatment, recurrent irradiation, split dose, colchi-mutation, 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 1990b). At this stage there is no need to review the technological details of the earlier works. The details of utilization of induced mutations and its prospects and released mutant varieties have already been reviewed (Datta 1988, Broertjes and Van Harten 1988, Datta 1997a, 1997b, 1997c, 2001, 2005, Ahloowalia *et al.* 2004, Bhatia 1991, Datta 2002, 2009a, 2009b, 2012, 2013, 2014, Datta and Chakrabarty 2005, Micke *et al.* 1987).

Determination of radiosensitivity is prerequisite for large scale irradiation for induction of mutations. For determination of radiosensitivity, large number of chrysanthemum cultivars were exposed to 1.5, 2.0 and 2.5 krad of gamma rays. The radiosensitivity of different cultivars with respect to influence of various factors including flower type, shape and colour, chromosome number, INV, ICV, 2c DNA content and chromosomal aberrations were estimated. On the basis of these observations and available literature, it has been very clearly indicated that radiosensitivity in garden chrysanthemum is a genotype dependent mechanism (Datta 1984, 1992, 2001, Banerji and Datta 1993, Datta and Banerji 1991).The suitable radiation dose for the induction of somatic mutations in chrysanthemum have been reported by many workers. Datta and his group detected LD_{50} of chrysanthemum cultivars varies between 1.5 to 2.5 krad. Previous workers have reported that some of the cultivars withstood 3000r X-rays and the optimum dose lay between 2000-4000r (Jank 1957, Sheenan and Sagawa 1959). Fujii and Mabuchi (1961) found that 2 to 4 Krad gamma rays showed the optimum number of survival while Bowen *et al*.

(1962) found only 50% lethality after 4.3 Krad. Dowrick and El-Bayoumi (1966b) has reported that 14 Krad of gamma rays was the suitable dose. Some authors, however, used higher doses like 25 Krad gamma rays, 10-12 Krad gamma rays and 8 Krad gamma rays (Broertjes 1966). The use of such higher doses was probably as the result of low dose rate application (1 kr/days' 125-150 rad/ha). On the basis of the earlier and present experiments, the optimum dose of gamma rays for inducing mutations is reported to be 1.5 to 2.5 Krad for chrysanthemum (Datta 2001).

Development of chlorophyll variegated varieties: Chlorophyll variegated varieties have been developed at CSIR-NBRI through both classical breeding and induced mutations. Conventional breeding and selection resulted development of six chlorophyll variegated varieties (DWS-2, DWS-12, DWS-15, B-16, B-17 and OO-2). Two chlorophyll variegated varieties (Kargil 99 and Niharika) have been developed through gamma ray induced mutations (Datta 1990 a).

Mutation in flower morphology: A number of mutants (Tulika, Shabnam, Lalima Tubular, Cosmonaut, Jhalar, Nirbhik, Nirbhaya) with changed flower morphology have been developed at NBRI through induced mutagenesis and commercialized (Banerji and Datta 1992, 2002, 2003, Datta 1990a, 1990b, Datta and Banerji 1985, Datta and Gupta 1981, 1984).

Mutant of a mutant: Mutant genotypes can be further improved through mutation and new mutant characters have been developed. Broertjes *et al.* (1980) were successful to develop hundreds of mutants by successive use of radiation induced mutants of chrysanthemum cv. Horim. New mutants (Sheela and Navneet Yellow) have been released as new cultivars by CSIR-NBRI (Datta 1985,1996b).

Recurrent irradiation: Recurrent irradiation experiment with chrysanthemum resulted more genetic variability and increased percentage and spectrum of mutations. It is advised that recurrent mutagen treatment may provide an even greater range of genetic variability than would a single mutagen treatment This method can be successfully used in routine mutagenesis programme for inducing novelties in flower colour/shape (Datta 1991).

Colour mutation: Pink cultivars have maximum number of dominant genes for flower colour. They have, therefore, greater possibilities of producing recessive mutations which can be detected in M_1V_1(Bowen *et al.* 1962, Broertjes 1966, Dowrick and El-Bayoumi 1966a, 1966b, Jank 1957, Bowen 1965). Jank (1957) reported induction of flower colour mutations in bronze cultivars. No mutations were detected in white flowering chrysanthemum (Gupta 1979). Chrysanthemum cultivars with yellow flowers have been reported to be very stable (Broertjes 1966, Bowen 1965, Gupta 1979). Datta and Gupta (1980) detected yellow sector in white flowered cultivar 'Lilith' after gamma irradiation. Datta (1985) successfully induced Cannary yellow flower colour mutation after irradiation of a gamma ray induced white mutant (Himani) of E-13, a mauve coloured, pompon type small flowered chrysanthemum (Gupta 1979). More than one flower colour mutations have been reported in different cultivars. Broertjes *et al.* (1980) have isolated a number of mutants in chrysanthemum cultivar 'Horim' by successive use of irradiation induced mutants in their mutation breeding programme. Some of the cultivars like Undaunted, E-13 (Gupta 1979), Otome Zakura (Datta and Gupta 1981), D5 (Datta and Gupta 1980, Datta and Gupta 1983), Surekha, Anupam, Khumaini, Kalyani Mauve and Lalima (Datta and Banerji 1991, 1993) are worth mentioning in this respect where series of mutants have been recorded from the same cultivar after gamma irradiation at NBRI.

Material and time for irradiation: Suckers are irradiated in March/April and cuttings are irradiated in July/August. The time of irradiation has a very positive effect on mutation. Suckers irradiated in March/April are healthier and more vigorous during the blooming period than cuttings irradiated in July/August. There is a better chance of eliminating abnormal cells induced after gamma irradiation in March/April because of the long period of vegetative growth. It was observed that the frequency of somatic flower colour mutation was higher in the July/August experiment but the plants (especially the mutant branch) were not as healthy as those developed from the March/April experiment. Therefore, healthy mutated branch cuttings were not available from the July/August experiment. On the other hand, isolation of the mutated tissue by cuttings from the March/April experiment was easier because of the healthy growth of the mutated branch. Thus, both the irradiation periods have their own advantages and disadvantages (Datta 1990b, 1990c).

Colchi-mutation (C-mutation): Colchicine for the first time has been successfully used and developed flower colour mutation (Colchi Bahar) after treating rooting cuttings of chrysanthemum with 0.065% colchicines (Datta 1987, 1990c, Datta and Gupta 1987).

Detection of mutants

Somatic mutation in vegetatively propagated plants are mostly detected in M_1V_1. Somatic mutations were also detected in M_1V_2 and later generations from normal looking irradiated plants in M_1V_1 or from mutant clones which were detected earlier. It has been observed by the author that chances of getting solid mutants are more in M_1V_2 and later generations. Results showed that screening for mutations should not be confined to M_1V_1 only, but it should be continued in M_1V_2 and subsequent vegetative generations. The mutated cell expresses its mutant character if it gets chance to express in M_1V_1. The mutated cells of the lower axilary buds remain in the dormant stage and expresses its mutant character when included during vegetative propagation in M_1V_2. A number of flower colour mutants have been detected in M_1V_2, M_1V_3 and M_1V_4 in chrysanthemum (Datta 2001, Gupta and Jugran 1978).

Possibilities of inducing desired flower colour mutation: Although, mutation is a chance process but from the repeated experiments with the same and/or different cultivars, it has been determined that if white varieties are irradiated, the

mutation will either be in flower shape or colour (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 2001, Datta 1990d)

Mutant varieties developed in India: CSIR-NBRI, Lucknow – Agnishikha (1987), Alankar (1982), Anamika (1974), Aruna (1982), Asha (1974), Ashankit (1974), Basant (1979), Basanti (1974), Batik (1994), Colchi Bahar (1985), Cosmonaut (1984), Gairik (1974), Hemanti (1979), Himani (1974), Jhalar (1975), Jugnu (1991), Kanak (1974), Kansya (1974), Kapish (1974), Kumkum (1987), Kunchita (1974), Lalima Head Shape, Lalima Tubular Mutant, Lohita (1974), Man Bhawan (1982), Navneet (1987), Navneet Yellow (1993), Nirbhaya (1974), Nirbhik (1974), Pingal, Pitika (1974), Pitamber (1977), Purnima (1977), Raktima (1996), Rohit (1979), Shabnam (1987), Shafali (1974), Sharad Har (1992), Sheela (1985), Shweta (1974), Surekha Yellow (1992), Sonali (1991), Subarna (1991), Tamra (1974), Taruni (1979), Tulika (1985).

Punjab Agricultural University, Ludhiana: Punjab Gold (1999, coppery red to golden yellow).

Management of chimera

There are disadvantages for induction of mutation in vegetatively propagated ornamentals. Treatment (physical and/or chemical mutagens) of bulbs, tubers, rhizomes, cuttings/suckers, other plant parts or whole plants all having buds with multicellular apices composed of a number of fairly autonomous cell layers, automatically leads to the formation of chimeras. In multicellular organisms, after irradiation of a multicellular apex, such mutated cell is exposed to the so called diplontic selection, i.e. the competition between the mutated cell and the surrounding non-mutated ones. The mutated cell develops a group of cells and finally a cell layer. The final result of a diplontic selection is a low number of mutated plants and a restricted mutation spectrum. The size of the mutant sector varies from a narrow streak on a petal to entire flower and from a portion of a branch to the entire branch. When an entire branch is mutated, isolation of mutant tissue is possible through conventional propagation methods while small sectorial mutation in the floret cannot be isolated using existing conventional propagation techniques. Therefore, a large number of new flower colour/shape mutants are lost every year. Hence, to isolate and establish the mutated chimeric tissues in a pure form, appropriate tissue culture method of plant regeneration directly from florets was necessary. Protocol has already been standardized for *in vitro* regeneration of chrysanthemum (Ben-Jaacov and Langhans 1972, Earle and Langhans 1974, Malaure *et al*. 1991, Nagatomi *et al*. 1993, Lu *et al*. 1990). Efficient technique has been standardized at CSIR-NBRI for direct shoot regeneration from individual floret of chrysanthemum. Using this direct shoot regeneration protocol a number of new flower colour/shape mutations have been isolated through management of induced and spontaneous mutant chimeric tissues (Chakrabarty *et al*. 1999, 2000, Chakrabarty and Datta 2009, Mandal and Datta 2005a, 2005b, Dwivedi *et al*. 2000). This *in vitro* approach has opened new vistas to produce a wide range of new mutant varieties through management of chimera. The management of mutated plant chimeras was almost unexploited in induced mutagenesis.

In vitro mutagenesis: Normally, *in vivo* mutagen treated plants are grown under field conditions. In this method, population size is restricted due to limitation of land and fund. The concept of i*n vitro* mutagensis developed which has opened new possibilities for inducing increased number of mutants and solid mutants. The main advantage of this method is that it helps to avoid chimera formation in the M_1V_1 (Maliga 1984, Ahloowalia 1995, Maluszyuski *et al*. 1995). A number of experimental results have been published (Preil *et al*. 1983,Huitema *et al*. 1989, Nagatomi and Degi 2009, Mishra and Datta 2003, Datta and Mandal 2005, Datta *et al*. 2001, Walther and Suer 1986a, 1986b, Jerzy and Lubomski 1991, Jerzy and Zalewska 1996).

Systematic efforts have been made to develop trait oriented mutation. Efforts were made to develop NaCl-tolerant chrysanthemum plants through *in vitro* mutagenesis. One NaCl-tolerant chrysanthemum variant has been developed in a stable form through whole plant selection in *in vitro* mutagenesis using ethylmethane sulfonate (EMS) as the chemical mutagen (Hossain *et al*. 2006a, 2006b, Hossain *et al*. 2004, Hossain *et al*. 2007).

Attempt has been made to regenerate chrysanthemum plants from a single cell, i.e. through somatic embryogenesis for management of single cell mutation event. An efficient somatic embryogenesis protocol has been standardized in chrysanthemum. Present technique will open up a new way for isolating new flower color/shape ornamental cultivars through retrieval of single mutated cell (Mandal and Datta 2005b).

Commercial varieties

Attempt has been made to tabulate (Table 1) details about mutant chrysanthemum varieties commercialized in different countries. Information about name of mutant and parent varieties, mode of origin, country and year of release and mutant character have been collected from available literature (Datta 1988, Anonymous 1977, 1985, 1988, 1989, 1990, 1992, 1994, IAEA Mutant Database, etc.). Mutant varieties not yet registered at IAEA Database have also been included. Every country should take initiative to prepare database of new varieties of such an important ornamental crop. This will give the clear picture about the extent of genetic variability one can see in a single crop.

Use of elemental species, interspecific hybridization in conjunction with classical breeding among varieties has long been the principal route to generation of present day novelty in Chrysanthemum. New chrysanthemum varieties are being produced in a routine way by cross-hybridization and mutation breeding techniques, separately or in combination. In floriculture industry, there is always a

Table 1 Mutant varieties commercialized in different countries

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
Agnisikha [D-5]	Gamma rays (15-25Gy)	India (1987)	Flower colour
Alankar [D-5]	Gamma rays (15Gy)	India (1982)	Flower colour
Amason		Japan (1998)	
Amber Boston	X-rays	Netherlands (1978)	Flower colour
Anamika [E-13]	Gamma rays (15Gy)	India (1975)	Flower colour
Angshoujingshi		China (1989)	
Apricot Deholta [Delta]	X-rays (17.5Gy)	Netherlands (1983)	Apricot flower
Apricot Impala [Impala]	X-rays (17.5Gy)	Netherlands (1983)	Apricot flower
Arajin-		Japan (2006)	
Aruna [Ashankit]	Gamma rays (15Gy)	India (1974)	Flower colour
Asha [Hope]	Gamma rays (15Gy)	India (1974)	Flower colour
Ashankit [Undaunted]	Gamma rays (15Gy)	India (1974)	Flower colour
Babette Gelb [Babette (white)]	Gamma rays	Japan (1985)	Flower colour
Baiogiku rainbow orange [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiogiku rainbow peach [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiogiku rainbow pink [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiogiku rainbow red [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiogiku rainbow white [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiogiku rainbow yellow [Seikouno-Kurnenai]	Gamma rays	Japan (1985)	Flower color
Baiyunyong		China (1991)	
Basant [Paul]	Gamma rays (10Gy)	India (1975)	Flower colour
Basanti [E-13]	Gamma rays (15Gy)	India (1979)	Flower colour
Batik [Flirt]	Gamma rays (20Gy)	India (1994)	Flower colour
Blue Redemine [Redamine]	X-rays (17.5 Gy)	Netherlands (1984)	Dark pink
Blue Star	X-rays	Netherlands (1984)	Flower colour
Blue Winner	X-rays	Netherlands (1975)	Flower colour
Bright Lameet	X-rays	Netherlands (1978)	Flower colour
Bright Star	X-rays	Netherlands (1977)	Flower colour
Bright Westland	X-rays	Netherlands (1976)	Flower colour
Bronce Kalinka [Kalinka]	X-rays (18 Gy)	FRG (1987)	Flower colour
Bronze Byoux [Byoux]	Gamma rays (17.5 Gy)	Netherlands (1985)	Flower colour
Bronze Charmette	X-rays	Nethrlands (1976)	Flower colour
Bronze Chinspy	X-rays	Netherlands (1978)	Flower colour
Bronze Miros	X-rays	Netherlands (1979)	Flower colour
Bronze Redemine [Redemine]	Gamma rays (17.5 Gy)	Netherlands (1986)	Bronze
Bronze Star	X-rays	Netherlands (1977)	Flower colour
Bronze Westland	X-rays	Netherlands (1976)	Flower colour
Bronze Winner	X-rays	Netherlands (1975)	Flower colour
Chuntao		China (1991)	
Cherry Deholta [Delta] [Dark delta]	X-rays (17.5 Gy)	Netherlands (1985)	Cherry red
Chongyangshaoyao		China (1989)	
Colchi Bahar [Sharad Bahar]	Colchicine (0.0625%)	India (1985)	Flower colour
Cream Deholta [Delta]	X-rays (17.5 Gy)	Netherlands (1985)	Pale yellow
Cream Impala [Impala]	X-rays (17.5 Gy)	Netherlands (1984)	Cream
Copper Marconi [Pink cultivar]	X-rays (17.5 Gy)	Belgium (19850	Flower colour
Coral Refla [Refla]	Gamma rays (17.5 Gy)	Netherlands (1986)	Coral

Contd.

Table 1 (*Continued*)

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
Coral Winner	X-rays	Netherlands (1975)	Flower colour
Cosmonaut [Nimrod]	Gamma rays (15-25 Gy)	India (1984)	Flower morphology
Cream Clingo	X-rays	Netherlands (1979)	Flower colour
Cream Deholta [Pearl Delta]	X-rays (17.5 Gy)	Netherlands (1985)	Flower colour
Cream Impala [Impala]	X-rays (17.5 Gy)	Netherlands (1984)	Flower colour
Cristiane		Brazil (1995)	
Dalekaya Zoezda	Gamma rays	USSR (1976)	Flower colour
Danny Boy	X-rays	Netherlands (1973)	Flower colour
Danny's Cape	X-rays	Netherlands (1973)	Flower colour
Danny's Pearl	X-rays	Netherlanda (1973)	Flower colour
Dark Charmette	X-rays	Netherlands (1976)	Flower colour
Dark Deep Tuneful	X-rays	Netherlands (1969)	Flower colour
Dark Gaby [Gaby(Pink)]	X-rays (18 Gy)	FRG (1988)	Flower colour Bloom size Stem length
Dark Lymon [Lymon]	X-rays (17.5 Gy)	Netherlands (1985)	Dark pink
Dark Mario	X-rays	FRG (1983)	Flower colour
Dark Miros	X-rays	Netherlands (1979)	Flower colour
Dark Oriette	X-rays	Netherlands (1976)	Flower colour
Dark Red Marconi [Pink Cultivar)	X-rays (17.5 Gy)	Belgium (1985)	Flower colour
Dark/Royal RendezVous [Rendez-Vous]	Gamma rays (12.5-17.5 Gy)	Netherlands (1986)	Violet
Dark Torino [Pink Seedling]	X-rays (17.5 Gy)	Belgium (1985)	Flower colour
Dark Westland	X-rays	Netherlands (1976)	Flower colour
Dipu Sei Roza (Reagan Royal)		Japan (1997)	
Dr X [Dr Dave]	X-rays (12 Gy)	U.S.A. (1966)	Darker Purple-red
Dreaming		Japan (2004)	
Emi-akari		Japan (2006)	
Enzett Axillia Gelb	Gamma rays (2x20 Gy)	GDR (1988)	Flower colour
Enzett Balina Rot	Gamma rays (20 Gy)	GDR (1985)	Flower colour
Enzeet Balina Weiss	Gamma rays (20 Gy)	GDR (1985)	Flower colour
Enzeet Dilana Gelb	Gamma rays (20 Gy)	GDR (1977)	Flower colour
Enzeet Dilana Rosa	Gamma rays (25 Gy)	GDR (1979)	Flower colour
Enzeet Heli Bronze	Gamma rays (2x20 Gy)	GDR (1987)	Flower colour
Enzeet Heli Gelb	Gamma rays (2x20 Gy)	GDR (1987)	Flower colour
Enzeet Mellit Gelb	Gamma rays (2x20 Gy)	GDR (1989)	Flower colour
Enzeet Minos Bronze	Gamma rays 920 Gy)	GDR (1985)	Flower colour
Enzeet Niva Bronze	Gamma rays (20 Gy)	GDR (1984)	Flower colour
Enzeet Niva Gelp	Gamma rays (20 Gy)	GDR (1983)	Flower colour
Enzeet Niva Lachs	Gamma rays (20 Gy)	GDR (1984)	Flower colour
Etenraku		Japan (2001)	
Franky Lane [Penny Lane]	Gamma rays (17.5 Gy)	Netherlands (1985)	Darker pink
Fuchengzao		China (1987)	
Funny Redemine [Redemine]	X-rays (17.5 Gy)	Netherlands (1984)	White flower
Funny Rendez-Vous [Rendez-Vous]	Gamma rays (17.5 Gy)	Netherlands (1986)	Violet stripes
Gairik [Belur Math]	Gamma rays (10 Gy)	India (1974) Flower colour	
Gamma	Gamma rays	Hungary (1969)	
Goldbronze Deholta [Delta]	X-rays (17.5 Gy)	Netherlands 1983)	Goldbronze
Golden Byoux [Byoux]	Gamma rays (17.7 Gy)	Netherlands (1985)	Yellow flower
Golden Clingo	X-rays	Netherlands (1979)	Flower colour
Golden Cremon [Cremon]	Gamma rays (10 Gy in vitro)	Thailand (1987)	Flower colour
Golden Deholta [Delta]	X-rays (17.5 Gy)	Netherlands (1984)	Dark yellow
Golden Geos [geo]	X-rays	FRG (1984)	Yellow flower
Coral Refla [Refla]	Gamma rays (17.5 Gy)	Netherlands (1986)	Coral

Contd.

Table 1 (*Continued*)

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
Golden Luck [Bronze]	X-rays (18 Gy)	FRG (1988)	Flower colour
Hae-no-Awabeni		Japan (2003)	
Hae-no-Eiokou		Japan (2003)	
Hae-no-Hatsu-yuki		Japan (1995)	
Hae-no-Kagayaki		Japan (1995)	
Hae-no-Kirameki		Japan (1995)	
Hae-no-Kurenai		Japan (1995)	
Hae-no-Miyarabi		Japan (1995)	
Hae-no-Myoujou		Japan (2003)	
Hae-no-Myoujou		Japan (2003)	
Hae-no-Yuugure		Japan (1995)	
Hemanti [Megami]	Gamma rays (15 Gy)	India (1979)	Flower colour
Himani [E-13]	Gamma rays (15 Gy)	India (1974)	Flower colour
Hoof Lane [Penny Lane]	Gamma rays (17.5 Gy)	Netherlands (1985)	Dark Yellow
Howaito Sei Roza (Reagan White)		Japan (19970)	
Huangjuanyun		China (1991)	
Iero Sei Roza (Reagan Yellow)		Japan (1997)	
IIzetka Kopenicker Barbarossa Rotstern		Germany (1962)	
Imajin		Japan (2006)	
Indianapolis Yel. Imp	X-rays	Netherlands (1970)	Flower colour
Ingrid		Brazil (1995)	
Ion-no-Hatsune		Japan (2003)	
Ion-no-Kouki		Japan (2003)	
Ion-no-Koumyou		Japan (2003)	
Ion-no-Mahou		Japan (2003)	
Ion-no-Reimei		Japan (2003)	
Ion-no-Seikou		Japan (2003)	
IRB 88-30		Japan (1991)	
IRB 88-47		Japan (1991)	
IRB 88-59		Japan (1991)	
IRB 88-60		Japan (1991)	
Izetka Filmstar Bronze [Filmstar]	X-rays (10-25 Gy)	GDR (1966)	Bronze
Izetka Herbstgold [Izetka Kopenioker Rayonnata]	X-rays (10-25 Gy)	GDR (1964)	Yellow-bronze
Izetka Kopenicker Barbarossa Goldkissen	X-rays (10-25 Gy)	GDR (1962)	Bordeaux red with bright yellow centre
Izetka Kopenicker Bronze Vogue [Vogue]	X-rays (10-25 Gy)	GDR (1964)	Red-bronze
Izetka Marienhain Cremeweiss [Izetka Marienhain]	X-rays (10-25 Gy)	GDR (1966)	Cream flower
Izetka Marienhain Dunkelrosa [Izetka Marienhain]	X-rays (10-25 Gy)	GDR (1966)	Dark pink
Izetka Marienhain Hellgelp [Izetka Marienhain]	X-rays (10-25 Gy)	GDR (1966)	Bright yellow
Jhalar [Undaunted]	Gamma rays (15 Gy)	India (1975)	Flower morphology
Jingguangsishe		China (1989)	
Jingxiuqiu		China (1989)	
Joy Apricot		Japan (1998)	
Joy Coral		Japan (1998)	
Joy Light Sermon		Japan (1998)	
Joy Light Yellow		Japan (1994)	
Joy Prelude Afu		Japan (2000)	
Joy Prelude Coe		Japan (2000)	
Joy Royal		Japan (1998)	

Contd.

Table 1 (*Continued*)

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
Jugnu [Lalima]	Gamma rays (15-20 Gy)	India (1991)	Flower colour
Kanak [Undaunted]	Gamma rays (15 Gy)	India (1975)	Flower colour
Kansya [Roseday]	Gamma rays (15 Gy)	India (1974)	Flower colour
Kapish [E-13]	Gamma rays (15 Gy)	India (1974)	Flower colour
Ki-uzushio [Uzushio]	Gamma rays (25 Gy)	Japan (1986)	Yellow flower
Kraski oseni	Gamma rays	USSR (1976)	Flower colour
KU-1 [Hangzhou]	Gamma rays in vitro	Thailand (1988)	Flower size
Kumkum [M-71]	Gamma rays (20-25 Gy)	India 1987)	Flower colour
Kunchita [Undaunted]	Gamma rays (15 Gy)	India (1974)	Flower colour
Lady Amber		Poland (1993)	
Lady Bronze		Poland (1993	
Lady Pink		Poland (1993)	
Lady Rosy		Poland (1993)	
Lady Salmon		Poland (1993)	
Lady Yellow		Poland (1993)	
Lemon Deholta (Delta) [White Delta]	X-rays (17.5 Gy)	Netherlands (1985)	Lemon yellow
Liangjihuang		China (1989)	
Lilac Byoux [Byoux]	Gamma rays (17.5 Gy)	Netherlands (1985)	Flower colour
Lilac Cindy [Cindy]	X-rays	FEG (1988)	Darker colour
Lohita [E-13]	Gamma rays (15 Gy)	India (1974)	Flower colour
Magali		Brazil (1996)	
Main Lane [Penny Lane]	X-rays (17.5 Gy)	Netherlands (1985)	Pale yellow
Man Bhawan [Flirt]	Gamma rays (15 Gy)	India (1992)	Flower colour
Mantianxin		China (1990)	
Marconi [pink cultivar]	X- rays (17.5 Gy)	Belgium (1985)	Flower colour
Mars	Gamma rays	USSR (1976)	Flower colour
Merkurii	Gamma rays	USSR (1976)	Flower colour
Middelry	Gamma rays	Netherlands (1976)	Flower colour
Mikrop	X-rays	Netherlands (1976)	Flower colour
Milava	X-rays	Netherlands (1976)	Flower colour
Milonka	X-rays	Netherlands (1976)	Flower colour
Mirazh	Gamma rays	USSR (1976)	Flower morphology
Miros	X-rays	Netherlands (1976)	Flower colour
Mlechnyi put	Gamma rays	USSR (1976)	Flower colour
Morning Sun	X-rays	Netherlands (1978)	Flower colour
Navneet [Kalyani mauve]	Gamma rays 15 Gy)	India (1987)	White flower
Navneet Yellow [Navneet]	Gamma rays (15 Gy)	India (1993)	Yellow flower
Nazerea Grace White		Malaysia (2001)	
Nazerea Soft Pink		Malaysia (2001)	
Nirbhik [Undaunted]	Gamma rays (15 Gy)	India (1975)	Flower morphology
Nirbhya [Undaunted]	Gamma rays (15 Gy)	India (1975)	Flower morphology
OHB-14		Japan (1991)	
OHB-8		Japan (1991)	
Orange Delta [Rafla]	X-rays (17.5 Gy)	Netherlands (1985)	Orange flower
Orange Impala [Impala]	X-rays (17.5 Gy)	Netherlands (1986)	Orange flower
Orange Lymon [Lymon]	X-rays 17.5 Gy)	Netherlands (1985)	Orange flower
Orange Mario	X-rays	FRG (1983)	Flower colour
Orange Miros	X-rays	Netherlands (1979)	Flower colour
Orange Rafla [Rafla]	X-rays (17.5 Gy)	Netherlands (1985)	Orange flower
Orenji Sei Roza (Reagan Orange)		Japan (1997)	
Orion	Gamma rays	USSR (1976)	Flower colour
Pale Remember [Remember]	X-rays (17.5 Gy)	Netherlands (1985)	Pale pink
Paru Sei Roza (Reagan Pearl)		Japan (1997)	

Contd.

Table 1 (*Continued*)

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
Peach Deholta [Pearl Delta]	X-rays (17.5 Gy)	Netherlands (1985)	Peach colour
Pearl Cindy [Lilac Cindy]	X-rays	FRG (1989)	Flower colour
Pearl Prism		Japan (1997)	
Pingal [Pink Casket]	Gamma rays (15 Gy)	India (1974)	Flower colour
Pink Clinspy	Gamma rays	Netherlands	Flower colour
Pink Impala [Impala]	X-rays (17.5 Gy)	Netherlands (1984)	Pink flower
Pink-Orizuru		Japan (1990)	
Pitaka [Kansya]	Gamma rays (15 Gy)	India (1978)	Flower colour
Pitamber [Otome Zakura]	Gamma rays (15 Gy)	India (1978)	Flower colour
Plutonii	Gamma rays	USSR (1976)	Flower colour
Pretty Wedding		Japan (2001)	
Princess Kagawa		Japan (2004)	
Privet Frantsii	Gamma rays	USSR (1976)	Flower colour
Purnima [Otome Zakura]	Gamma rays (15 Gy)	India (1978)	Flower colour
Radii	Gamma rays	USSR (1976)	Flower colour
Raktima	Gamma rays	India (1996)	Flower colour
Ray Sunrise		Japan (2002)	
Red Lymon [Lymon]	X-rays	Netherlands (1985)	Flower colour
Red Marconi [Pink cv.]	X-rays (17.5 Gy)	Belgium (1985)	Flower colour
Rohit	Gamma rays (15Gy)	India (1979)	Flower colour
Royal Wedding		Japan (1998)	
Salmon Byoux [Byoux]	Gamma rays (17.5 Gy)	Netherlands (1985)	Flower colour
Salmon Impala [Impala]	X-rays (17.5 Gy)	Netherlands (1984)	Salmon colour
Salmon Lymon [Lymon]	X-rays (17.5 Gy)	Netherlands (1985)	Salmon colour
Saturn	Gamma rays	USSR (1976)	Flower colour
Selena	Gamma rays	USSR (1976)	Flower colour
Shabnam [D-5]	Gamma rays (15 Gy)	India (1987)	Flower morphology
Shafali [Undaunted]	Gamma rays (20 Gy)	India (1974)	Flower colour
Sharad Har [Sharad Mala]	Gamma rays (15 Gy)	India (1992)	Flower colour
Sheela [Himani] (20-25 Gy)	Gamma rays(15Gy)	India (1985)	Flower colour
Shukla	Gamma rays (15Gy)	India (1974)	Flower colour
Shveta [Fish Tail]	Gamma rays (15 Gy)	India (1974)	Flower colour
Sijifeng		China (1989)	
Sijihong		China (1989)	
Sijihuang		China (1989)	
Sijimohong		China (1986)	
Sointse	Gamma rays	USSR (1976)	Flower colour
Sonali [Ratna]	Gamma rays (20 Gy)	India (1991)	Flower colour
Sputnik	Gamma rays	USSR (1976)	Flower colour
Subarna [Flirt]	Gamma rays (20 Gy)	India (1991)	Flower colour
Surekha Yellow [Surekha]	Gamma rays (15 Gy)	India (1992)	Flower colour
Svarnim	Gamma rays (15Gy)	India (1975)	Flower colour
Tamra [Goldie]	Gamma rays (20 Gy)	India (1974)	Flower colour
Taruni [Kingsford Smith]	Gamma rays (25 Gy)	India (1979)	Flower colour
Torini [Pink Seedling]	X-rays (17.5 Gy)	Belgium (1985)	Flower colour
Tsezii	Gamma rays	USSR (1976)	Flower colour
Tulika [M-24]	Gamma rays (15 Gy)	India (1985)	Flower colour
Uncle Danny	X-rays	Netherlands (1973)	Flower colour
VCM1		Viet Nam (2010)	
VCM2		Viet Nam (2011)	
VCM3		Viet Nam (2011)	
White Cindy [Lilac Cindy]	X-rays	FRG (1989)	Flower colour
White Clinspy	X-rays	Netherlands (1978)	Flower colour

Contd.

Table 1 (*Concluded*)

Cultivar/Mutant/[Original]	Mutagen	Country	Mutant character
White Danusia	X-rays	Netherlands (1977)	Flower colour
White Lineker OW-1		Japan (2000)	
White Redemine [Redemine]	X-rays (17.5 Gy)	Netherlands (1984)	White colour
White Rafla [Rafla] X-rays (17.5 Gy)		Netherlands (1985)	White colour
White Remember [Remember] (17.5 Gy)	Gamma rays	Netherlands (1985)	White colour
White Ronny [Ronny(pink)]	X-rays (18 Gy)	FRG (1988)	Flower colour
White Westland	X-rays	Netherlands (1978)	Flower colour
White Winter	X-rays	Netherlands (1975)	Flower colour
Xishihanxiao		China (1991)	
Xueyinghong		China (1991)	
Yalta	Gamma rays	USSR (1976)	Flower colour
Yellow Bettina [Bettina (white)]	X-rays (18 Gy)	FRG (1988)	Flower colour
Yellow Cindy [Lilac Cindy]	X-rays	FRG (1989)	Flower colour
Yellow Clingo	X-rays	Netherlands (1979)	Flower colour
Yellow Clinspy	X-rays	Netherlands (1978)	Flower colour
Yellow Danusia	X-rays	Netherlands (1977)	Flower colour
Yellow Gold	Gama rays	India	Flower colour
Yellow Lymon [Lymon]	X-rays (17.5 Gy)	Netherlands (1985)	Yellow colour
Yellow Prism		Japan (1997)	
Yellow Redemine {Redemine] (17.5 Gy)	Gamma rays	Netherlands (1986)	Yellow colour
Yellow Rafla [Rafla] (17.5 Gy)	Gamma rays	Netherlands (1986)	Yellow colour
Yellow Rendez-Vous [Rendez-Vous] (12.5-17.5Gy)	Gamma rays	Netherlands (1986)	Flower colour
Yellow samba [Samba White]	X-rays (18 Gy)	FRG (1988)	Flower colour
Yellow Torino [Pink Seedling]	X-rays (17.5 Gy)	Belgium (1985)	Flower colour
Yellow Westland	X-rays	Netherlands (1978)	Flower colour
Yellow Winner	X-rays	Netherlands (1975)	Flower colour
Yingsidai		China (1991)	
Yupiter	Gamma rays	USSR (1976)	Flower colour
Zitiane		China (1990)	
Zixia		China (1989)	
Ziyuntuoyue		China (1991)	

demand and necessity for new varieties. *Chrysanthemum morifolium* is an unique genetic material for breeding. Its genetic heterozygosity is being utilized for developing new and novel varieties using classical and modern techniques. The art of recognizing desirable traits and incorporating them into future generations is very important in plant breeding. Possibilities of chrysanthemum improvement have not been exhausted. Most of the small flowered chrysanthemum cultivars in India have been developed by natural or artificial pollination followed by seedling selection. Many recessive and dominant genes which govern the various important characteristics are present in unexploited wild species which when utilized in breeding programme can make significant contribution to the improvement of garden chrysanthemum. Selection of parent cultivar is very important and, at the same time, it is also very difficult to do. Long-term efforts have made substantial changes in genetic improvement in chrysanthemum by conventional breeding. There are, however, limits to the progress of conventional breeding for every crop. In breeding, there is always an ultimate limit, beyond which the species cannot go. Breeders usually find that, after a few generations, an optimum is reached beyond which further improvement is impossible. But chrysanthemum appears to be a repository of never ending hidden treasure of genetic richness to generate new variability(Datta 2013).Induced mutation techniques have contributed impressive amounts of genetic variability to chrysanthemum breeding. During improvement process, selection is an important step. Through such selective procedure, man only select direct beneficial genotypes and the other variants are eliminated by negative selection. The objective of breeding chrysanthemum has been different at different place in India. CSIR-NBRI and ICAR from the beginning were determined and realized that any new variety, unless it is superior to existing ones in the group and has the ability to satisfy all sections concerned - wholesaler, retailer, exhibitor or customer – is not likely to succeed in replacing the established ones. Although, breeding with heterozygous material like chrysanthemum, the breeder does not know exactly what genes have been introduced to the new cultivars. But new varieties of chrysanthemum are being produced regularly through intelligent and methodical work. The

information generated by such studies have helped in the circumscription of 'gene pools' and their utilization in the creation of new and novel cultivars of commercial importance keeping in view the direction of market trend (Khoshoo 1968, 1971, 1979, 1981).

Hybridization has played a dominant and decisive role in the origin of diversity in chrysanthemum. Perhaps, the most important single factor responsible for the evolution of colourful chrysanthemum has been the repeated cycles of hybridization. High heterozygosity in chrysanthemum has been supported by chromosomal studies (Datta and Banerji 1995). Existence of heterozygosity for chromosomal interchanges in same diploid taxa of *C. coronarium* has been confirmed through meiotic and karyotypic studies. Nazeer (1981) reported 2n=18 and 2n=36 chromosomes in *C. aludosum* and *C. rutescens,* respectively. Cytological evolution reveals that garden chrysanthemum is a polyaneuploid complex, ranging from 2x to 25x (2n=36, 45, 47, 51-75). 183 cultivars have been analysed with a view to obtaining an idea about the underlying mechanisms of the genetic-evolutionary differentiation. Chromosome analysis of 183 cvs. revealed numbers like 2n=36, 45, 53-60, 62-65, 67, 68 and 72. The nodal number is 2n=54 (6x) followed by 2n=55 (6x+1) and 53 (6x-1). There is a decrease in size of the chromosome with an increase in the grade of ploidy. However, DNA content among cultivars varies from 12.64 to 25.33 pg. Analysis of the chromosome compliment reveals that considerable reshuffling and structural alterations have taken place during the course of domestication, while the analysis of the meiotic system indicates that the complex is segmental alloploid in character. The chief mechanisms underlying evolution are outbreeding, spontaneous and intentional hybridization coupled with mutation, chromosomal differentiation and repatterning and polyploidy (Nazeer and Khoshoo 1982, 1983, 1985,Srivastava 1980,1982, 1983).A study of the extent and nature of variation in phenotype and breeding shows that the garden chrysanthemum is highly heterozygous, often seed sterile and almost totally vegetatively propagated by suckers and cuttings. Repeated cycles of hybridization in different geographical areas have resulted in a wide spectrum of variation. From the present review, it is very clear that chrysanthemum is very rich in genetic diversity and it is very sensitive to human selection. It has been very successfully utilized for development of desired genotypes of usefulness. It appears that genetic stock of chrysanthemum has not been exhausted. It will be utilized the more and more new combinations of genetic diversity will develop. Documentation and characterization of varieties will help to identify the novel genes and their utilization in developing further new varieties through future gene transfer technology.

There is always demand and necessity for new varieties in floriculture industry. Genetic diversity of any crop is very important for developing new varieties. Unfortunately, there is no international database crop wise. There is no record of total chrysanthemum varieties available world wide. Present article reports the total chrysanthemum varieties developed in India through classical and induced mutation and total mutant varieties developed world wide.

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