Breeding of new ornamental varieties: Rose

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Floriculture has become an important industry in many countries as a result of advanced scientific techniques and stable supply of improved varieties. Development of new varieties and their fast marketing are major challenges in floriculture trade. Rose is grown mainly for cut flowers for floriculture industry. All the present-day colourful varieties and their novelties are the result of extensive random hybridization, spontaneous and induced mutations and selections. Voluminous literature is now available on rose breeding using different technology. Here we highlight how present knowledge can be exploited to regulate various desirable characters of rose for selective hybridization, target-oriented induced mutation and *in vitro* mutagenesis. Molecular breeding offers new and exciting challenges for future improvement of rose.

Keywords: Floriculture, genetic diversity, hybridization, mutation, pigments, rose breeding.

ROSE is the world's most popular flower due to its long history, symbolism, colour, fragrance and sheer elegance of form. The flower originated in Central Asia, dating back to between 60 and 70 million years – the period known as the Eocene epoch. It gradually spread all over the northern hemisphere. Roses were highly cherished and cultivated extensively by the Egyptians, Chinese, Greeks, Romans and the Phoenicians as early as 5000 years back. Missionaries introduced Chinese roses to Europe in the 14th century. The genetic basis of the 'modern rose cultivars' was developed due to extensive hybridization among the Chinese, European and Middle-Eastern roses[1,2]. These flowers are the most ancient and highly appreciated ornamentals. We find every stage within one genus, from entirely wild species and early cultivated forms to the most highly evolved garden forms of today. All these forms have been artificially created by the concentrated efforts of many great rosarians. The genus *Rosa* consists of about 200 species and thousands of cultivars in which more than 150 species have been catalogued[3,4]. Also, only 11 out of 200 *Rosa* species have contributed to the origin of modern cultivars[5,6]. A wide range of variability in flower type and plant growth has been developed in the genus *Rosa* due to considerable advancement in rose breeding technology for the last 200 years. Unfortunately, just a small portion of this variability has been used in the present breeding[7].

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It is difficult to postulate when rose cultivation started in India. The medical monographs of Charaka and Susruta endorse that roses grew from time immemorial and that they play an important role as part of the social, medical, cultural and religious fabric. Early introduction of rose in India is not the focus of this article. However, one can gather knowledge on this aspect from the literature[8–10]. This article covers breeding aspects for development of new rose varieties. The modern era of rose growing in India started with breeding by the pioneer Indian hybridizer, B. S. Bhattacharji in the 1940s. However, wild roses of the Himalayas – *R. brunonii*, *R. sericea*, *R. webbiana*, *R. foetida*, *R. ecae*, *R. longicuspis*, *R. macrophylla*, *R. gigantean*, *R. beggariana*, *R. eglanteria*, *R. laevigata*, *R. banksii* and *R. bracteata* are worth mentioning[8].

There is always demand and the need for new varieties in floriculture, and the global flower industry prospers on novelty traits such as flower colour, form and scent which are primary novelty markers in consumer choice. For development of a new variety, creation of genetic variability is a pre-requisite. Genetic diversity plays an important role in breeding because hybrids between genetically diverse parents manifest greater heterosis than those between closely related parents[11–14]. A number of plant breeding methods like cross-breeding, induced mutagenesis and molecular breeding play an important role in the development of new varieties. Interspecific hybridization of ornamentals has resulted in many award-wining cultivars. Knowledge on the basic genetic information about the breeding system is the most important for a meaningful breeding/improvement programme. This can be achieved through experimental hybridization among the cultivated and elemental species from the wild as the genetic system controls their heredity and variation. Commercial novel characters in ornamental plants can be created through breeding. Breeders should be conscious about the potential and limitations of different breeding approaches. This will help them to select the most appropriate as well as economic strategy for achieving their goal under prevailing circumstances of variety improvement. This is not always easy, but by understanding some of the genetics involved, one can make decisions as to which crosses might lead to success. The breeding objectives of flower crops differ from crop to crop and depend upon the nature of the plant and the part used for commercial exploitation. Roses have many beneficial components for the consumer that can be created, enhanced or improved through breeding programmes using classical and modern techniques. Breeders should have clear breeding objectives for developing new varieties. The important part is accumulation of enough gene pool and identification of desirable genes or genotypes. Selected genes or groups of genes are utilized in crossing to create more favourable combinations. The next step is selection of superior genotypes followed by testing and release of improved cultivars.

Normally for developing new varieties through hybridization in any ornamental crop, we start crossing among varieties/species available at hand. If this is successful we obtain a new variety. However, this variety may not have any/much market value. Scientific manpower and time are wasted. Therefore, we must acquire relevant knowledge before starting hybridization.

All the present-day changes in growth habit, flowering and flower shape, colour, size and fragrance of roses have been evolved through complex inter-specific crosses among elemental species, open pollination, indiscriminate hybridization, spontaneous and induced mutation and molecular breeding[14–16].

Rose and chrysanthemum are perhaps the two ornamentals where maximum breeding work has been done. At early breeding stage each of the rose species might have contributed to a specific trait. For example, *R. gallica* and other robust polyploid species lent the trait of cold hardiness, *R. chinensis* brought recurrent blooming, and *R. foetida* bestowed the yellow flower[17]. The rose has undergone the most dramatic and fascinating changes during its life history of millions of years. Till AD 1800 there were only wild rose species and their derivatives resulting from natural crossing, such as damasks (*R. damascene*), albas (*R. alba*), centifolia (*R. centifolia*), gallicas (*R. gallica*), muska (*R. moschata*) and a few others. Subsequent introduction of the Far Eastern rose species, *R. chinensis* and *R. gigantean* into Europe and their hybridization with the European species, *R. damascene*, *R. galica* and *R. moschata* brought about significant developments in the improvement of roses. The important types of roses evolved from these inter-specific crosses till the first quarter of the 19th century were Bourbon, Noisette, Portland, Hybrid Perpetuals and Tea[18]. *R. gallica* (also called French rose) has been identified as the oldest rose that exists even today. *R. damascena* or the damask rose originated from *R. gallica.* It is popular for its fragrance and has been an essential part of the history of roses since its first appearance in 900 BC. Rose breeding is now done on large scale mostly by highly competitive private companies, but they do not publish their applied genetics knowledge[5,19–24].

In India, rose breeding was initially considered as a hobby for self-fulfilment by amateur rosarians. Now amateurs, commercial or non-commercial professionals, researchers, nurserymen, etc. are engaged in breeding. After the pioneering work of Bhattacharji nearly 90 years ago, a number of amateurs, some nurseries and a few institutions took to the developing of new rose varieties in our country. Though several new varieties are developed every year, only a handful of them are ultimately released and find their way in nursery catalogues or books. The earliest Indian rose 'Dr S. D. Mukherjee' was introduced in 1935 by D. K. Roy Choudhury. Later other breeders and the Indian Agricultural Research Institute (IARI), New Delhi took up such breeding studies. The Division of Floriculture and Landscaping, IARI, remained the pioneer in rose improvement evolving numerous varieties utilizing various breeding tools. B. P. Pal, the doyen of Indian rose science, developed the first hybrid rose 'Rose Sherbet' (Fl.) in 1956. In 1956–57, the Division of Floriculture and Landscaping, IARI, started research on different aspects of roses. The first varieties 'Pusa Sonia' (HT), 'Himangini' and 'Suryodaya' (Fl) and 'Swati' (Polyantha) were released in 1968. As a result of intensive hybridization, a series of new rose varieties were evolved, described and released in 1991 ('Rakitma', 'Preyasi' and 'Shreyasi' – HT; 'Lahar', 'Manasi' – Fl and 'Climbing Sadabahar')[25-27]. The main objectives of breeding were to evolve varieties suitable for gardens, exhibition and cut flower under subtropical and tropical conditions. Then breeding for disease resistance began. Although a good amount of new varieties have been developed through hybridization in our country, no systematic work has been done by geneticists to explore the scientific basis of rose breeding. The flower has a wealth of information on genetics that remains unexplored[28–30]. Literature survey indicates that rose breeding in the country is still random. Majority of breeders start breeding with varieties available at hand. Due to the heterozygous nature, new flower colours/forms are detected in the segregating population and breeders are satisfied with new traits and release new varieties. Researchers are also satisfied with a new variety. India is now flooded with such varieties. There are hardly any data available in the country regarding the market acceptability of these varieties and also their use as parental material in further breeding programme. India is now well equipped with knowledge and technology in floriculture and appreciably is contributing in world floriculture trade. We must now assess our floricultural activities in the context of world activities. This article focuses on practical breeding of rose. Important aspects of rose breeding in the context of results reported by different breeders and based on experience gathered from years of breeding different ornamentals are discussed. We will not discuss in detail about the available technologies, only the achievements and few interesting examples of varieties will be cited as ready reference. Literature survey shows that valuable knowledge has been accumulated on rose breeding. Important characteristics (trait/s) have been identified in different genera, species and cultivars. Appreciable breeding concepts have been reported by different breeders and amateur growers. Unfortunately such wealth of information has not been utilized by successive breeders. It is difficult to obtain all information as it is scattered in different journals. Another major constraint is that most commercial breeders do not disclose their breeding details. We now need all the valuable information to properly plan for successful breeding. If the experience is properly utilized, the expected results may be achieved more easily and in less time. We should change our random breeding strategy and start selective breeding to develop particular desired phenotypic traits (characteristics) by choosing parents having desirable characters. Breeding objectives may be diversified as need and societal benefits. The main objectives of rose breeding, realized by different breeders, should be to create evergreen everblooming garden varieties, with greater vigour, new attractive flower colours, prickle-free, form, fragrance, floriferousness, recurrent flowering, long stems, winter hardiness, resistance to pests and diseases, resistance to heat and easily propagated by cuttings, suitable for growing under subtropical conditions, high oil content, etc.

Rose breeding in other countries is mainly carried out by private companies and they never disclose their applied genetic knowledge. Furthermore, some technical factors make rose a difficult model system for genetic studies[3,6,31]. Available knowledge on genetic background of morphological and/or physiological characters of roses is limited. Highly heterozygous and polyploidy nature (diploid, triploid, tetraploid, aneuploid, etc.), high male and female sterility, chromosomal disorders, poor seed setting and seed germination, etc. are the major hindrance in rose breeding to develop desired combinations[32]. Modern hybrids are highly heterozygous as they bear the genes of many ancestors and therefore, it is practically impossible to forecast the result of any specific cross. An attempt has been made to prepare the evolutionary tree of a modern rose 'America's Junior Miss' (Figure 1). It is clear from the figure how complex rose hybridization is for developing a new variety. New roses can be easily developed from seedling selection, but development of a real good rose is a difficult task. Selection and identification of parent varieties with desirable character/s is most important for hybridization. Although it is difficult for a rose breeder to have directed breeding to achieve the desired results, it may be possible for him to be successful to some extent by genetic manipulation of the breeding technique and by carefully choosing the parents for hybridization.

Hybridization

Rose breeding is now done on large scale in France, Germany, the Netherlands, UK, USA, Canada and other developed countries. Crosses between Chinese and European roses resulted in the development of modern roses such as Portland, Bourbon, Noisette, Hybrid Perpetuals, etc. 'La France' was the first hybrid tea rose developed by Guilot in France in 1867 by crossing a Hybrid Perpetual with a Chinese Tea rose[32]. Hybridization of different species has been primarily responsible for the evolution of new groups of roses. All characters are present in elemental species and varieties. Breeders must know some fundamental facts about genetics to obtain target-oriented results. Each chromosome consists of many genes which are the carriers of characters and are the units of heredity. One gene may influence a particular characteristic, many characteristics or a particular characteristic may be influenced by several genes together. Blossom colour, leaf shape, plant stature, disease resistance, etc. are controlled by a single gene. Modern hybrids possess genes for many colours either in dominant or recessive form. Some information has already been generated on the pattern of inheritance of a few important characters. Plant vigour is inherited maternally. One may, therefore, use a tall and vigorous growing cultivar as a female parent with a view to combining its vigour with other desired characters. The inheritance of prickles is caused either by a single or two complementary dominant genes in the diploid rose populations. Recurrent flowering segregates as a single recessive gene confirming other studies in tetraploid and diploid populations[33–36]. Double flowers are known to be inherited as monogenic traits in many plant species and several are transmitted as dominant genes. Inheritance of characters like double flowers, pink colour and prickles has been reported to be controlled either as single dominant genes or as complementary genes in crosses between diploid *R. multiflora* hybrids[37,38]. In spite of significant progress in rose breeding in recent years, there is an unlimited field for the improvement of garden roses. Even the most ardent rosarian will admit this fact, for no known rose is perfect; none has all the qualities we desire. There are still many characters (greater vigour and hardiness, resistance to diseases and pests, and new colours not yet obtained) we would like to see in the garden roses. Accumulation of desired scattered characters is also important. With the advancement of knowledge, rose breeding is becoming more scientific. However, the experience gained through numerous studies conducted worldwide suggested directed breeding for desired objectives. Certain interesting possibilities for directive rose breeding are highlighted here.

Breeding for disease resistance

This has not received much attention from the rose breeders. Some breeding lines have been identified which may be utilized as resistant parents in the breeding programme: Iowa State University, USA; US Department of Agriculture and others have developed varieties resistant

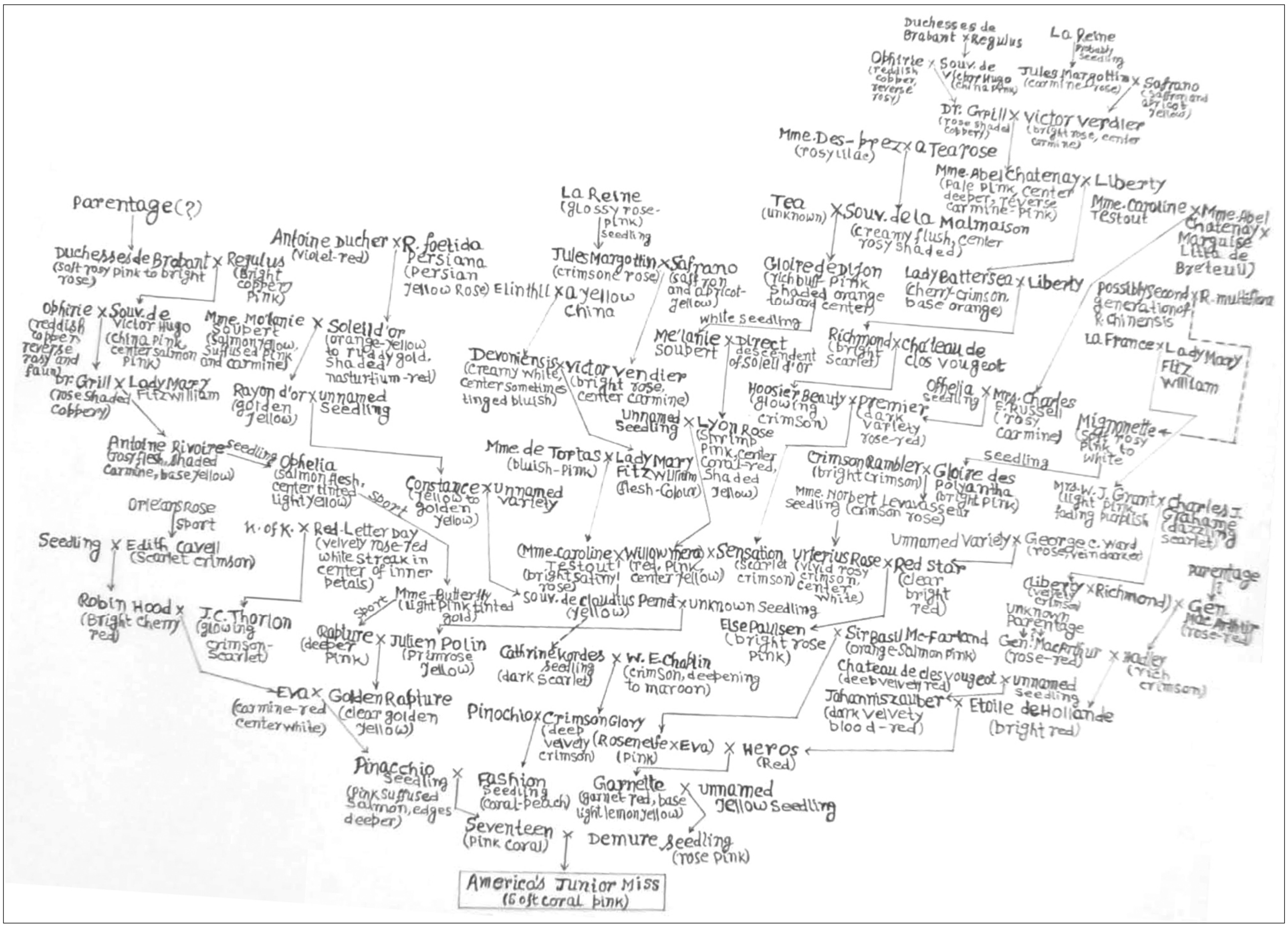

Figure 1. Schematic representation of evolutionary hybridization tree of rose cv. 'America's Junior Miss'.

to black spot and powdery mildew – 'Spotless Gold', 'Spotless Yellow', 'Spotless Pink', 'Ballet', 'Ovation', 'Captain Thomas', 'Prairie Princess', 'Music Maker', 'Appllow', 'Dezant', 'Gabricab', 'Jaguar', 'Golden Showers' (developed by W. E. Lammerts), 'A Mackenzie', 'Charles Albart', 'Champlan', 'William Battin', etc.[18,32,39,40]. *R. bracteata* is immune to black spot. *R. clinophylla* is closely related to this species and may well transmit black spot resistance. Other sources of black spot resistance are the tetraploid *R. multiflora* seedlings. With regard to mildew resistance, the climber 'Golden Showers' is worth a mention. Many of the modern H.T.'s are also mildew-resistant, e.g. 'Slver Jubilee', 'Pristine', etc.[41].

Breeding for cold resistance

In the temperate countries like Germany, USA and Canada, attempts have been made to evolve winter hardy varieties. Winter hardiness has been derived from *R. rugosa* and *R. wichuriana*[18,42,43].

Breeding for heat resistance

Breeding for heat resistance in tropical countries is of considerable importance. Possible strategies for tropical rose breeding include the use of heritage roses like 'Archduke Charles', 'Parle d'Or', 'Cecile Brunner', 'M. Falcot', etc. which do well under warm conditions. Selected garden roses like 'Montezuma', 'Maria Callas', 'Peter Frankenfeld', etc. do well in warmer parts of the world. 'Delhi Princes' (India) has been identified as heat-tolerant[18]. *R. clinophylla* is the only rose species found in the tropical tracts of India. This is perhaps the only representative species of the tropical region of the world. This species has not yet been included in breeding to develop better heat resistance rose strain in India. It is diploid, whereas standard roses are tetraploid[41,44]. The remarkable concepts and prospects of breeding with *R. gigantean* have been highlighted by eminent rosarians. It flowers freely and sets seeds quite easily with standard varieties. The flower colour in *R. gigantean* seedlings ranges from greenish-white to pure white, cream and light yellow[45].

Breeding for thornless roses

Roses generally have thorns. The desire for thornless varieties has probably existed since cultivation of roses began. Thorns may be curved, hooked, straight, dense, short, soft, needle-shaped, etc. Many do produce a few thorns, but their numbers are so few that they are often considered thornless. Some of the early thornless roses were developed in France in the early to mid 1800s and are thought to be derived from the species *R. pendulina*, *R. blanda* – the 'Smooth Rose'[46]. It is sometimes called the 'Hudson Bay Rose' or 'Labrador Rose'. Varieties have been developed having less thorn or are relatively thornless ('Betty Bland', 'Prairie Youth', 'Modern Fire-glow', 'Allister Stella Gray', 'Blush Noisette', 'Nastarana', 'Mine Legras de St.Germain', 'Chloris', 'Celestial', 'Paul Neyron', 'Elizabeth Arden', 'Sutter's Gold', 'Old Soothie', 'Harmonie', 'Jacaranda', 'Stryker', 'City of London', 'Playgirl', 'Louis Bugnet', 'Betty Bugnet', 'Metis', 'Martin Frobisher', 'J.P. Connell', 'Royal Edward', 'Kathleen Harrop', 'Zephirine Drouhin', 'Adam Messerich', 'Honorie de Brabant', 'Charles de Mills', 'Belle de Crecy', 'Cardinal de Richelieu', 'Cramoisi Picote', 'Hippdyte', 'Duchesse de Buccleugh', 'Empress Josephine', 'Officinalis') and thornless ('Grand Gala', 'Nevada', 'Cecile', 'Brunner', 'Mrs. John Laing', 'Hermosa', 'Mme Pierre Oger', 'La Reine Victoria', 'Camaieux', 'Zephirine Drouthine', 'Bella Multiflora'). Croses between *R. carolina* (tetraploid) × 'Hugh Dickson' resulted in one thornless variety (coded as 65-626). Seventy-five roses with no or few thorns with particular emphasis on varieties having fragrance and with a view to their being used in a garden for the blind have been reported. Some grow in public gardens in USA ('Nevada', 'Cecile Brunner', 'Mrs John Laing', 'Hermosa', 'Mme. Pierre Oger', 'La Reine Victoria', 'Camaieux', 'Zephirine', 'Drouhine'). More species and varieties have been identified having few or no thorns – Species roses: *R. banksie lutes* – almost thornless, *R. blanda*, *R. lherifieranea*, *R. multiflora*, *R. penduliana*, *R. wichuriana*; Climbers: thornless or few at base – 'Amadis'-Laffay 1829, 'Amethyster'-Norin 1911, 'Reve d'or'-1869, 'Veilehenbleau'-Schmidt 1909, 'Zephirine Drouhin'-Bizot 1968, Allister Stella Gray', 'Blush Noisette', 'Nastarana', 'Burgundiana Rose', 'Tourde Malakoff', 'Mine Legras de St. Germain', 'Chloris', 'Celestial', 'Georg Arends', 'Mrs. John Laing', 'Paul Neyron', 'Ulrich Brunner Fils', 'Souv. due Dr Jamain', 'Blush Rambler', 'Tausendsction'; Shrubs: 'Bellinda'-Bentalf 1936, 'Ballerina'-Bental 1937, 'Cecile Brunner'-Ducher 1881, 'Gestendirector Otto Linne'-Lambert 1934, 'Lavender Lassie'-Kordes 1960, 'Margo Koster'-Koster 1931, 'Marguerite Hilling'-Hilling 1959, 'Nevada'-Dot 1927, 'Nyphenburg'-Kordes 1954; Old modern roses: 'Adam Messerich'-Lambert 1920, 'American Beauty'-Ledechalex 1875, 'Baroness Rothschild'-Permer Pere 1868, 'Belle de Crecy'-Roerer 1848, 'Bells Isis'-Permemtier 1845, 'Blush Noisette'-Noisette 1817, 'Camaieux'-Vibert 1980, 'Celestial', 'Champney's Pink Cluster', 'Chloris', 'Commendant Beaurepaire'-Moreau-Robert 1874, 'Complicats', 'Ducherse de Montebello', Ferdinand Pichard'-Tanne 1921, 'Frau Karl Druschki'-Lambert 1901, 'George Arends'-Hinner 1910, 'Hermosa'-Marcheseau 1840, 'Katheleen Harrop'-Dickson 1919, 'La Reine Victoria'-Schwartz 1872, 'Lady Hillingdon' Lowe & Shawyer 1910, 'Louise Odier'-Margottin 1851, 'Madame Legras de St. Germain', 'Madome Pierre Ogre'-Ogre 1878, 'Madame Plantier' Plantier 1835, 'Maman Cochet'-Cochet 1893, 'Marchioness of Londonderry'-Dickson 1893, 'Marie Pavie'-1888, 'Mary Washington'-Rossw 1891, 'Mrs Dudley Cross'-1917, 'Mrs. John Laing'-Berner 1887, 'Petite Lisette'-Vibert 1817, 'Paul Neyron'-Berner 1887, 'Prince Charles'-1842, 'Reine des Violettes'-Millet-Malet 1860, 'Rosa Galica Officinalis', 'Rosa Mundi'-Pre 1851, 'Rosette Delizy'-Nabonnand 1922, 'Ulrich Brunner'-Levert 1881); Floribunda: 'Apache Tears'-Edmunde 1978, 'Apricot Nectar'-Boerner 1966, 'Dusky Maider'-Le Grice 1947, 'Gruss an Aachen-Geduldig 1909; *HT*: 'Gpsy'-Swim & Weeks 1973, 'Medallion'-Warriner 1973, 'Sterling Silver'-Fisher 1957; Miniature: 'Andrea'-R.S. Moore 1978, 'Angel Dust'-Dee Bennet 1978, 'Cinderella'-de Vink 1953, 'Cinderella Gold', 'Jack Horner'-T. Robinson 1955, 'Little Linda'-Ernet Schwartz 1976, 'Madelyn Lang'-Williams 1974, 'Mistee'-Moore 1979, 'Royal Ruby'-Morey 1972, 'Pompon de Paris' (1939), 'Sweety Fairy', 'Melody Marshall' (1993), 'Halo Today' (1994), 'Halo Rainbow', 'Pretty Penny', 'Elizabeth Arden', 'Sutter's' Gold (1950), 'Blue Moon' (1964), 'Old Soothi' (1978), 'Harmonie' (1981), 'Jacaranda' (1985), 'Audrey Hepburn' (1992), 'Stryker' (1994). 'Sugar Palm', 'English Porcelain' (1995), 'Fortune Cookie' (1996), 'Col Dude'; Greenhouse Roses: 'Grand Gala', 'Pink Parfait', 'City of London', 'Playgir', 'Bella Multiflora', 'Smooth Melody', 'Smooth Angel', 'Smooth Lady', 'Smooth Perfume', 'Smooth Romance', 'Heritage', 'Charlotte', 'Sir Walter Roleigh'[46,47]. It is now possible to develop more thornless roses through selective breeding.

Breeding for fragrance

Rose and fragrance are synonymous. The flower becomes more beautiful if it has a sweet mellowed fragrance. The fragrance is due to the presence of volatile oils. The amount of fragrance is determined by several factors such as rose varieties and climatic conditions. The contour of fragrance depends on soil, warmth, humidity, time of the day, etc. Rose perfume of commercial importance is derived from *R. damascena* and *R. centifolia*. There are several hybrid teas and floribundas having fragrant flowers. The inheritance of fragrance is governed by several genes. Even when two fragrant roses are crossed, it is not necessary that the seedlings will have fragrance because of random segregation and unfavourable recombination of genes for fragrance[10]. The genes in the rose cells responsible for perfume are many times linked with some undesirable characteristics, which make it difficult to have scent along with a good rose. Breeding for fragrance appears to be feasible if parents with good scent as well as other desirable characteristics are selected. However, no breeding is done purely for perfume, but Indian hybridizers appear to be paying special attention to this quality. The British also cherish fragrance as one of the desirable qualities in a rose and the Royal National Rose Society offers the 'Clay Challenge Vase' for the best new scented rose raised in a year by a British hybridizer[48].

The types of rose scent described in the literature vary from the mystical seven noted by Le Grice (1969)[49] – Rose, Nasturtium, Orris, Violet, Apple, Lemon and Clove – to about 40 recorded by S. C. Harlord. These include Alonond, Black berry, Honey, Magnolia, Musk, Myrrh, Pineapple, Raspberry, as also Bugs and Turpertine. Over 30 compounds are involved in rose fragrance. The most common frequencies reported in Indian varieties are lemon ('Radhanath'); apple, clove, nasturtium, orris, violet, musk ('Heart Throb', 'Week End', 'Tribute', 'Double Helix'); raspberry, Parsley, wine orange, pineapple, mixed fruits ('Lalima', 'Kum Kum', 'Anirban', 'Bhanu', 'Brahm Datta', 'Red Perfume', 'Kasturi Rangan'); citrus, myrrh, strawberry, dianthus, tea ('Haridra', 'Raja Ram Mohan Roy', 'Sunanda', 'Corn. Sukumarda', 'Nefertiti', 'Ganges Mist', 'Manipur Magic', 'Climbing Kanyakumari', 'Bhargav', 'Shantaraj', 'Willian Carey', 'Bharati'); honey, spicy ('Kishori', 'Fragrant Mauve', 'Touch of Heart', 'Mrs. Davis', 'Sudhanshu', 'Sweet India', 'Stealthy Kiss', 'Rajni', 'Asha'); Rose ('Sugandha', 'Fragrant Beauty', 'Rose Bengal', 'Our Indira', 'Classic', 'Pride of Nagpur', 'Dr Kane')[50,51].

Fragrant rose varieties have been analysed in the agro-climatic conditions of the Tarai region of Uttar Pradesh. The quality of fragrance has been generally inflated through superlative terms like 'glorious', 'intriguing', 'intoxicating', 'alluring', 'penetrating', etc. to deceive the gullible customer[52]. The merit rating of fragrance (F) is scaled from 1 to 10, the higher the number, the better the fragrance: 'Gruss An Coburg' (H.T., 1927, F9), 'The Doctor' (H.T., Howard 1936, F9), 'Lady Luck' (H.T., Miller 1956, F8), 'Granada' (H.T., Lindquist 1963, F8), 'Oklahoma' (H.T., Swin & Weekes 1964, F9), 'Inge Horstmann' (H.T., Tantau 1964, F9), 'Blue Moon' (H.T., Tantau 1954, F8), 'Lemon Spice' (H.T., Armstrong 1966, F8), 'Whisky Mac' (H.T., Tantau 1967, F8), 'Perfume Delight' (H.T., Swim & Weeks 1973, F9), 'Double Delight' (H.T., Swim & Ellis 1977, F9), 'Sweet Sarrender' (H.T., Weeks 1983, F10), 'Blue River' (H.T., Kordes 1984, F9), 'BelAmi' (H.T., Kordes 1985, F9), 'Ranjana' (H.T., Dr. B.P.Pal, F7), 'Sunsprite' (Flori., Kordes 1974, F8), 'Shocking Blue' (Flori., Kordes 1974, F9), 'Magali' (Flori., Meilland 1986, F8), 'Climbing Crimson Glory' (Jackson & Perkins 1946, F9). Some other hybrid tea and grandiflora roses with significant fragrance include: 'Arizona', 'Command Performance', 'Electron', 'Friendship', 'Love', 'Perfume Delight', 'Sundowner', 'Sheer Bliss', 'Sweet Surrender' and 'White Lightnin'. Some fragrant floribundas are 'Angel Face', 'Apricot Nector', 'Cathedral', 'Cherish', 'Intrigue' and 'Saratoga'. 'White America' is a climber with a spicy scent. It has been observed that roses with dark colour petals, more petals, thick petals and velvety petals are highly scented. Red and pink ones are most likely to smell like a 'rose', while white and yellow ones incline towards orris, nasturtium, violet, or lemon. Orange-shaded roses usually have scents of fruit, orris, nasturtium, violet or clover. In addition, some of today's most fragrant Bush Roses are – 'Scented Air', 'Ena Harness', 'Fragrant Cloud', 'Margaret Merrill' (1977), 'Fountain', 'Royal Gold', 'Radox Bouquet', 'Double Delight' (1977) and Climbers are – 'Compassion', ' Breath of Life', 'Rosy Mantle'. To this list one can add 'Papa Meilland' (1963), 'Oklahoma' (1964), 'Mr. Lincoln' (1964), 'Sutter's Gold' (1950), 'Super Star' (1960), 'Tiffany' (1954), 'Lemon Spice' (1966) – most fragrant roses grown in India. Some early varieties need mention which serve as source of fragrance are – 'Lady Mary Fitzwilliam' (1882), 'Devonienses', 'Victor Verdier', 'Mme. Croline Testout' (1890), 'Opelia' (1912), 'Catherine Kordes' (1930), 'Crimson Glory' (1935), 'Soleil d'Or' (1900), 'Sensation' (1922), 'Souvenir de Claudius Pernet' (1920), 'Julien Potin' (1927), 'Talisman' (1929), 'Souer Therese' (1931), 'Peace (1945)', 'Signora' (1936), 'Charlotte Armstrong' (1940), 'Ena Harkness' (1946), 'Fashion' (1949), 'Sutter's Gold', 'Lemon Spice', 'Fragrant Cloud' (1963), 'Prima Ballerina' (1957), 'Tenerife' (1972), 'Forgotton Dreams' (1981), 'Dolly Parton' (1984), 'Velvet Fragrance' (1987), 'Radox Bouquet (1980), 'Mr Lincol', 'Rosy Mantle' (1965), 'Compassion' (1972), 'Rajni' (1984), 'Somasila' (1987), 'Breath of Life', 'Spartan' (1955), 'Little Darling' (1956), 'Elizabeth of Glamis' (1965), 'June Park', 'Avon', 'Josephine Bruce', 'Wendy Cussons', 'President Hoover', 'Eden Rose', 'Tahiti'. 'Chrysler Imperial', one of the most dependable fragrant roses of all times carries a rose-clove flavour. 'Queen Elizabeth' is ideal for those who wish to capture an outdoors or wood-like fragrance inside their homes. 'Mister Lincoln' combines tea and damask; 'Camelot' is spicy; 'Tiffany' – lemony; 'Granada' – spicy-tea; 'Polynesian Sunset' – fruity; 'Junior Miss' like a tea rose. Other roses with distinctive fragrances are: 'Angel Wings' – apple scent; 'Mirandy' – rose–lemon. 'Golden Showers' – orris; 'Sutter's Gold' – quince; 'Charlotte Armstrong – lemon–nasturtium; 'Tickled Pink' delicate but long-lasting. Damask-type perfume is a strong rose scent, but confined to a few varieties such as 'Eiffel Tower', 'Crimson Glory', 'Papa Meilland', 'Avon', etc. The various 'Deshi' roses such as Edouard (red and pink), Chait, etc. also have a delightful fragrance[48,51,53]. In 1951, W. E. Lammerts found that a few of the older rose varieties were either only moderately scented or had no scent at all. In 1956, J. A. Gamble found on the examination of 3900 rose varieties, both old and new, that 25% were scentless, 20% strongly scented, and the rest had some scent.

Rose pigments

Rose flower colours are due to the presence of pigments like anthocyanin, flavonols and carotenoids. The commonly occurring anthocyanidins (cyanidin, peonidin and pelargonidin) provide a distinctive colour, specially most of the red-coloured and purple-coloured flowers. Similarly, two commonly occurring flavonols are quercitin and kaempferol. Besides, a number of carotenoids (yellow and orange) and xanthophylls (yellow) are present. Generally, white or yellow varieties do not contain anthocyanidins, but are rich in kaempferol rather than quercetin. Most of the red varieties have few carotenoids along with high cyanidine and quercetin content. Pink roses have both cyanidine and pelarghonidin, rather than quercetin. In bright orange-coloured flowers, pelargonidin and cyanidine with kaempferol are present with high carotenoid content[15,54–58]. In newly opened roses anthocyanins occur mainly in the diglucoside form called cyanin, peonin and pelarginin. Each changes to less intensely coloured monoglucoside with age under genetic control. Anthocyanins are also pH indicators, being more red and fairly stable in acid conditions but more blue and fading in alkaline media[56,59]. Cyanin is present alone in many modern roses and together with one or both of the other red pigments in all other red or pink roses. Highly pigmented roses are classical blood red in colour and produce varying shades when diluted. The most prominent red pigment peonin occurs frequently in the Rosa sections Cinnamoneae, Carolinae and Minutifoliae. Rose containing only peonin has not yet been reported. It occurs in *R. rugosa* and many of its hybrids, where it imparts pinkish or purplish shades of red. Cardinal red colours of cultivars 'Europeana' and 'Adalaide Hoodless' are due to peonin. Scarlet and shrimp pink shades in roses ('Independence' and 'Tropicana') are due to the presence of pelargonin. It has not been reported in any wild rose. Pelargonin seems to appear only in the presence of cyanin, where it may or may not be associated with peonin[56].

Marshall *et al.*[56] and Marshall and Collicutt[59] studied pigments of native species, hardy and non-hardy cultivars and seedlings, and reported that each of the three red pigments was highly heritable and inherited quantitatively. Cyanin and peonin ratings showed some dominant genetic characteristics, while pelargonin was in part recessive. Three pigments appeared to be controlled by few to many genes and several levels of pigmentation developed due to interactions among the three pigments. These genes control the amount of different pigments and maintain a positive correlation between cyanin and either or both of peonin and pelargonin. Genes sometimes eliminate cyanin and increase the concentration of peonin and pelargonin. Interaction between peonin and pelarginidin creates difficulty in breeding among the recent rose cultivars. Genes for cyanin were found in old roses of Europe and Asia. Peonin was possibly introduced from Austrian copper when yellow was introduced into hybrid roses. Many old peonin-bearing cultivars, and *R. rugosa* and *R. roxburghii* have been used as parents in breeding programmes. Segregation could have separated genetic factors for peonin which, when combined with other genetic factors, resulted in the pelargonin pigment appearing where no scarlet had been known previously[59–64]. Bright orange colour is derived from a mixture of pigment cyanidin mixed with carotenoid. Likewise, bronze colouration may be due to the admixtures of flavonoids in higher concentration with carotenoids. Pink roses have both cyanidin and pelargonidin and in the scarlet colour pelargonidin is more than cyanidin. In the bright orange-coloured flowers pelargonidin and cyanidin with kaempferol are present with high carotenoid content. Carotenoid is mostly present in yellow and orange roses. Anthocyanins impart pink and red colours, particularly to 3,5-diglycosyl anthocyanidins in association with 3-glycosylated flavonols[2,65,66]. This broad, general information on various pigments present in different flower colours would be useful in the choice of parents for hybridization.

The rose flower colour has a complex inheritance with several genes controlling different flower colours. The inheritance of pink flower in *R. multiflora* hybrid populations is controlled by a single or two complementary genes. Often pink colour is dominant over red or dark red. Similarly, light yellow is dominant over deep yellow. For developing white or yellow varieties, one should use only similar coloured varieties. When a multi-coloured or bicoloured rose is used as a parent in hybridization, it is most likely that as a result of random segregation of genes, the hybrid seedlings will have a wider range of flower colours. The flower colour is mainly due to additive gene action of several genes or different kinds of pigments. It may be possible to some extent to choose and manipulate the parental combinations in hybridization in order to achieve a particular flower colour by pooling the favourable additive genes and random segregation and recombination of genes for the desired pigments in new varieties to be developed[18].

In rose there are varieties where colour changes as they develop, mature, fade and die. The popular rose 'Masquerade' is yellow in bud, orange–yellow when freshly open and deep red before fading. Yellow carotenoid is produced at early stage, whereas cyanin synthesis is delayed until maturity. The undersides of red petals have yellow patches, indicating that anthocyanin synthesis in this variety is light-dependent. It has been identified that the gene or genes causing the colour change in this variety are dominant. Light and temperature affect the colour variations in some roses. Cooler temperatures enhance rose colours towards darker shades. Heat of mid-summer changes pink or yellow roses to white or near white. Temperature and light also induce variations in rose colour by affecting the availability of sugars in the bud stage[67,68]. Temperature plays a major role on anthocyanins biosynthesis[69]. Environmental factors (temperature and light intensity) affect petal pigmentation[70]. Higher accumulation of anthocyanin takes place at low temperature and higher temperatures result in a lower concentration of anthocyanins in roses[71,72]. Pigment production ceased at temperatures above 30°C (ref. 73). Reduced supply of carbohydrates at higher temperature may be the cause of reduction of anthocyanin contents[74–76]. Sound knowledge of different groups of pigments, their biosynthetic pathways, biochemical mechanisms, co-pigmentation effects and change in pH influencing flower colour will help create new colours in roses. Kanichi Arisumi (1964–1968) has published a series of four papers entitled 'Studies in the flower colours in *Rosa*' highlighting the role of biochemical and genetic control in practical breeding[61,62]. Rose breeders should take all these factors into consideration when selectively breeding for colour.

Breeding for brown colour

Brown roses are unique and fascinating. Le Grice[49] introduced a series of striking brown-coloured roses – 'Amberlight', 'Tombrown', 'Cesper', etc.[41]. Some more beautiful brown roses have been reported – 'Chocolate Prince', 'Colorbreak', 'Hot Chocolate', 'Hot Cocoa', 'Brown Velvel', 'Mayflower rose', 'Auguste Renoir', 'Tasman Bay', 'Dark Moments', etc.[77]. Important varieties for development of brown roses are 'Jocelyn', 'Tane', 'Mary Sumner', 'Princesse', 'Kirsty Jane', 'Mary Summer'.

Breeding for better red roses

Cyanidin imparts red colour. Two more pigments – chrysanthemin and paeonin – produce much more brilliant red and are less prone to fading, than cyanidin. Varieties containing large amounts of these pigments may be selected by breeders in breeding programmes to develop perfect red roses. Climbing rose varieties 'Francois juraiville', 'Dorothy Perkins' and 'Souvenir de la Malmaison' contain large amounts of chrysanthemin. Several rose species (*R. foetida* bicolour, *R. rugosa*, *R. stellata*, etc.) and few floribunda varieties ('Piccolo'-Tantau 1957, 'Red pinocchio'-Boerner 1947 and 'Ruby lips'-Swim 1958) also contain paeonin[59,62,78].

Breeding for better yellow and orange roses

Pelargonidin has the tendency to co-exist with the Kaempferol type of yellow rose, but is not normally found with the quercetin type. Kaempferol and quercetin are flavonols present in a number of rose species and varieties, and generally found in most yellow roses in combination with carotenoid. Mixture of pelargonidin and carotenoid will produce brilliance of colour. 'Louise de Funes' (Meilland 1984) is derived from a mixture of the pigment cyanidin with carotenoid[62,79].

Breeding for miniature roses

Mini roses are a fascinating group of flowers with all the characteristics of large roses reduced to mini proportions. Popularity of miniature roses is increasing day-by-day due to their growth habits, and diverse and interesting flower forms and colour. Their origin, breeding system and multipurpose use are interesting. Miniature roses are now the fastest growing segment of the rose market. There is tremendous scope for multidisciplinary research for improvement of miniature roses. The increasing popularity of miniature roses has motivated the hybridizers to successfully develop many new miniatures. Many miniatures do not make good seed, but they are good in producing the pollen. Therefore, minis can be used as pollen parent and crossed with climbers, floribundas and shrub roses. When a miniature is crossed with a climber, we may get a mini, or a climber, or something in between. Mini gene is generally dominant, so one can expect 90% of the progeny to be miniatures. Literature has already been generated on different aspects – history, development, culture, uses, breeding, improvement, characterization, available varieties, etc.[80–86]. All these have been reviewed recently[87].

Dominant and recessive factors

Several important desirable characters behave as dominants. Their expression depends on the action of one, or at most few factors. Climbing habit is dominant to dwarf bush habit due to the action of a single factor. Desirable climber or pillar-type and bush-type can be developed through backcrossing. We can always recover one half of the progeny as the recessive dwarf bush habit and a small percentage of these dwarf progeny with the desirable features of the climber[37]. Dull foliage is recessive as dull-leaved varieties always produce plants with dull foliage. Crosses between dull × glossy results in glossy and dull-foliaged plants. Long urn-shaped bud is dependent on dominant factor/s. Short-budded varieties ('Crimson Glory') give only short-budded seedlings when crossed with other short-budded varieties ('Captain Thomas'). It has been experimentally proven that doubleness is dominant and quantitative in its expression. 'Recurrent Flowering', 'dwarf character' and 'moss character' are inherited monogenically[17,34–36,88]. Double flowers, pink flower colour and prickles are inherited as single dominant genes or as complementary genes in crosses between diploid *R. multiflora* hybrids[37,89].

Knowledge accumulated through breeding experiments indicates that different characters – vigour, fragrance, thorniness, strength of neck, length of cutting stem, width of leaf, bud shape, etc. are intermediate in their expression and quantitative nature of inheritance due to interaction of many factors. One should selectively cross plants having dominant factors as glossy leaf, long bud, double flowers, mildew resistance, strong necks, well-shaped buds and flowers, wide leaves, etc. in the breeding programme. Backcrosses are also necessary to obtain desired combinations[17,34,36,37,88,89].

Colour inheritance and limitations of breeding

Knowledge on genetic background of rose breeding is limited. Breeding experiments on ornamental crops are comparatively less in comparison to other agricultural crops. There is lack of proper planning for breeding techniques on ornamental crops according to the needs of consumer. Also, there is gap between the research institutions and breeding companies. Research topics are chosen, managed and restricted within the institutions. Breeding experiments on ornamental crops should be designed according to the needs of the breeding companies[90]. Geneticists have not been able to develop a proper model system for rose breeding due to its high heterozygotic and ploidy nature and difficulties in sexual reproduction[6]. To understand the genetic complexity of modern rose an attempt has been made, to trace out the evolutionary family tree of a rose cultivar 'America's Junior Miss'. Its flower bud is ovoid, flower medium size, double, high centred, fragrant, soft coral-pink. Foliage glossy, vigorous, bushy, abundant bloom. It has developed by crossing 'Seventeen' × Demure seedling. Figure 1 shows the complex evolutionary structure of hybridization for development of rose in general and 'America's Junior Miss' in particular. Modern hybrids carry the genes of many ancestors and it is practically impossible to predict the results of any specific cross. It is not yet clear whether blossom colour, leaf shape, stature, disease resistance of a plant is controlled by a single gene or many. Modern hybrid roses carry genes for many colours, which are either in dominant or recessive form. A single dominant gene governs leaf texture, disease resistance or susceptibility, plant stature, petalage, etc. The interaction of several genes controls vigour, fragrance, thorn structure, rigidity and length of flower stem and shape of flower. Dark maroon–red flower colour is dependent on recessive factors. Red (rose-red to Tyrian rose) can be obtained by crossing deep red varieties ('Crimson Glory' or 'Night') to yellow varieties. Red flowers sometimes fade rapidly to magenta–red. Nonfading dark maroon–red colour ('World's Fair') can be developed by crossing red with maroon varieties. Orange–yellow, yellow, white and scarlet are recessive in their inheritance. Bicoloured ('yellow and silver reverse') petal colour in 'Condessa de Sastago' and 'Contrast' is recessive to self-colour. Dark red, scarlet, orange, yellow or white, are recessive. Dominant and recessive nature of different characters along with pollination mechanism has been reported by different workers[17,34–36,43,56,88,89,91].

Characterization

Characterization is important for correct identification of cultivars. It helps understand the genetic diversity, 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 parameters of cytology, morphology, physiology, chemical and biochemical, DNA markers, etc. are utilized for characterization. Different characters like stem, young leaf and flower colour; pickles per unit area and prickle shape; petals per flower; leaf and petal size; number of leaflets; pollen grain size and fertility; phenolic compounds in leaves and petals; chlorophyll content in leaves; carotenoids in petals; RAPD markers, etc. have been taken into consideration for characterization of different rose varieties. Recently, about 150 rose cultivars have been critically analysed. Good amount of variety-specific morpho-chemical characters and desirable genes have been identified through such characterization[14]. Analysis showed that carotenoids play an important role for the visible colours of roses. Carotenoids in combination with anthocyanidins and flavonols will be significant to breeders for selecting proper genotype to develop selective combination of flower colour as desired by trade[92]. Half of the wild rose species is polyploidy and chromosome numbers vary from $2n = 2x = 14$ to $2n = 8x = 56$ (refs 93, 94). Pentaploids nature of *R. canina* shows unusual asymmetric meiosis[95–98].

Rosa prealucens from the Sino-Himalayan region had the highest naturally occurring ploidy (decaploidy) in the genus[99]. Changes in ploidy level during evolutionary process have been suggested due to adverse environmental conditions (high temperature)[100]. Neumeyer selected and prepared a list of rose species and their hybrids according to chromosome number as reported in Modern Roses 8. Gudin and Mouchotte[21] studied pollination mechanism, seed maturation and germination for better hybridization. Singh *et al.*[27] identified parent varieties ('Sweet Afton', 'Pink Parfait', 'Crioson Glory', 'Charles Mallerin', 'Golden Splendour', Buccaneer', 'Swati', 'Anna Wheatcraft', 'Charleston', 'First Prize', Orangeade', etc.) having high female and male fertility. Characterization and identification of rose varieties on the basis of molecular characters have been reported[101–110]. Recently, different aspects of breeding and pigment composition have been discussed with special reference to development of coloured tuberose[111].

Bud sports

'Sport' is a natural mechanism by which a plant of an existing variety puts forth a shoot in which genetic change has occurred. This genetic mechanism plays an important role in increasing the range of variation and giving rise to a new variety. The most important bud sport is the climbing habit in Hybrid Teas. Some important climbing sports are available in 'Crimson Glory', 'Mrs Sam McGredy', 'Climbing Blue Moon', 'Climbing Cinderella', 'Climbing Fragrant Cloud', 'Climbing Guitare', 'Climbing High Field', 'Climbing Kronenbourg', 'Climbing Ladies' Choice', 'Climbing Miss Harp', 'Climbing Mr. Lincoln', 'Climbing Over the Rainbow', 'Climbing Peace', 'Climbing Queen Elizabeth', 'Climbing Rina Herholdt', 'Climbing Sterling Silver', 'Climbing Yellow Doll', 'Climbing Zambra', etc. About 18% of the varieties in the Hybrid Tea group have originated as sports ('Mme Butterfly', 'Lady Sylvia', 'Rapture', 'Better Times', 'Jewel', 'Royal Beauty', etc.). A huge amount (about 54%) of varieties have been developed through bud sports in the Dwarf polyanthas ('Miss Edith Cavell', 'Coral Cluster', 'Juliana Rose', 'Locarno', 'Cameo', 'Ideal', 'Little Dorrit', etc.). A number of striped roses have been developed ('Careless Love' from 'Red Radiance'; 'Candy Stripe' from 'Pink Peace'; 'Banhar' from 'Charlotte Armstrong'; 'Harry Wheatcraft' from 'Picadilly'). Few more bud sports are 'Anand Rao', 'Balwant', 'Careless Love', 'Chandralekha', 'Chicago', 'City of Lucknow', 'Dazzling Flame', 'Durgapur Delight', 'Family Circle', 'Harry Wheatcroft', 'Hutton Village', 'Janaki, Kanchani', 'Nava Sadabahar', 'Orange Sparks', 'Pink Montezuma', 'Priti', 'Rose Bansal', 'Sahasra Dhara', 'Shanti', 'Shirakawa Star', 'Siddartha', 'Tapti', 'Tata Centenary', 'White Queen Elizabeth', etc.[32,112].

Induced mutation

Many new rose varieties have been developed through induced mutation technique using both physical and chemical mutagens. More than 67 mutant varieties have been reported worldwide. Induced mutagenesis at its present status appears to be well standardized, efficient and cost effective[14,113–119].

Recurrent irradiation

Recurrent irradiation means irradiation of plant materials that had already been irradiated in one or more subsequent generations. Such irradiation methodology expanded more genetic variability which otherwise not possible through single irradiation. Recurrent irradiation induced more genetic variability and increased mutations and spectrum of mutations in rose[14].

Colchi mutation: Colchicine can be used for induction of flower colour mutations in rose[14].

Management of chimera: Diplontic or intrasomatic selections are considered as the main bottlenecks in mutation breeding. *In vitro* technique offers advantages over conventional methods. Novel tissue culture technique has been standardized for management of chimeric tissue through direct shoot regeneration. Chimera management and *in vitro* mutagenesis have more scope for developing new roses[14].

Molecular breeding

Rose cannot synthesize blue pigment delphinidin due to a deficiency of the enzyme dihydrokaempferol 3′5′ hydroxylase. Presence of co-pigments and vacuolar pH affect flower colour. All basic information/techniques on flavonoid composition, pH of petal juice, transfer of 'blue gene', etc. have been worked out. The most exciting development of molecular biology is the synthesis of blue rose. Calgene Pacific Company, Melbourne; Suntory Limited, Japan, and Petunia Genetics Group at the Institute National de la Recherche Agronomique, Dijion, France, have jointly developed transgenic rose which had blue hues[120–123].

Conclusion

- A lot of breeding work can be done in rose to develop new genetic variations using conventional breeding techniques in segregating population due to its high heterozygosis and polyploidy nature[90].
- Breeding technique and wise selection of parents for hybridization will help to some extent achieve the desired results through directive breeding.
- Hybridizers in India can achieve success in developing desired varieties according to the demand of international markets if they have proper laboratory facilities and patronage, suitable trial ground, monetary benefits and markets, recognition and royalty as their counterparts in other countries[124,125].
- Every rose breeder must have definite objectives for breeding. A good rose hybridizer must be, as far as possible, technically sound and experienced. He

should be scientific-minded, methodical, patient and should have knowledge about selection of 'aceptor' and 'donor', pedigree and history, and all other desirable characteristics of rose[24].

- Selective breeding has now been realized as the most essential to develop varieties according to requirement of the trade. This will be possible in two ways – utilizing all available knowledge as guidelines and identification of desirable genes through characterization of varieties prior to cross-breeding. Classical breeding is still a powerful tool in the breeder's hands for improvement as there is huge pool of variation in the yet unexploited *Rosa* species[21].
- Induced mutation combined with *in vitro* technique has tremendous potential to change one or a few characters of an otherwise outstanding cultivar without altering the remaining and often unique genotypes[14].
- Molecular techniques have been applied recently to *Rosa*, but further research is needed before they can be used with full efficiency.

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