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Taxonomy and Grafting of Ornamental Cacti: A Review

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ABSTRACT

Nowadays, cacti and succulents are widely utilized in landscaping. These plants suit very effectively for both indoor and outdoor decorations. The family Cactaceae comprises of 130 genera with 2000 species and this is primarily divided into three tribes namely: Pereskieae, Opuntieae and Cereeae. Cactus flowers are very attractive and are diverse in size, number, form and color. The nocturnal flowers are always white, with light-yellow or red tones, whereas diurnal flowers are white, purple, yellow-orange, red or green. Basically, an areole is a transformed axillary bud situated over a tubercle with spines and often with hairs and trichomes. Due to their low maintenance requirements and their ability to withstand harsh environments, cacti are extremely popular as ornamental plants across the planet. Cacti can be propagated by seeds, cuttings, offsets and grafts. Grafted cacti are now regarded as one of the most admired ornamental indoor plants worldwide. In cacti, grafting has become a commercial method of propagation to accelerate and hasten the growth rate of slow growing species, to ensure the survival of the plants with poor root system, to ensure the survival of genetic aberration of variegated and bright coloured cacti (red and yellow caps) that lack chlorophyll, to accelerate the growth of plants for commercial use, in order to keep cristate and monstrose forms look attractive. Successful grafts have been obtained when the species like *Trichocereus spachianus*, *Trichocereus macrogonus*, *Trichocereus pachanoi*, *Hylocereus trigonus*, *Hylocereus undatus*, *Selenicereus grandiflorus*, *Opuntia bergeriana*, *Opuntia ficus-indica* are grafted onto *Nopalea spp*. The exogenous application of IBA has a positive effect on the vegetative growth of grafted plants using (*Gymnocalycium mihanovichii* scion grafted onto *Trichocereus spachianus* rootstock.

Key words: Anatomy, Cacti, Grafting, Ornamental, Propagation, Taxonomy.

Ornamental horticulture is one of the potential sectors in global horticulture. India is bestowed with several agro-climatic zones conducive for production of sensitive floriculture. Among the floricultural plants, cacti are xerophytic plant, which have attractive morphological characteristics for which it is widely used in ornamental gardening. The infinite, unique variations in shape, size, colour of areoles and spines make the plants look more. Nowadays, cacti and succulents are widely utilized in landscaping industry. These plants are suitable for both indoor and outdoor decorations. Rock garden is an interesting feature in any type of garden. A well laid out rock garden at suitable location, with good arrangement of rocks and plants, will give immense pleasure and surprise the viewers.

Cacti plants have a complex organ, a cushion like structure, spirally arranged over the stem which is known as areole. They are the vital growing areas of the cacti from which points, branches, leaves, spines, flowers and new joints arise. Apart from this characteristic feature, certain other forms make the cacti, a unique one. They include cristate and monstrate forms, cephalium bearing cacti, variegated cacti, achlorophyllous cacti *etc.,* (Bewli, 2016). The appealing and captivating form of cacti, make them a potential element in the field of landscaping. Despite their attractiveness, the hardness and the survival capacity of the cacti, make them an integral part in landscaping features *viz.,* rockery, xeriscaping *etc.*

Cacti can be propagated by seeds, cuttings and offsets or grafting. Some species of *Ferocactus, Mammillaria, Melocactus* are self fertile and hence they form seeds whereas species of *Astrophytum* and *Gymnocalycium* are self sterile and hence require artificial cross pollination to achieve seed development. The vegetative propagation is due to the prevailing constraints *viz*., slow growing nature and self-sterility *etc* (Bewli, 2016). Grafting, being an efficient mode of perpetuation of planting materials in their true to type nature, offers many genera of cacti, a way of survival. The graft success in inter-specific and inter-generic grafts also make the grafting a successful mode of multiplication of plants. It has been noted that, the ordinary mode of multiplication *viz*., cutting, layering, offshoot *etc*., are not found to be economical and feasible for large scale production of cacti like *Gymnocalycium mihanovichii*, owing to its achlorophyllous nature.

Grafted cacti are now regarded as one of the most admired ornamental indoor plants in worldwide. In cacti,

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grafting has become a commercial method of propagation to accelerate and hasten the growth rate of slow growing species, to ensure the survival of the plants with poor root system, to ensure the survival of genetic aberration of variegated and brightly coloured cacti (red and yellow caps) that lack chlorophyll, to accelerate the growth of plants for commercial use, in order to keep cristate and monstrose forms look attractive to provide a handy tool in the hands of conservationists to save endangered species and to attain some unusual distinct growth forms that get developed on graft.

Owing to the prevalence of un-preferable morphological modifications in majority of the cacti genera, they are generally hard to be preferred as garden plant or for interior-scaping. But, with the aid of grafting technology, species which are attractive and thorny such as *Gymnocalycium* sp. and *Mammillaria* sp. can be grafted onto thorny or hardy rootstocks such as *Hylocereus* sp., *Myrtillocactus spp. etc.,* which helps to make an excellent indoor plant. Apart from this, it provides a new venture in the field of ornamental nursery production which enhances the self employment and entrepreneurship development for the youth. With this background, the research works pertaining to the evaluation and performance of cacti and studies on grafting in ornamental cacti is reviewed hereunder.

Taxonomy of cacti

The word cactus is derived from Latin word 'kaktos' meaning 'a spiny plant'. Cactus is a member of the family Cactaceae within the order Caryophyllales with succulent stem to store water (Johnson and Smith, 1947). Cactaceae is classified into three subfamilies: Pereskioideae, Opuntioideae and Cactioideae (Barthlott and Hunt, 1993). The family possesses succulent stems aiding the storage of water. It is a unique group of plants, found in its natural environment, exclusively in North and South America. The family Cactaceae comprises of 130 genera with 2000 species. This family is primarily divided into three tribes namely: Pereskieae, Opuntieae and Cereeae. The tribe Pereskieae is the most primitive tribe. The plants bear leaves similar to that of other families with spines but no glochids or bristles. *Opuntieae* is characterized by the presence of glochids whose stems and branches are fleshy, armed with spines but not ribbed. The largest tribe Cereeae has the plants which are ribbed, fleshy but not glochids. The tribe, Cereeae is further classified into eight sub-tribes *viz.*, *Cereanae, Hylocereanae, Echinocereanae, Echinocactanae, Cactanae, Corypanthanae, Epiphyllanae* and *Rhipsalidinae*. The large group under the tribe, *Cereeae* is known by its ribbed, fleshy stems of continuous growth in columns or globes (Bhattacharjee, 2005).

It has been reported that cacti show remarkable variation in growth form including large tree like or columnar forms, solitary or clumped globular or globose habits and even epiphytes and climbers. They are generally characterized by highly organized fleshy stems and branches either bearing reduced or highly modified leaves or leaves are often replaced by specialized spines, hairs, bristles or scales borne to a central swollen fleshy structure called areoles. Most cacti members are characterized by the presence of areole an important diagnostic character of the family. Cactus flowers are very attractive and they are diverse in size, number, form and color. The nocturnal flowers are always white, with some light-yellow or red tones, whereas diurnal flowers are white, purple, yellow, orange, red or green (Barthlott and Hunt 1993). Cactus spines are probably the most distinctive feature and they consists central, prominent spine, surrounded by many radial spines. The spines not only provide shade and collect the humidity; also they can protect the plants from predators that are seeking food or water (Cullmann *et al.,* 1986).

In *Mammillaria*, areoles are carried by nipple like structures (hence the name *Mammillaria*) instead of being organized into ribs related to many other cacti. The flowers do not bloom from the areoles, but from the area at the juncture of two tubercles (Fernández *et al.,* 2013). Cacti are those plants belonging to xerophilous family which are large and diverse, including broadleaf plants (*Peresikia*), giant arborescent plants (*Carnegiea gigantea, Pachycereus pringlei and Pachycereus schotti*), columnar species (*Neobuxbaumia polylopha, Cephalocereus columna-trajani*), candelabriform species (*Myrtillocactus geometrizans, Pachycereus weberi*), globose forms (*Mammillaria* and *Corypantha*) and epiphyte forms (*Hylocereus* and *Rhipsalis)* (Bravo and Scheinvar, 1995). Among *Myrtillocactus* spp., the dominant cacti species that grows in central Mexico is *Myrtillocactus geometrizans*. *Myrtillocactus spp* are also known as the blueberry or the whortle berry cacti, being named after observing the plants during fruiting stage which shows similarity in size and colour of their respective fruits (González, 1999).

Hylocereus species are morphologically epiphytes or hemi-epiphytes whose segmented stems are succulent in nature with three ribs that has the ability of producing aerial roots. Spines, the transformed leaves, are grouped into areoles which is a morphological adaptation for being a xerophyte (Simpson, 2006).

Melocactus species are one among the most remarkable cacti which develop a cephalium bearing flowers after reaching the full body size. This genera of cacti holds a good number of disadvantages in cultivation *viz.*, late flowering, reduced germination capacity and no off shoot production (Hernandez *et al.*, 1994). *Gymnocalycium* was originally developed from a single chlorophyll deficient mutant seedling in Japan during 1941. They occur occasionally but they die soon because of their inability to produce photosynthates. Hence, the red seedlings were grafted on the green cacti which are able to furnish its nutrient and vascular requirements.

Adaptations of the cacti

Anatomical adaptation

It has been reported as follows in view of anatomical adaptations of cacti stem: In primary shoots of most of the dicotyledons, vascular bundles run along the stem and

perform basic function of connecting the leaves to the rest of the plant. Thus, vascular bundles join leaves along the length of the shoot and their distribution in the stem is strongly linked to the external arrangement of the leaves, *i.e.* to the phyllotactic pattern (Tomlinson and Wheat, 1979). With the appearance of secondary growth, a continuous cambial layer develops, the vascular bundles disappear and the leaves (or the branches that have developed from the axillary buds) become connected to a continuous woody tissue. However cacti commonly retain the bundle arrangement of vascular tissues (Gibson, 1978). Additionally, the leaves and the subtended axillary buds are reduced in most of the cacti in to a series of spine cushions known as areoles, a distinctive feature of the cactus family. Basically, an areole is a transformed axillary bud situated over a tubercle with spines and often with hairs and trichomes. The basic vascular morphology of cacti, however, is similar to that of the seedlings of non-succulent dicots and the vascular bundles run along the stem connecting neighboring areoles (Gibson and Nobel, 1990).

Physiological adaptation

All cacti are succulents and they have highly specialized water storage tissues. Another interesting physiological specialization of cacti is that mostly undergo the Crassulacean acid metabolism (CAM) pathway for photosynthesis that intake CO_2 at night for conserving moisture due to comparatively decreased rates of evaporation at night. The cacti absorbed CO_2 an acid (carbonic acid) in this metabolic pathway which is eventually released during the day for the purpose of photosynthesis. Due to their low maintenance requirements and ability to withstand harsh environments, cacti have become extremely popular as ornamental and horticultural plants all across the planet. Like other CAM plants, *Opuntia* shows a wide range of geographic distribution, as a result of their remarkable physiological plasticity (Herrera, 2008). The seasonal studies on photosynthesis in cultivated species like *Agave tequilana*, *Opuntia ficus–indica* and *Stenocereus queretaroensis* have shown that these species have the capacity to maintain the fixation of atmospheric CO_2 during the dry season (Nobel *et al.,* 2002).

Morphological adaptations

On evaluation of some cacti for their growth and morphological adaptations, the results revealed that *Ferrocactus latispinus* has around 5-13 ribs at the upper portion and they are not longitudinally arranged but slightly helicoidal. In *Neobuxbaumia tetetzo*, the numbers of ribs are in the range of 7-19 and they are longitudinally arranged (Altesor and Ezcurra, 2003).

Propagation

Studies have revealed that cacti can be propagated by seed, cuttings or grafting. Grafting is a commercial method and has a major role in cactus propagation (Cullmann *et al.,* 1986). It has been reported that some species of *Echinopsis* and *Lobivia* are propagated through offsets whereas perpetuating hybrids and valuable plants like *Epiphyllum*, *Zygocactus* and *Schlumbergera* are commercially propagated by means of stem cuttings. The type of cutting used for multiplication varies with the genera. *Aporocactus*, *Cepahalocereus* and *Espotea* are multiplied through softwood cuttings whereas *Pereskia* is propagated by means of tip cuttings. Tubercles (nipple like part at the apex) are the propagating materials for *Mammillaria plumosa*, *Opuntia biglovii etc*. Some species of *Schlumbergera* and *Rhipsalidopsis* are multiplied using phylloclade (Bhattacharjee, 2005). The commercially followed propagation methods of certain cacti are follows. *Acanthocereus tetragonus* and *Astrophytum myriostigma* can either be propagated by seeds or grafts; *Brasiliopuntia brasiliensis*, *Hamatocactus sp*, *Myrtillocactus geometrizans, Opuntia cochenillifera, Opuntia elatior, Opuntia microdasys* and *Pereskia grandifolia* can be perpetuated either by seeds or stem cuttings; *Echinocactus grusonii, Echinocactus texensis, Ferocactus peninsulae* and *Mammillaria beneckei* are multiplied by seeds; the species multiplied by stem cuttings are *Schlumbergera kautskyi, Opuntia cylindrica, Harrisia martini* and *Cereus hexagonus* whereas *Epiphyllum anguliger* is propagated through leaf cuttings (Patel *et al.,* 2016).

Grafting

Grafting refers to the union of two living plant parts so that they grow as a single plant. Cacti are easy to be grafted and it's possible to graft almost any two cacti successfully. Some specific reasons for grafting include: saving plants severely rotted or diseased, ensuring better growth and flowering by grafting scions of slow growing species onto fast growing stocks, developing unusual forms and the main reason for grafting cacti is to get faster growth. Some of cacti species are rare and grow slow, thus grafting is a worthy way to propagate them faster (Anderson and Brown, 2001). It has been found that *Hylocereus*, *Pereskia* and *Selenicereus* are commonly used as rootstocks for glass house condition whereas *Trichocereus spachianus* is highly suitable for grafting under desert conditions. *Bolivicereus* or *Borzicactus samaipatanus* is found to be a good rootstock for small scions whereas *Lemaireocereus pruinosus* and *Lemaireocereus marginatus* are good for large scions. Successful grafts have been obtained when the species like *Trichocereus spachianus, Trichocereus macrogonus, Trichocereus pachanol, Hylocereus trigonus, Hylocereus undatus, Selenicereus grandiflorus, Opuntia bergeriana, Opuntia ficus-indica* are grafted on *Nopalea spp.* (Huffman, 2003).

Effect of growing condition on success of grafting

An experiment was conducted to assess the effect of growing conditions *viz.*, temperature and photoperiod on scion necrosis in the plants of *Chamaecereus silvestrii* grafted onto *Hylocereus trigonus* and the results are as follows: In scion, necrosis increased under short day conditions at 8 hours light and a growing temperature of 12°C and was nearly eliminated by long day conditions and a growing

temperature of 16°C. Irradiation did not affect scion necrosis. Plant quality rating was found to be high when the plants were grown under long day conditions at 16°C (Erwin, 1996). The effect of grafting season (spring and autumn), on graft success revealed that spring season found to be the best season for grafting. Moreover, *Borzicactus samaipatanus* performed well as scion during spring, while the rootstocks *viz*., *Borzicactus samaipatanus* and *Cleistocactus candelilla* showed higher efficiency (Bayat *et al.,* 2016).

Vegetative parameters

It has been reported that the genetics of the rootstock and scion has a pronounced effect on the growth of the graft. The study has revealed that the homograft with *Opuntia ficus-indica* as stock and scion has shown an increased scion height of 28.8 cm at 90 days after grafting whereas hetero-grafts involving *Opuntia leucotricha* and *O. cochinera* as rootstocks and *O. ficus-indica* as scion has reduced scion height *i.e.,* 18.4 cm and 16.3 cm respectively (Estrada-Luna *et al*., 2002). Results showed that fresh and dry weight of cacti grafted plants in autumn season was significantly affected by different rootstocks and scions. The maximum fresh weight was recorded by the plants grafted spring season (*Gymnocalycium* and *Coryphantha*) while the maximum dry weight was observed in *Coryphantha.* The maximum dry weight in plants grafted in the spring was related to *Harrisia pomanensis,* while the minimum dry weight was obtained for *Borzicactus samaipatanus* and *Cleistocactus candelilla* (Bayat *et al.,* 2016).

The experiments conducted with *Opuntia ficus-indica* as rootstock and *Pelecyphora aselliformis* as scion by *in vitro* micro-grafting has showed that the type of the scion material has an effect on the growth of the scion after grafting. It has been noticed that the scion height was maximum when apical portion was used as the scion which recorded 31 cm and 38 cm after 3 and 6 weeks from grafting respectively whereas sub-apical portion as scion has recorded 28 cm and 35 cm after 3 and 6 weeks from grafting respectively (Badalamenti *et al.,* 2016).

An experiment was conducted to study the effect of plant growth regulator on micro-grafting of cacti using *Gymnocalycium mihanovichii* and *Trichocereus spachianus* as scion and root stock results revealed that IBA @ 100 ppm was the most effective treatment to improve the growth of the grafted cacti and to increase the scion height up to 31.66 mm which is only 6.67 mm in control. The exogenous application of IBA has a positive effect on the vegetative growth of *in vitro* grafts involving *Gymnocalycium mihanovichii* and *Trichocereus spachianus* as scion and rootstock, respectively. The stem girth was found to be high in the micrografts provided with IBA 100 ppm once which is about 27.66 mm whereas 9 mm growth was observed in control (Moghadam, 2012). *In vitro* micro-grafting with *Opuntia ficus-indica* as rootstock and *Pelecyphora aselliformis* as scion revealed that the nature of the scion has influenced the number of offshoots produced from the grafts. When apical portion of the seedling was used as scion, the number of offshoots produced was maximum *i.e.,* 2.70 per shoot whereas sub-apical as the scion has reduced number of off shoot *i.e.,* 1.00 per shoot (Badalamenti *et al.,* 2016).

Evaluation of homo and heterografts obtained using *Opuntia streptacantha, O. leucotricha, O. robusta, O. cochinera* and *O. ficus-indica* as rootstocks and *O. ficus-indica* as scion material by wedge grafting and horizontal grafting under *in vitro* conditions revealed that horizontal grafting showed higher success percentage *i.e*., 90% whereas wedge grafting showed lower success percentage of 30%. In wedge micro-grafts, the growth of several side shoots from the rootstock drastically limited the graft union of scion with rootstock due to the lack of food supply to the scion. Reduced success percentage in wedge grafts was mainly due to mismatched tissues between stock and scion coupled with the problems of offshoot production from the rootstock (Estrada-Luna *et al*., 2002).

It has been reported that the type of scion material has a significant effect on the success percentage of *in vitro* micro-grafted plants. In this experiment, *Opuntia ficus-indica* was used as rootstock and *Pelecyphora aselliformis* as scion. Here, the success percentage was higher when apical portion was used as scion (97%) against sub-apical portion which showed only 81% success (Badalamenti *et al.,* 2016).

The morphological characterization of the cacti has revealed that *Hylocereus triangularis* and *Myrtillocactus geometrizans* can be used as potential rootstocks whereas *Mammillaria beneckei*, *Hamatocactus setispinus*, *Ferocactus latispinus* and *Gymnocalycium mihanovichii* can be used as suitable scions in grafting programme (Perumal *et al.,* 2018).

Histological studies

The results of the experiment showed with when grafting was done by using 'Shishiomaru (*Notocactus submammulosus* var. *pampeanus*) and rooted cuttings of 'Sankakuchu' (*Hylocereus trigonus*) as scions and stocks. Callus cells were observed in the graft region on 2 to 4 days after grafting and the procambial cells differentiated into vessel membranes, sieve tubes and cambial cells on 12th day after grafting by adopting close proximity (Shimomura and Fuzihara, 1977).

The following histological observations were observed when *Opuntia ficus- indica* is micro-grafted over *O. streptacantha, O. robusta, O. cochinera, O. leucotricha* and *O. ficus-indica* by using axillary buds as explants, development of necrotic layer, proliferation of callus at the graft interface, differentiation of new vascular cambium, restoration of new vascular tissue, restoration of continuity of external epidermal tissue at the union zone (Estrada-Luna *et al*., 2002).

It has been stated that the regulation of vascular development as follows: A. Formation of the longitudinal pattern of primary vascular strands; B. formation of the radial pattern of xylem and phloem within vascular strands; C. differentiation of specialized cell types from xylem and

phloem precursors and D. Cell proliferation and cell differentiation within the vascular cambium (Dengler, 2001).

CONCLUSION

The cacti genera suitable for the tropical conditions for the purpose of landscaping and grafting are *Hylocereus triangularis, Myrtillocactus geometrizans, Mammillaria beneckei, Hamatocactus setispinus, Ferocactus latispinus* and *Gymnocalycium mihanovichii*. The intergeneric graft compatibility was found to be good when scions like *Mammillaria beneckei* and *Echinopsis mamillosa* were grafted onto *Hylocereus triangularis* where as *Hamatocactus setispinus* and *Mammillaria beneckei* were found to be the suitable scions when *Myrtillocactus geometrizans* is used as rootstock. Reduced inter-generic graft compatibility was noticed when *Ferocactus latispinus* is used as scion, due to the presence of lignified stem which in turn may be used as a potential rootstock owing to the same reason.

In future, the following aspects may be given importance to enhance the potentiality of cacti in the human livelihood: to analyze the release pattern of CO_2 and O_2 from the cacti, standardization of media and climatic requirements for different types of cacti cultivation *etc.* In regard of future thrust in the field of grafting, biochemical analysis on phenolic content, enzyme assays, plant growth regulators synthesis which in turn enhances the graft success percentage.

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