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Genetic improvement of cauliflower

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Abstract: Cauliflower is an important winter season vegetable crop which belongs to the family *Brassicaceae* and is grown in many countries like India, China, Italy, Europe, America, etc. It isgrown for its highly suppressed 'prefloral fleshy apical meristem' branches called "curd." It is a cross-pollinated crop.There are different groups based on their characteristics. Multiple pollination mechanisms, e.g., self-incompatibility and male sterility, not only encourages cross-pollination but also found useful in the commercial hybrid seed production of the crop. As the main hindrance to the popularization of F1 hybrids for conventional agriculture is unavailability and high cost of hybrid seed. In cauliflower, F1 hybrids have been found been found bred for earliness, high early and total yield, better curd quality with respect to compactness and color, uniform maturity, resistance to insect pest, diseases and unfavorable weather conditions. Many studies have been done on the aspects of genetic improvement, resistance for biotic, abiotic stresses and on bio-technological aspects. Recently, breeding for organic agriculture has been considered with the main objectives of adaptation to many conditions and quality for the products. To enhancing biodiversity and to respect IFOAM Organic Principles, population varieties are preferred to F1 hybrid varieties.

Keywords: Cauliflower, Genetic improvement, resistance breeding, male sterility, self-incompatibility.

Introduction

Cauliflower (*Brassica oleracea* L. var. *botrytis* L. 2n = 2x = 18) is one of the most popular Brassica vegetable after cabbage. This is cultivated worldwide in different climatic conditions, ranging from temperate to tropics during most of cropping seasons and is available round the year in the market. The word cauliflower comes from Latin term caulis and floris, meaning stem or stalk and flower, respectively. Its worldwide total area and production is 23,73,818 ha and 68840531 metrictones, respectively during 2011 (http://faostat.fao.org/site/567/Desktop Default.aspx?PageID=567) while it occupied an area of 3,69,000 ha with production of 67,45,000 metric tones in India during the year 2011(NHB, 2011). It is grown for its white tender head or curd. The curd of cauliflower has been described as a pre-floral structure, which has the characteristics of both the vegetative and reproductive apices (David, 1978). The vegetative shoots follows the 5 to 8 phyllotaxy of leaves, but the leaf development reduced so that only bracts are formed. The lateral buds of the shoot meristem elongate and are much branched whose apices form the surface of the curd. The whole shoot system are much shortened and thicker and can give rise to the future inflorescence. So the present understanding is that, cauliflower curd is a prefloral fleshy apical meristem, which invariably precedes floral initiation compared to the closely related another *Brassica* vegetable broccoli (*Brassica oleracea L.* var. italica Plenck.), whose head are composed of flower buds. Cauliflower is generally used as cooked vegetable either singly or mixed with potato, carrot, and peas. In raw form, it is also mixed with green salad or its pieces are dipped into sauces. It is also used in the preparation of pickle or mixed pickle with other vegetables. Cauliflower is low in calories, but is a good source of ascorbic acid and contains substantial amount of protein, and nutrients like phosphorus, calcium, and iron. Apart from India and China, the other major producers of cauliflower are France, Italy, United Kingdom, United State of America, Spain, Poland, Germany, and Pakistan.

Origin and Evolutionary History

Brassica oleracea L. grows wild in primitive form in Atlantic coasts of Europe. It was eventually brought to

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east Mediterranean region where it became fully domesticated and started giving rise to wide range of cultivated forms. So like other cultivated forms of cabbage group, the cauliflower is also believed to be descendent of wild cabbage (*Brassica oleracea* var. sylvestris.), which is still found growing wild, in the coastal area of Mediterranean sea and western Europe. But recently, a polyphyllectic origin by incorporation of genes into the *Brassica oleracea* genome from different wild Mediterranean species was suggested (Gustafsson, 1979; Snogerup, 1980). This resulted in giving rise to wide range of Brassica oleracea forms and their adaptation. But again possibility of introgression found is very less.

Schulz (1919) suggested B. cretica. as the probable progenitor of cauliflower. The taxonomical studies suggested that the progenitor of Brassica oleracea exists in the 9 chromosomes wild B. oleracea kale (Snogerup, 1980). RFLP studies also revealed that a primitive cultivated Brassica oleracea might have evolved from wild B. oleracea (Song *et al.,* 1988 a & b; Figdore *et al.,* 1988). The accessions of B. oleracea could be divided in to three groups.

Thousand head kale and chinese kale; cabbage group (cabbage, collard, savoy cabbage, kohl rabi, Portugese cabbage) and broccoli (Marrow stem kale, broccoli, brussels sprouts, Jersey kale). Earlier studies by Crisp (1982) and Gray (1982) suggested that cauliflower originated from broccoli but above RFLP investigation showed that two cauliflower accessions phyllogenetically were more close to cabbage rather than broccoli group. A large divergence of cauliflower from other accessions suggested that it does not belong to either group. It is also possible that cauliflower have morphotype origin in cabbage group or may have independent origin from wild species such as Brassica cretica as suggested by Snogerup (1980).

According to Boswell (1949), it originated in the island of Cyprus, from where it moved to other areas like, Syria, Turkey, Egypt, Italy, Spain, and north western Europe. It was unknown in its present form before early mid age. Cauliflower might have originated gradually from the wild cabbage through mutation, human selection and adaptation and suppose to have been domesticated in the eastern Mediterranean region (Helm, 1963). According to Hyams (1971), cauliflower was first noticed, selected, and propagated in Syria.

The Herbalist, Dodens (1578) presented the first description and illustration of cauliflower. It was in cultivation in France around 16th century and was available in the markets in England as early as 1690. In the USA, it was first mentioned in 1806 but attained commercial status after 1920. It was introduced to India by Dr. Jemson, a botanist, at Kew garden London in 1822 and the Royal Agri-Horticultral Society, South Africa in 1824 (Swarup and Chatterjee, 1972). Seeds were imported from South Africa and England was also given to the growers in north India. In about 100 years (1822-1929), these growers through selections, though unconsciously evolved the present day Indian cauliflower with ability to grow under high temperature and humid conditions, with the ability to produce seeds in north Indian plains. It is likely that Cornish types has contributed most of the genes like long stalk, open growth habit, and yellowish, uneven, and strong flavored curds. Some of the leaf and curd characteristics were also contributed by 'Roscoff' 'Italian' and 'Northern' types. So the present day Indian (tropical) cauliflower is the result of introgression of all the above types. The Indian cauliflower has been recognised as a different type not only at national but at international level also by the earlier workers like Nieuwhof, 1969 (Netherland); Swarup and Chatterjee, 1972; Chatterjee and Swarup, 1972 . The Indian cauliflower has been further divided on the basis of temperature requirement for curd development and maturity as, (a) Early (20-27°C), (b) Mid (16-20°C), and (c) Mid-late (12-16°C) and under north Indian plains, the respective period for production are August end-mid November, Late November-mid December, and late December-mid January. Mid late maturity group is followed by annual temperate types, which includes Snowball, Erfurt or Alpha strains maturing in January-February at a mean temperature range of 10°C-16°C (Chatterjee 1993). So in India, only annual types are grown.

In addition to these two annual types, there are other developments in this crop, which took place independently in different regions of the world. They remained genetically isolated for a long period (except for the Italians or originals) and thus maintained their characteristic features. It would, therefore, be worthwhile to classify these broad groups so that a proper understanding and relationship of the present-day cultivars is possible. Swarup and Chatterjee (1972) classified these groups as shown in Table 1. Crisp (1982) has classified the cauliflowers according to their phylogeny in Table 2. However, Chatterjee (1993) recommended that further studies are required for separate grouping of the North European annual and Australian types.

Genetic Resources

With the adoption of improved modern cultivars, the genetic variability in most of the cole crops including cauliflower present in the form of land races, and the

primitive types are disappearing. Moreover, inadequate taxonomic knowledge of the wider variability found in this crop and efforts made to improve it by transferring desirable traits from distant botanical varieties (cabbage or kale) instead of close relative (broccoli) has also resulted in loosing the variability. Replacement of open-pollinated cultivars with narrow genetic based F1 hybrids has resulted in the genetic erosion of cauliflower and other cole crops. So, sincere efforts are needed to preserve the germplasm.

Germplasm conservation is encouraged by an international organization: IPGRI (International Plant Genetic Resources Institute). At the European level, ECP-GR (European Cooperative Program for Crop Genetic and Resources networks) have grouped 35 countries. For Brassica, information is centralized in the Wageningen University (The Netherlands) in a Center for Genetic Resources (CGR). The European Brassica collection is spread in several countries. A comprehensive base collection of cultivated Brassica oleracea including cauliflower has been established at Vegetable Gene Bank of Horticulture Research International (HRI), Wellesbourne, Warkwick, UK. The Institute voor de veredeling van Tuinbouwgewassen Wageningen, The Netherlands; and the Instituto del Germoplasm, Bari, Italy (Van der Meer *et al.,* 1984), in the INRA of Le Rheu, in France. In India, National Bureau of Plant Genetic Resources (NBPGR), New Delhi, has been assigned the duty of conserving the germplasm of all crops, including vegetables. Germplasm of tropical cauliflower types and that of temperate (Snowball) types are being maintained at Indian Agricultural ResearchInstitute, New Delhi and Dr. Y. S. Parmar University of Horticulture and Forestry, Solan (Himachal Pradesh), respectively. Large collection of cauliflower is also available with the United State Department of Agriculture, Plant Introduction Service.

Pollination Control Mechanisms

The flower structure of cauliflower is complete in nature but the crop is basically a cross-pollinated one. There are some varieties, which set seeds freely even in self-pollination conditions. There are two naturally occurring mechanisms for ensuring cross-pollination in a hermaphrodite species like cauliflower are self-incompatibility and male sterility. The use of both these systems is very useful in the commercial hybrid seed production (Singh, 2000).

Table 1. Classification of cauliflower (Swaroop and Chatterjee, 1972)

Cauliflower types	Country of origin	Probable period of first cultivation	Characters
Italians or Original	Mediterranean	16th Century	Plants short; leaves erect broad with rounded tips, bluish green; curds good not protected by leaves
Cornish	England	Early 19th Century	Plants vigorous; long stalked; leaves loosely arranged, broadly wavy; curds flat, irregular, loose, not protected, yellow, highly flavored
Northerns	England	19th Century	Leaves petiolate, broad, very wavy, serrated; curds good, well protected
Roscoff	France	19th Century	Plants short; leaves long erect, slightly wavy with pointed tip, midrib prominent, bluish green; curds white or creamy, hemispherical, well protected
Angers	France	19th Century	Leaves very wavy, serrated, greyish green; curds solid, white, well protected
Erfurt and Snowball	Germany and Netherlands	18th Century	Plants dwarf; leaves short, erect, glaucous green; curds solid, well protected
Indian cauliflower	India	Late 19th Century	Plants short, long stalked; leaves loosely arranged, broadly wavy; curds flat, somewhat loose, yellow to creamy, not protected and highly flavored.

Table 2. Classification of cauliflower (Crisp, 1982)

Group	Chief characteristics	Common types
Italian	Very diverse, include both annuals and biennials and curds with peculiar conformations and colors	Jezi, Naples (Autumn Giant), Romanesco, Flora Blanca
North-West European biennials	Derived within the last 300 years from Italian material	Old English, Walcheran, Roscoff, Angers, St. Malo
North European annuals	Developed in northern Europe for atleast 400 years. Origin unknown, perhaps Italian or Eastern Mediterranean	Lecerf, Alpha, Mechelse, Erfurt, Danish
Asian	Recombinants of European annuals and biennials developed within 250 years, adapted to tropics	Four maturity groups are recognized by Swarup and Chatterjee (1972)
Australian	Recombinants of European annuals and biennials and perhaps Italian stock, developed during the last 200 years	Not yet been categorized

Self-Incompatibility (SI)

Self-incompatibility is genetically controlled, physiological hindrance to self-fruitfulness or self-fertilization, and is probably the most important way to enforce out crossing. Selfing could be avoided by other factors like, embryo abortion, but self-incompatibility is prezygotic and prevents embryo formation. Self-incompatibility is, therefore, the prevention of fusion of fertile male and female gametes after self-pollination. Two types of incompatibility has been reported, gametophytic, and sporophytic. In the former system, the pollen-pistil interaction is genetically governed by the haploid genome of each pollen grain and the diploid genome of the pistil tissue, and in the latter system, by the genome of the somatic tissue (of the sporophyte) in which the pollen grains are formed. Members of Brassica family including cole crops posses homomorphic sporophytic self-incompatibility associated with trinucleate pollen and inhibition of pollen germination at stigma surface (Bateman,1955). In monofactorial sporophytic self-incompatibility, pollen from a compatible pollination adheres to the papillae of the stigma, imbibes, and then germinates. It was reported that cutinase enzyme digests the cuticle by its action (Linskens and Heinen, 1962) and then pollen tube grows into the papillae. The growth of pollen tube continues down the style to effect fertilization. With light microscopy, it appeared that the tube grow down between the cuticle and the cellulose-pectin layer of the papilla, but electron microscopy has shown that the tube actually grows down inside the cellulose-pectin layer (Kroh, 1964; Elleman *et al.,* 1988).

Inhibition of self-incompatible pollen takes place on the surface of the papilla (Christ, 1959) and it is accompanied by deposition of callose inside the papillae. There are two main reasons for the expression of self-incompatibility, (i) due to lack of adhesion, hydration and germination of the pollen grain, and (ii) the failure to penetrate the papillae.

Homomorphic incompatibility in both the systems is generally controlled by a series of alleles at a single locus S (Bateman, 1952). The structure of this locus is complex with at least 3 important genes described (Nasrallah 2000; Dickinson 2000): S locus glycoprotein (SLG), S locus receptor kinase (SRK) and S locus cysteine-rich (SCR). The 2 first ones are determinants of the SI specificity in stigma. SLG is a soluble cell-wall localized protein and SRK is a plasma-membrane anchored signaling receptor, the extra cellular domain of which shares similarity with SLG. SCR is the male determinant recently discovered by Nasrallah laboratory (Schopfer *et al.,* 1999). It is a small highly charged and polymorphic cysteine rich protein, exclusively expressed in anthers during pollens development. The allele forms of the locus are designated "haplotypes." They shows a tremendous variability which reflects a molecular divergence in the organization and sequence of the S-locus genes. More than 90 haplotypes had been described for the species Brassica oleracea (Hodgkins *et al.,* 1988; Ruffio-Chable *et al.,* 2001). Modifier genes are reported to influence self-incompatibility (Nasrallah and Wallace, 1968). Nasrallah et al. (1985) also reported the presence of glycoprotein, which inhibits germination of pollen tube of homozygous self-incompatible lines.

Thompson and Taylor (1966) reported that ancestral Brassica oleracea was highly self-incompatible. On this basis, it is but natural that the cole crops would be self-incompatible. In cauliflower, systematic studies on self-incompatibility was initiated by Watts (1963,1965b). He found higher level of self-incompatibility in biennial winter and autumn types and low in European summer types (snowball, alpha and erfurt). This was also confirmed by Nieuwhof (1974), Hoser-Krauze (1979) and many other workers. Chatterjee and Mukherjee (1965) found that medium duration strains of cauliflower were more compatible than long duration strains and further reported that fully self-compatible to self-incompatible forms occur. The distribution of S-haplotypes were performed by Ruffio-Chable et al. (1997), ten S-haplotypes were detected by immunochemical analysis. Half of the plants analyzed (126 belonged to 82 open pollinated populations, representing the variability of the group) possessed the same haplotype designated S15 in the Ockendon nomenclature. The self-compatibility of summer and autumn types were caused by the presence of the SC-haplotype which would have lost the kinase activity of SRK (Ruffio-Chable, personal communication). Annual Indian cauliflower and biennial winter cauliflower have stronger self-incompatibility mechanism. A detailed investigation in Indian cauliflower of self-incompatibility revealed that inbreds/lines of maturity group I have strongest self-incompatibility followed by maturity group II, group III showed weak self-incompatibility (Murugiah,1978; Vidyasagar, 1981; Chatterjee and Swarup,1984; Sharma *et al.,* 2001). Murugiah *et al.,* (1983) reported that among the identified self-incompatible alleles with varying degree of dominance, high ranked Sd Sd and Sv Sv alleles retained their incompatibility throughout flowering period whereas mid-ranked SmSm and low ranked SaSa lost it gradually in Indian cauliflower having homozygous alleles. But loss in low ranked was slow than mid-ranked lines.

The dominance/independence relationship of the S-alleles in the pollen and pistil may differ. In a cross involving

S1S3 . S1S2 (male) as demonstrated by Frankel and Galun (1977) showed complex reaction of self-incompatible system as shown in Table 3. Being a natural method, self-incompatibility has no adverse side effects, such as those often found with cytoplasmic or chemically induced sterility. However, it is often less than perfect. Although the possibility of using self-incompatibility to produce hybrids was suggested over 70 years ago (Pearson 1932), it was not until 1950 that they first appeared in Japan, and in 1954 in the USA (Wallace, 1979). However, in the recent years, use of self-incompatible lines has become a standard practice for the production of commercial hybrid seed in several Brassica vegetable crops.

One of the most important aspects of self-incompatibility is that in this mechanism, pollen and nectar production are unaltered. This may not matter much with wind-pollinated plants, but with insect-pollination, it is very important. Some insects, especially honeybees are highly discriminatory when foraging amongst flowers. Faulkner (1971) suggested that only slight differences in flower color or UV reflectance may cause such behavior. Butler (1971) showed that bees were first attracted by color, but were unlikely to investigate a flower further if unable to sense any perfume. It is not likely, therefore, that bees will pay much attention to male-sterile flowers without nectaries. This is probably the reason why self-incompatibility has become more important in the production of hybrids in insect-pollinated crops, and this is particularly so in the case of cauliflower.

Table 3. Sporophytic self-incompatibility system in cauliflower; S_1S_3 X S_1S_2 (male)

Pollen reaction	Pistil reaction	Compatibility
Independent	Independent	Incompatible
S1 dominant to S2	Independent	Incompatible
S2 dominant to S1	Independent	Compatible
Independent S1	dominant to S3	Incompatible
Independent S3	dominant to S1	Compatible
S1 dominant to S2	S1 dominant to S3	Incompatible
S1 dominant to S2	S3 dominant to S1	Compatible
S2 dominant to S1	S1 dominant to S3	Compatible
S2 dominant to S1	S3 dominant to S1	Compatible

Male Sterility

Male sterility has also been reported in cauliflower. It is of two types, i.e., genic and cytoplasmic.

Genic Male Sterility

Male sterility in cole crops are mainly recessive character. A single recessive ms gene mutated from male fertile Ms gene has been reported in cauliflower by Nieuwhof (1961), Borchers (1966), Nieuwhof (1968), and Ahluwalia *et al.,* (1977), and was designated as ms-4 and ms-C. Van der Meer (1985) reported, male sterility under the control of duplicate dominant genes with cumulative effect. Dominant male sterility have been described in cauliflower (Ruffio-Chable, 1997). This has some possible practical value in hybrid seed production programs, because of inadequate and unreliable nature of self-incompatibility system in some of the cauliflowers. This sterility can be responsive to temperature and humidity.

Cytoplasmic Male Sterility (CMS)

Cytoplasmic male sterility is not apparently found in cauliflower or other cole crops but has been introduced from several other sources. Cytoplasmic male sterility has been reported in an identified cultivar of Japanese radish by Ogura (1968) and was introduced by transferring to Brassica oleracea genomes through repeated back cross with broccoli (Bannerot *et al.,* 1974 and Mc Collum,1981). Later Dickson (1975) and Hoser-Krauze (1987) transferred it from broccoli to cauliflower. The Ogura type cytoplasmic male sterility was transferred into heat tolerant Indian cauliflower from kale and broccoli through repeated back crosses, four lines, MS-91, MS-51, MS-11, and MS-110 from the former and five lines, MS-01, MS-04, MS-05, MS-09, and MS-10 from the later were developed, which are now being used in heterosis studies by Sharma (2003). Pearson (1972) crossed Brassica oleracea (cabbage) with Brassica nigra and developed male sterile lines. Chiang and Crete (1987) introduced male sterility from Brassica napus into cabbage and later from cabbage to cauliflower (Crisp and Tapsell, 1993).

Both genic as well as cytoplasmic male sterility have been associated with physiological problems. Some forms of genetic male sterility are temperature sensitive and result in to self-pollination when used for F1 seed production Nieuwhof (1968). Pearson (1972) type of cytoplasmic male sterility functional nectaries are not developed making them unsuitable for commercial hybrid seed production (Pelletier *et al.,* 1983). Both the Ogura and McCollum type of cytoplasmic male sterile plants or their hybrids when grown at low temperature less than 12°C, show chlorosis and loss of vigor at their early stage of growth (Dickson, 1985; Hoser Krauze, 1989). High regeneration capacity from cultured mesophyll cells of a cauliflower line having Ogura system was reported by Jourdan *et al.,* (1985). This was useful step in the possible production of cytoplasmic mutants, transgenics or recombinants superior male sterile genotypes. Non-chlorotic male sterile lines, using cybrids followed by protoplast fusion between sterile and normal genotypes have also been developed in cauliflower and other cole crops. Male sterile cybrids

with normal photosynthesis and improved nectar secretion were obtained through chloroplasts exchange and mitochondrial recombination. The Ogura CMS system was first improved in B. napus in 1983, and then in B. oleracea in 1989 (Delourme and Budar, 1999).

University of Delhi, South Campus already awarded patent on "Development of cytoplasmic male sterile *Brassica oleracea* plants and the method of producing such plants". They used "*Oxy"* sterile cytoplasm from *B. oxyrrhina* to create alloplasmic *B. oleracea* through protoplast fusion (WO/2004/098271). Seminis Vegetable Seeds, Inc. also obtained patent on "Cytoplasmic male sterile *Brassica oleracea* plants which contain the polima CMS cytoplasm and are male sterile at high and low temperatures" through protoplast fusion and conventional back-crossing methods (US Patent 6046383, April 4, 2000).

By genetic engineering, it has become possible to develop female parents having barnase genes, which inhibit the activity of pollen producing tapetum cells and make them male sterile. The introduction of barstar genes in the male parent, which restore fertility in hybrid seed by inactivating the functioning of barnase genes responsible for disruption of pollen development in female parent (Reynaerts *et al.,* 1993).

Crop Improvement

Before the start of any crop improvement programme, the objectives should be clear so the strategic methodology can be adopted to achieve the targeted results. In cauliflower, besides yield, special emphasis is needed to improve its quality characters, including nutritiveness and insect-pest and disease resistance. The improvement in yield can be achieved through its component characters, which have direct or indirect effects. The important components are, curd size, weight, depth, compactness and color of the curd besides their uniformity in size and maturity. The plant type including frame, stem length, harvest index and resistance to common biotic and abiotic stresses also need attention of the breeder. Recently some intra-crosses were attempted between tropical and temperate types to transfer desirable traits in cauliflower. Honma and Cash (1986) reported three varieties, viz., Supreme, Beta-White, and One-up are developed by intra-crosses. While Supreme and Beta-White originated from the Pua-kea (tropical) and with Self-Blanche Snowball (temperate summer), the cultivar One-up was derived from a series of crosses involving Snowball M1, Pua-kea, vans Osena, February L, Early Fuji, and Self-Blanche. However, commercial possibilities of such varieties have to be seen. Gill *et al.,* (1987) isolated a pure line, called Pusa Himjyoti, having retentive white curd from MGS 2-4 for July to October cultivation in hilly areas of Himachal Pradesh, India. Sel.12, a black rot resistant line has been developed, using a black rot resistant tropical type line SN-445 and Pusa Snowball-1 at IARI, Katrain, India (Gill *et al.,* 1983).

A lot of work has been reported on the genetics of qualitative and quantitative traits, genetic advance, heritability and combining ability in cauliflower as shown in Table 4. The inheritance of qualitative characters was studied in detail in Indian cauliflower by Ahluwalia *et al.,* (1977) and gene symbols for different traits were assigned as: stalk length-long St, short st; leaf apex-round Ro, pointed ro; habit-errect E, branching e; curd color-yellow Y, white y; flower stalk length-long F, short f; flower stalk color-variegated V, green v; siliqua length-long SL, short sl (Ahluwalia *et al.,* 1977).

Combining ability was studied to select the parents for hybridization and good cross-combinations for production of hybrids. The inbred 103 exhibited the best gca for all characters and cross-combination 105 X108 showed the maximum sca for yield potential in early Indian cauliflower (Lal *et al.,* 1977). Further, Lal et al. (1978) found that parent 308, 303, 302 had high gca for curd weight and curd size index in mid-Indian cauliflower. In Snowball group, Lawyana was the best general combiner for curd weight, curd size, and leaf size. Sel.12 and Pyramis were best general combiners for early maturity and gross weight, respectively (Sharma *et al.,* 1988). Line IHR3, IHR4, IHR9 and IHR36 were good combiners for most of the characters. The selection of parents on the basis of per se performance and general combining ability was effective (Pandey and Naik, 1986), days to curd initiation, curd weight, number of leaves and plant height and diameter, and curd weight highly influenced the plant weight (Pandey and Naik, 1985). According to Gangopadhayay *et al.,* (1997), in early cauliflower, self-incompatible lines cc-13 and vv-(351) were found to be the best general combiners for earliness, curd color, compactness, and yield contributing characters, respectively.

Breeding/Selection Methods

Crop breeding is a breeder's activity, picking up useful characteristics and putting up them together to develop a variety having desirable traits. Population improvement method has been commonly followed for the improvement of cole crops. In India, mass selection has been widely used for the improvement of cauliflower. Though this method is useful for the improvement of simply inherited traits, but is not much effective in case of polygenic characters. Moreover, this method is time

consuming and hence not found as an ideal option. Based on progeny evaluation, modifications like, mass pedigree method and family selection method have proved better than mass selection (Nieuwhof, 1959).

The choice between these methods depends also on the populations, according to their level of homogeneity due to the system of self-incompatibility. Recurrent selection method in cole crops have been found as a better option for the improvement of quantitative characters especially those, which are under the control of additive gene action. This method has been found effective for the improvement of curd compactness, yield and other economic characters in cauliflower. Significant improvement after one generation of recurrent selection in the yield (18-47%) and diameter, depth and weight of curd over the original material was reported by Tapsell (1989). Inbreds, thus developed have been used in the breeding of hybrids, synthetics and open pollinated varieties or in intervarietial hybridization program. In the recent past, a variety, 'Pusa Sharad' in mid-maturity group of Indian cauliflower has been developed using recurrent selection method (Sharma *et al.,* 1999). The

Table 4. The genetics of quantitative characters of cauliflower*

Character	Nature of gene action	References
Curd weight	Dominance and epistasis	(Swarup and Pal, 1966)
	Pronounced over dominance and epistasis	(Singh et al., 1975)
	Additive and dominance gene action	(Singh et al., 1976a; Jyoti and Vashistha, 1986; Gangopadhayay et al. 1997; Sharma et al., 1988)
Curd to plant ratio	Partial dominance	(Kale et al., 1979)
Curd diameter	Predominance of dominance gene action	(Lal et al., 1979)
Curd size index	Pronounced over dominance and epistasis	(Singh et al., 1975)
	Dominance and epistasis	(Swarup and Pal, 1966; Lal et al.,1979)
	Additive dominant gene action	(Singh et al.,1976; Sharma et al., 1988)
	Partial dominance.	(Kale et al., 1979)
Curd angle	Pronounced additive gene action	(Lal et al., 1979)
	Additive and dominant gene action	(Dadlani, 1977; Chand, 1980)
Curd compactness	Polygenic.	(Nieuwhof and Garretson, 1961)
	Dominance and additive gene action	(Lal et al., 1979)
	Additive	(Vashistha et al., 1985)
Maturity Earliness	Partially dominant gene action	(Watts, 1964)
	Dominance and epistasis	(Swarup and Pal, 1966)
	Predominance of additive gene action	(Singh et al., 1975; 1976b; Lal et al., 1979; Mahajan et al., 1996; Gangopadhayay et al., 1997),
	Additive gene action	(Kale et al., 1979)
(ii) Lateness	Additive and dominant gene action	(Sandhu and Singh, 1977; Sharma et al., 1988)
	Recessive polygenes	(Watts, 1963)

*Adopted from Chatterjee (1993)

cross combinations involving inbreds, with low inbreeding depression and high heterotic residual effects due to additive gene action, which shows better response to selection, are used in the breeding of composite varieties.

Back cross method has been commonly followed to transfer resistance from donor to recurrent parent. This method has been followed to develop 'Pusa shubhra' a cauliflower variety resistant to black rot, curd blight and riceyness (Singh *et al.,* 1993). However, Kalloo (1988) has reported that family breeding method was found to be more important for the improvement of cauliflower and other cole crops. In this method, seeds of the selected plants on the basis of progeny testing are used to develop synthetics. Similarly disruptive selection method to break tight linkage has been recommended for the improvement of Brassica vegetables (Kalloo, 1996). In this method, only extreme type of population is selected and intermediate one is discarded.

Pusa Early Synthetic and Pusa Synthetic cauliflower varieties were developed by synthesizing 6 and 7 parents, respectively, and were released in India for commercial cultivation (Singh *et al.,* 1997 and Gill, 1993). Development of synthetic variety is based on the exploitation of additive genetic variance.

The desirable inbred lines to be synthesized are selected after testing their combining ability. To test general combining ability, diallel cross or top cross or poly cross method may be used. Two to seven or more such lines are selected for developing synthetic varieties. The advantage of synthetic varieties are many fold: (i) its seeds can be produced by the farmer himself from his own crop like any other open pollinated variety, (ii) it is particularly useful in the places where commercial seed industry is not well developed and mechanism (floral biology) is not available for commercial seed production, (iii) it serves as a reservoir of germplasm, and (iv) it adapts better to varying growing conditions unlike F1 hybrids.

Heterosis Breeding

In vegetable crops, Tamassy (1973) described heterosis in to three types, i.e., somatic, reproductive and additive, manifested in terms of greater vegetative growth, seed production, and tolerance or resistance to adversities, respectively. In cauliflower heterosis was first reported by Jones (1932). However, Haigh (1962) and Nieuwhof fail to found appreciable amount of heterosis in European summer cauliflower (Snowball, Erfurt or Alpha type) which may be due to their narrow genetic base. Later, Watts (1965a) observed sufficient heterosis for earliness

and curd size. Swarup and Pal (1966) and Pal and Swarup (1966) found appreciable heterosis in snowball types for earliness (5-7 days), curd weight (24.5-28.2%), curd size index (22.54-34.85%) over better parent. In different maturity groups of Indian cauliflower, appreciable heterosis for economical characters were reported by many workers. Kumaran (1971) made a study of three maturity groups of Indian cauliflower and recorded appreciable amount of heterosis for curd weight, plot yield, curd size index, maturity of curd, stalk length and leaf size index. Maximum percentage of heterosis observed by him was 22.85, 12.07, 24.64, 21.53, 49.76, and 32.46 percent, respectively. Swarup and Chatterjee (1972, 1974) investigated heterosis in Indian cauliflower and reported better manifestation of it in first maturity group, compared to other groups. Similarly, maturity group second was superior over maturity group third. In this respect, they recorded heterosis of 41.23, 16.00, and 23.41 percent for yield, curd size and curd weight, respectively in maturity group second, while in maturity group third, it was 22.22 and 27.00 percent for curd size and curd weight, respectively. Appreciable amount of heterosis was reported in Indian cauliflower for different characters in different groups (Deshpande, 1975; Singh *et al.,* 1975; and Sandhu *et al.,* 1977). Verma (1979) using male sterile lines as female parent, observed sufficient heterosis over better parent. The observed heterosis was 93.3, 91.1, 55.6, 44.4, 20.0, and 2.2 for curd weight, plant height, curd size index, curd to plant ratio, early maturity and number of leaves, respectively. Hoser-Krauze *et al.,* (1982) reported heterosis for earliness, curd diameter, curd weight and quality in 2 and 3 way reciprocal F1 hybrids, which were made using three self-incompatible Indian cauliflower and three temperate self-incompatible lines. Pandey and Naik (1985) studied heterosis in hybrids of different sub-species of Brassica. Brazilian broccoli line 137 was crossed with two cauliflower lines 138 and 149 from the USA and 10 Indian cauliflower cultivars. Heterosis for tallness, number of leaves and leaf area index was positive, except for the cross, Superfine Maghi X137 which showed negative heterosis for leaf number. They also concluded that lines with high heterosis can be selected at the seedling stage itself. Gangopadhayay *et al.,* (1997) using four self-incompatible lines in maturity group first as female parent with 11 male parents in the early and 7 in mid group reported 31.2, 25.3, 34.5, 25.0, 16.6, 25.7, 53.5, 87.0, 49.5, 71.8 and 82.3% heterosis in early and 19.4, 17.7, 39.3, 42.9, 13.5, 20.8, 38.3, 20.6, 49.6, 51.9, and 63.2% heterosis in mid-group for days to maturity, days to 50% maturity, curd compactness, color, number of leaves, curd diameter, curd depth, curd size index, gross weight, marketable weight, and curd weight, respectively.

Breeding for Biotic Resistance

Cauliflower being a delicate crop is more prone to insect-pests and diseases. All the cole crops have common insect-pests and diseases problems. With the evolution of large number of cultivars for different seasons/ climates, cauliflower and other cole crops are being grown round the year. All this has resulted in the continuous built-up of disease inoculum and insect population. The common diseases of cauliflower are, black rot, bacterial soft rot, sclerotinia rot, downy mildew, dark black spot (Alternaria spps.), cabbage yellows, club root, and wire stem. The important insect pest are diamond back moth, cabbage butterfly caterpillar, aphids, cabbage head borer, cutworm, and Bihar hairy caterpillar (Spilosoma oblique). Management of these diseases and pests using chemical pesticides is not only cumbersome and costly but also health hazardous. So it is imperative to have resistant varieties for which identified resistant sources and knowledge of genetics of resistance for a particular disease and pest is a pre-requisite. The related information for economically important biotic stress of cauliflower is discussed here.

Diseases

Downy Mildew: It is caused by an obligate parasite, Peronospora parasitica which can infect the crop at any stage of growth. It is systemic in nature and infection observed at seedling stage can reappear at curd and marketing stage (Crute and Gordon, 1987). In cauliflower, Igloo, snowball Y, Dok Elgon, and RS355 (Kontaxis *et al.,* 1979); BR-2,CC and 3-5-1-1; EC177283, Ec191150,

EC191157, Kibigiant, Merogiant, EC191140, EC191190, EC191179, and Noveimbrina (Singh *et al.,* 1987; Mahajan *et al.,* 1991); MGS2-3,1-6-1-4, 1-6-1-2 and 12C (Chatterjee, 1993); KT-9 (Sharma *et al.,* 1991); Early Winter Adam's White Head (Sharma *et al.,* 1995); CC-13, KT-8, XX, 3-5-1-1, CC (Trivedi *et al.,* 2000); Perfection, K1079, K102, 9311 F1 and 9306 F1 (Jensen et al., 1999); Kunwari-7, Kunwari-8, Kunwari-4 and First Early Luxmi (Pandey et al., 2001) were reported resistant to moderately resistant. Pusa Hybrid-2 (Singh *et al.,* 1994) of Indian cauliflower and Pusa snowball K-25 (unpublished) of snowball type having resistant to downy mildew were released for commercial cultivation in India. Resistance to downy mildew has been ascribed to a single gene with dominant effect

(Sharma *et al.,* 1991; Mahajan *et al.,* 1995; Jensen *et al.,* 1999), single gene with recessive effects (Hoser-Krauze *et al.,* 1984; Mahajan *et al.,* 1995) or several genes (Hoser-Krauze *et al.,* 1995).

Sclerotinia Rot. The disease is caused by Sclerotinia sclerotiorum. It has a very wide host range and can infect most of dicot crops, but is more severe in the seed crop of cauliflower, though, it may attack the crop at an early stage of its growth also. Moderately resistance to this pathogen was reported in EC131592, Janavon, EC103576, Kn-81, Early Winter Adam's White Head, EC162587, EC177283 (Kapoor, 1986; Baswana *et al.,* 1991; Singh and Kalda, 1995; Sharma *et al.,* 1995 and Sharma *et al.,* 1997). Resistance is polygenically controlled and recessive in nature (Baswana *et al.,* 1993; Sharma *et al.,* 1997). Pusa Snowball K-25 developed by using EC103576 as resistant source with Pusa Snowball-1, has recently been released for commercial cultivation, which possess field resistance against this disease.

Black Rot. The disease is caused by a bacterium Xanthomonas campestris (Pam) Dawson. Yellowing of leaves starts from leaf margin and extend in the direction of the midrib, followed by blackening of veins (vascular bundles). Cauliflower lines reported resistant sources are Sn 445, Pua kea and MGS2-3 (Sharma *et al.,* 1972); RBS-1, EC162587 and Lawyana (Sharma *et al.,* 1995); Sel-12 (Gill *et al.,* 1983); Sel-6-1-2-1 and Sel-1-6-1-4 (Chatterjee,1993); Sakata 6, Takki's February, Nazarki Early, Henderson's Y 76 and Henderson's Y 77 (Moffett *et al.,* 1976); Avans and Igloory (Dua *et al.,* 1978).

Some of the above sources have been used in the development of resistant varieties. Pusa Shubhra was developed, using Pua kea and MGS2-3 lines and recommended for commercial cultivation (Singh *et al.,* 1993). The resistance was dominant and governed by polygenes and the dominance components of variation were more pronounced than additive (Sharma *et al.,* 1972). But Jamwal and Sharma (1986) reported that dominant resistance is governed by a single gene.

Alternaria Black Spot. In cole crops, the black leaf spot disease is caused by Alternaria brassicae or Alternaria brassicicola. Brown to black, small to elongated spots appears on leaves, stems of older leaves. In younger plants, it may cause symptoms like Rhizoctonia solani. When the fungus infects the curd, specially in case of seed crop, the disease is called as inflorescence blight. Resistance was found in Indian cauliflower lines, MGS2-3, Pua kea and 246-4 (Sharma *et al.,* 1975); 23-7, 466, MS98, 210-21, Sel-9, 443-7 (Trivedi *et al.,* 2000); IIHR142 and IIHR217 (Pandey *et al.,* 1995); and Snowball KT-9 (Sharma *et al.,* 1991). Resistance to curd blight is dominant in nature, pollygenically inherited and in general additive effects were found more pronounced than dominant one (Sharma *et al.,* 1975). Pusa Shubhra having resistance to curd blight has been released for commercial cultivation (Singh *et al.,* 1993). Both additive and dominant gene action played a role in resistance but partial dominance is more important (King and Dickson, 1994). No linkage was found by them between leaf color (red or green) and leaf spot resistance.

Club Root. The disease is caused by Plasmodiophora brassicae which has as many as nine races. Gall formation takes place on lateral roots and gives the shape of spindle. Walker and Larson (1960) reported resistance is recessive in nature and polygenically inherited. Gallegly (1956) also supported polygenic theory. Crisp *et al.,* (1989) found differences for disease severity between 845 varieties of cauliflower and broccoli, were mainly attributed to selection pressure within locality. More recently, two lines of a resistant kale were selected for their highly resistance against a large range of pathotypes of the pathogen. These lines presented a sufficient level of resistance to be directly useful in the breeding program in order to develop cauliflower and broccoli hybrids resisant to clubroot (Mazanares-Dauleux *et al.,* 2000).

Yellows. It is caused by Fusarium oxysporum f. conglutinans. Vascular tissues become yellow to brown, causing wilting of plants. It has two races type A and type B, the resistance in former is inherited monogenically, and in later polygenically and is dominant in nature as reported in cabbage by Walker (1930).

Pests

Cauliflower is infested by a large number of insect-pests. Many workers have reported varietal differences in susceptibility to various pests in cauliflower under field conditions. Resistance to lepidopterous pests in cauliflower and cabbage is attributed to non-preference in conjunction with either tolerance or antibiosis (Shelton *et al.,* 1988). A glossy leaved cauliflower PI234599 was reported to be resistant to lepidopterous pests, diamond back moth (Plutella xylostella), cabbage looper (Trichoplusia), imported cabbage worm (Artogeiso rapae) by Dickson and Eckenrode (1980). Genetic resistance to lepidopterous pests has been quantitative with additive dominance and relatively low heritability, ranging from 22% to 47%. Ellis *et al.,* (1986) found the PI 234599 resistant to other leaf pests (Mamestra brassicae and Evergestis forficorlis) but more succeptible to flea beetle, and in general, red leaved

varieties are found more resistant to these pests than normal green leaved ones.

The glossiness character of leaves though as such is not undesirable character, but associated with small sized plants, having poor curd quality. Recombinants has also not yielded encouraging results in breeding program. Resistance to cabbage head borer (*Hellula undalis* L. Fabricius) has been reported in cauliflower, ES-97, ES-96, Katiki (J.B), KW-5, KW-8, KW-10, Kunwari (RB), Kathmandu Local, Early Patna, EMS-30 and PSK-16 (Lal *et al.,* 1991). Lal *et al.,* (1994) also found resistance under field conditions in Indian cauliflower F1 hybrids like aa X ES102, aa X Katiki (JB), aa X First Early, aa X First Crop, aa X Sel.100, aa X Sel.41 and aa X 824 have resistance to Bihar hairy caterpillar (*Spilosoma oblique* Walker). Aphids causes major losses to cole crops. The aphid species responsible for economic losses in cauliflower and other cole crops are cabbage aphid (*Brevicoryne brassicae*), green peach aphid (*Myzus persicae*) and turnip aphid (*Lipaphis erysimi*). Resistance to cabbage aphid has been reported in NY 13816, NY101181, NYIr9602, and NYIR 9605 but work on cauliflower is very scanty. Natural occurring compounds like, glucosinolates, pipecolic acid and ß-nitroprionic acid in the tissues of Brassicaplants are responsible for resistance to cabbage looper and imported cabbage worm. Breeding resistant varieties in cauliflower and other cole crops for most of pests and some diseases still remains elusive because hardly any resistant source with desirable degree of resistance is available in the germplasm. So, biotechnological tool like genetic engineering offers a safe and long lasting solution. Cauliflower can be conveniently transformed by using Agrobacterium provided suitable genes are available. Introduction of genes coding for Bacillus thuringiensis (Bt) insecticidal crystal protein; cowpea and soybean trypsin inhibitors and cytokinin biosynthesis enzymes are known to provide substantial protection against the insects in the crop (Kumar and Sharma, 1997) (Table 5).

These Bt genes in genetically transferred plants have proved quite successful. Similarly, there are some plant enzymes, which solublize fungal cell walls and cause membrane damage. Some of the antifungal proteins listed in Table 6 for different fungi responsible to cause disease in cauliflower and other crops (Kumar and Sharma, 1997). Transgenic plants expressing genes coding for such proteins could be developed for developing resistant varieties.

Biotechnology and Its Application

Recent development in the area of plant biotechnology can be used as an effective tool in speeding up and providing precision to the process of conventional breeding, creating genetic variability through harvesting genes from wild and relative species, and evolving novel genotypes through recombinant DNA (genetic engineering) technology. Following biotechnological tools have been employed in cauliflower.

Table 5. Important insect-pest of vegetable brassicas and potential gene that confer insect resistance

Common name	Scientific name	Useful genes
Diamondback moth	*Plutela xylostella*	Cry 1A class
Cabbage butterfly	*Pieris brassicae*	Cry 1A class
Stem-borer	*Hellula undalis*	Cry 1A class
Hairy caterpillar	*Spilosoma oblique*	Cry 1A class
Cut-worm	*Agrotis ipsilon*	Cry 1A class
Aphids	*Brevicorne brassicae*	Snowdrop lectin
	Myzus persicae	Snowdrop lectin
	Lipaphis erysimi	
Thrips	*Caliothrips indicus*	Cry 2A
	Thrips tabaci	
Leaf-minor	*Phytomyza hartiocola*	

Table 6. Important fungal diseases of vegetable brassicas and useful genes that confer fungal resistance

Disease	Causative fungus	Useful genes
Damping off	*Pythium spp.*	Permantis
Downy mildew	*Peronospora parasitica*	Chitinase
Wire-stem	*Rhizoctonia solani*	Glucanase
Leaf-spot	*Alternaria brassicae/ Alternaria brassicicola*	Thionin
Cabbage yellows	*Fusarium oxysporum*	RIP
White rust	*Albugo candida*	Osmotin
Black-rot	*Xanthomonas campestris*	Chitinase
Soft-rot	*Erwinia carotovora*	Chitinase

Tissue Culture/Micropropagation

Mass multiplication of plants, using tissue culture technique, is more commonly used in cauliflower and other cole crops, especially in case of self-incompatible and male sterile lines. Explants like leaf, peduncle, pedicel, anther, meristem, tip and segments of root, stump and stem can be used for in vitro multiplication. For seed production, industrial production of in vitro hybrid parent plants has been performed by curd explants. Thousands plants can be obtained by this way (Kieffer *et al.,* 1994). Production of disease resistant plants in vitro have been discussed in detail by Ross (1980).

Anther and Microspore Cultures and Production of Dihaploids

Anther and microspore cultures are more suitable to develop homozygous lines in cauliflower and other Brassica oleracea crops. The anther culture is quick, which decrease the incidence of aneuploidy. However,

the number of embryoides obtained from anther culture depends upon the factors like, sucrose concentration, growth hormone's concentrations, pretreatment with high temperature and developmental stage of donor anther (Lillo and Hansen, 1987). Considerable differences occur among cauliflower genotypes in their efficiency to produce embryoides (Ockendon, 1988).

Uninucleate stage has been found the best for microspore or anther culture in most of Brassica species (Simmonds *et al.,* 1989). The plants obtained from anther culture may be haploid, diploid, tetraploid and rarely aneuploids. Counting the chromosome numbers of nuclear cells is most reliable way to confirm ploidy. Ockendon (1988) obtained very few haploids, and mostly diploid and tetraploid regenerants. These results were confirmed by Boucault *et al.,* (1991).

For haploid embroids, the apices of such plants are treated with 0.05 percent colchicine at an early stage of growth to double their chromosome. These dihaploid (DH) plants, after selfing, form homozygous uniform population. The natural diploid plants in anther cultured may have arised spontaneously as doubled haploid, which may be used in breeding homozygous lines, depending upon their behavior after selfing.

Somaclonal Variation

Decapitation of cauliflower does not follow development of axillary branches as axillary buds are not commonly produced/developed in this crop. However, sometimes branches may develop from leaf scars near the base of stem or exposed roots. These shoots shows abnormality for morphological as well as reproductive characters, which may be analogous to somaclonal variation as recovered from cell culture or callus culture in many crops (Crisp and Tapsell, 1993).

Somatic Hybridization

Protoplast isolated from root tips, cotyledons, leaves and hypocotyls have been induced to form callus in Brassica species. The success of callus to differentiate into somatic embryoides depends upon a number of environmental factors and medium components. In cauliflower, Jourdan *et al.,* (1990) developed an improved procedure for protoplast culture. Jourdan and Earle (1989) found that genotype played a critical role in determining the success rate of leaf protoplast culture in five cruciferous species including Brassica oleracea. Protoplast fusion is a potential tool to create cybrids through hybridizing divergent, texas, which otherwise are non-crossable. The cybrid contains organelles from both the parents to create genetic variability. This also helps in bringing together cytoplasmic traits, which is rather impossible through conventional breeding. Schenck and Robbeln (1982) synthesized Brassica napus through protoplast fusion of Brassica campestris with B. oleracea for the first time. However, later, it was reproduced by many workers. Jourdan *et al.,* (1989) developed cybrid plants through protoplast fusion of cauliflower and a variety of Brassica napus which have cytoplasmic derived resistant to atrazine. These cybrids showed no segregation in population on selfing, which confirmed the cytoplasmic inheritance transfer of this character in the offspring. Protoplast fusion has also been used for the effective transfer of Ogura type of cytoplasmic male sterility traits from radish to cauliflower and other cole crops to devoid them from associated physiological abnormalities (Kagami *et al.,* 1990).

Embryo Rescue

The embryo culture technique in vitro has been used to rescue non-variable interspecific hybrids in Brassica species (Ayotte *et al.,* 1987). Embryos of the cross of Brassica oleracea and Brassica napus were rescued by them between 11-17 days after pollination. Later, they transferred triazine-resistance characters from Brassica napus into cauliflower, cabbage, broccoli, and kale. Usually it is difficult to obtain F1 hybrid seeds by crossing *Brassica oleracea* with *B. campestris* but by using embryo rescue techniques, Inomata (1977) got success.

Molecular Breeding

It is now possible to select desirable genotypes from a segregating population with very high degree of precision and predictability by using biotechnological tools. Restriction Fragment Length Polymorphism (RFLP) and Random Amplified Polymorphic DNA (RAPD) are the most fundamental tools, which have raised high hopes among the breeders. A detailed analysis of Brassica species has been carried out by many researchers using RFLP markers. A series of monosomic Brassica oleracea chromosome addition lines were established in genetic background of B. campestris, using RFLP markers, plant morphology and isozymes and these gene markers were mapped on some Brassica oleracea synteny groups (McGrath *et al.,* 1990). A detailed RFLP based genetic maps constructed in Brassica oleracea (Landry *et al.,* 1992), have also been used to study the origin of Brassica oleracea and its relationship with other Brassica species (Song *et al.,* 1988, 1990) and among Brassica oleracea varieties (Osborn *et al.,* 1989). RAPD has been used to identify club root resistant plants in segregating population (Grandclément *et al.,* 1996). Molecular Assisted Selection (MAS) is still in infancy stage in India in cole crops. However, some work is in progress to develop

tropical cabbage lines having resistance/tolerance to a serious pest diamond back moth (Unpublished) using transformation technique.

Breeding for Organic farming/cultivation

In Europe, the lack of organic seed and varieties came into sharp focus when European Union regulation required their use for organic agriculture in 2004. Conventional breeding strategies, which develop varieties with broad adaptation by means of inputs, do not fit the needs of organic agriculture, which requires specific adaptation to the environment. Moreover, several current breeding methods do not respect ideas of the organic principles that are at the foundation of organic agricultural ethics which are promoting by IFOAM (International Federation of Organic movements) (IFOAM, 2005a).

Organic farming is based on the natural process. The performance of organic agriculture will be improved by the cultivation of adapted varieties while no inputs could modify the environment. The diversity within the crop appears to be a means of enhancing biodiversity in the field and favoring health of the plants. Thus, population varieties are preferred, as they are able to evolve in time. The private sector of plant breeding finds it economically difficult to satisfy the demand from Organic Agriculture, characterized by a great diversity of quality and adaptability criteria, and by breeding methods which must respect the natural characteristics of species (Lammerts van Bueren *et al.,* 2002), and the integrity of the organisms (Lammerts van Bueren *et al.,* 2003). IFOAM has determined the breeding methods which are compatible with organic breeding (IFOAM, 2005b).

For cauliflowers, an answer has been proposed in France where organic farmers organized themselves the selection of the varieties which they need. This organization is named: "Participatory Plant Breeding" (PPB). The notion of PPB is relatively recent. Most of the experiences have begun within the last decade and showed the various strategies for technical and organizational aspects (Sperling *et al.,* (2001). Selection methodology and organization were adapted to the diverse forms of cauliflower. For each group (autumn, winter or colored types), one has to integrate the constraints due to the history of cultivar groups, the availability of genetic resources, the breeding aims and the biological characteristics (cycle length, reproductive biology) (Chable *et al.,* 2008). On farm, mass selection is mainly performed. Some farmers may use genealogical breeding method.

Breeding and seed production take place on farm where the farmers integrate the selection in his production activity as it was done since the beginning of the agriculture.

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