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Crop improvement in chillies: An overview

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Abstract
Chilli ($2n = 24$) belongs to the family Solanaceae that is grown all over the world. Chili has been used as part of the human diet as spice, condiments, and vegetables for its appealing color, flavour, and pungency since the advancement of civilization. In spite of tremendous potential use, good scope for export as a spice, high nutritive value, good acceptability among the average Indian farmer and consumer, and a wide range of available genetic variability, India is still far behind in attaining the required optimum productivity in chilli. Moreover, all the available information regarding the quality parameters has been confined to a few genotypes with very scanty data available for parameters like capsaicin, ascorbic acid, and oleoresin contents. Therefore, concentrated efforts are necessary to improve yield and yield components. Hence, evaluation of the potential of existing genetic resources in India is essential because crop improvement programs depend on the genetic diversity of the crop. The magnitude of heritable, and more particularly genetic components, is clearly the most important aspect of the genetic constitution of the breeding material, which has a close bearing on its response to selection. Selection of one trait invariably affects a number of associated traits, which evokes the necessity to determine the interrelationship of various yield components, both among themselves and with yield.

Keywords: Crop improvement, grown all over world, Chili

Introduction
Chilli (*Capsicum* spp.) is an important commercial spice and vegetable crop for small and marginal farmers in Asia, Africa and South America and it is grown throughout the world. The name is derived from Capsicum' = Greek word 'kapto', meaning "to bite" or "to swallow." Almost 400 types of chillies are grown throughout the world. Among the 5 cultivated species of the genus *Capsicum*, *C. annuum* is the most widely cultivated in India for its pungent (chilli syn. hot pepper) and non-pungent (sweet pepper syn. capsicum, bell pepper) fruits. The cultivation of *C. frutescens, C. chinense,* and *C. baccatum* is limited and usually restricted to homestead gardening in different regions. It comprises numerous chemicals including steam volatile oils, fatty oils, capsaicinoids, carotenoids, vitamins, proteins, fibres and mineral elements (Bosland and Votava, 2000) [7].

Taxonomy
Solanaceae is a plant family comprising about 2300 species, nearly one-half of which belong to the genus *Solanum*. Most species within this genus are endemic to the America, only 20% are Old World species. Family *Solanaceae* has been the source of many morphologically different domesticated species. Doganlar *et al*. (2002) [11] explained this phenomenon with the fact that only a few conserved major loci are responsible for the dramatic phenotypic changes that accompanied domestication in this family. Like tomato and egg plant chillies is an autogamous diploid with 12 chromosomes.

Importance
- An important part of daily diet.
- Key Element in many regional cuisines, pickles, soups, sauce, Salads, curries etc. due to its unique flavor, aroma and colour.
- Increase the taste and palatability.
- Fresh green capsicum contains more vitamin C than citrus fruits and fresh red chilli has more vitamin A than carrot (Than *et al*. 2008).
- Chillies are low in sodium and cholesterol free.

- Medicinal Properties are found
- Stimulate blood circulation
- improves the digestion process
- rich source of antioxidants
- source of natural bactericidal agents
- Apart from medicinal uses, chilli also used in cosmetic, liquor industries and as a weapon for self -defense (chilli spray).

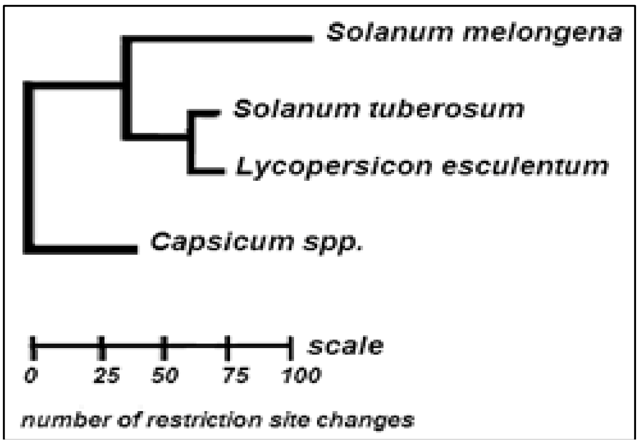

Fig 1: Dendrogram of crop plants from *Solanaceae* family (Olmstead and Palmer 1997) [41]

Scientific Classification

- Kingdom : Plantae
- Class : Angiosperm
- Order : Solanales
- Family : Solanaceae
- Genus : Capsicum
- Species : annum
- Scientific name : *Capsicum annum* L. var. annum var. paprika
- Chromosome no : 2n=24 & 2n=26

Cultivars

Capsicum annum

Capsicum annuum, bell, sweet, or chilli pepper—with cultivated varieties including bell, sweet, chilli, and paprika peppers—is a perennial herbaceous plants in the Solanaceae (nightshade family), which originated in Central and South America and the Caribbean and was domesticated over 5,000 years ago. Peppers from *C. annuum* have been developed into numerous varieties that are now cultivated around the world for sweet and hot varieties of green and red bell peppers and chilli peppers, that are one of the world's most widely used spices, with dried forms including paprika, chili powder, and cayenne.

Capsaicin, which is obtained from *C. annuum* and other *Capsicum* species, is an intense skin and eye irritant, and is the ingredient used in pepper sprays sold for self-defense. However, it also has numerous medical uses, including topical pain relief for muscle soreness, shingles, skin irritations, and rheumatism, and also as an anti-inflammatory. Recent medical research has also documented antimicrobial and antifungal activity of capsaicin obtained from several *Capsicum* species, and on-going studies are exploring its use in cancer treatment.

Capsicum chinense

Capsicum chinense is a species of chilli pepper native to the America. *C. chinense* varieties are well known for their exceptional heat and unique flavors. Some taxonomists consider them to be part of the species *C. annuum*, and they are a member of the *C. annuum* complex. *C. annuum* and *C. chinense* can generally be identified by the number of flowers or fruit per node, however one for *C. annuum* and two to five for *C. chinense*, though this method is not always correct. The two species can also hybridize and generate inter-specific hybrids. It is believed that *C. fruitescens* is the ancestor to the *C. chinense* species

Resistance to TSWV was found in several *C. chinense* accessions, including PI152225 and PI159236 (Kenyon *et al*. 2014) [14]. The resistance is controlled by the dominant gene Tsw and is expressed as a hypersensitive-like localization of the virus (Boiteux & de Ávila, 1994) [5]. This gene has been fine mapped to a 259-kb region of the distal portion of chromosome P10 where 22 genes are predicted, among which eight show annotations of NBS-LRR resistance proteins (Hoang *et al*., 2013) [16, 37]. This region is closely linked to, or may contain, the dominant potyvirus resistance genes Pvr4 and Pvr7. The resistance conferred by Tsw is broken at high temperatures; it depends on plant age, with young plants being more susceptible.

Capsicum frutescens

Capsicum frutescens is a species of chilli pepper that is sometimes considered to be part of the species *C. annuum*. Pepper cultivars of *C. frutescens* can be annual or short-lived perennial plants. Flowers are white with a greenish white or greenish yellow corolla, and are either insect- or self-pollinated. The plants' berries typically grow erect; ellipsoid-conical to lanceoloid shaped. Fruit typically grows a pale yellow and matures to a bright red, but can also be other colours. *C. frutescens* has a smaller variety of shapes compared to other Capsicum species, likely because of the lack of human selection. More recently, however, *C. frutescens* has been bred to produce ornamental strains, because of its large quantities of erect peppers growing in colorful ripening patterns.

Diversity, conservation and enhancement of genetic resources

The National Bureau of Plant Genetic Resources (NBPGR), New Delhi facilitates collection, regeneration, characterization, conservation and distribution of chilli germplasm to researchers in India. However, at NBPGR indigenous collections constitute only 18% of the total Capsicum collections, while the majority of the accessions are exotics (Kalloo *et al*., 2005) [18].

Sources of biotic stress resistance in Chillies

Development of biotic resistant cultivars has been a part of the plant breeder's tool since long time. Cultivation of resistant or tolerant cultivars is one of the best options to minimize the losses due to disease/insect occurrence. This is especially at this juncture, when there is growing public sensitivity about the environmental pollution and residual effects on produce due to the indiscriminate use of hazardous chemicals and emergence of new races/biotypes. For the development of resistant varieties and pre-breed lines, sources of resistance are the prerequisite and backbone of breeding programme. Such sources may be present in the indigenous cultivars, land races, folk cultivars, semi-wild relatives and allied species of the vegetable crops.

Chilli is highly susceptible to a number of fungal, bacterial and virus diseases (Rahim and Samraj, 1974) [50]. But the most serious are anthracnose (fruit rot and die back caused by *Colletotrichum* spp.), powdery mildew (*Leucillula taurica*), cercospora leaf spot (Cercospora *capsici*), bacterial leaf spot (*Xanthomonas campestris* Pv vesicatoria) and wet rot (*Choanephora cucurbitarum*). TMV, CMV, PVX, PVY, chilli mosaic virus and tobacco leaf curl virus are the most common viral disease in this crop (Singh and Kaur, 1990; Saini and Rathan, 1971) [52]. Yield losses ranged from 80 to 100% has been reported in case of early infection of viral diseases. Resistance sources in chillies crop have been reported for anthracnose, phytopthora blight, bacterial wilt, fruit rot and viral complexes.

Sanjay *et al*., (2006) [53] screened 307 lines belonging to four cultivated and one wild species against pepper leaf curl virus under field and artificial conditions. Out of which only three genotypes, *viz.*, GKC - 29, BS-35 and EC-497636 showed no symptoms. These lines should be used for future breeding programme against leaf curl viruses in combination with modern biotechnological tools. Important insects which attack chillies crop are thrips, mites, pod borer and aphids. These are more serious in tropical region of India and often causing 25 to 50% yield losses (Ananthakrishnan, 1973). The resistance source in chillies crop to various insects are summarized in table. (Tewari *et al*., 1985).

Punjab Agricultural University, Ludhiana has developed 18 multiple disease resistant lines in chillies crop (Singh and Kaur, 1990). Among these, 'Punjab Lal' (S-118-2) has been released as multiple resistant chilli variety in 1985 for general cultivation in the State (Thakur *et al*., 1987). The other important multiple resistant lines are 'Perennial', 'BG-1', 'Loral', 'Tiwari', 'Indonesian Selection', etc. these are not only found resistant to various fungal and viral diseases in India but also in France, Hungary, Spain, Malaysia, Korea, USA and Taiwan. Another variety 'Pant C-1' found resistant to mosaic and leaf curl virus, has been released by Pant Nagar Agricultural University, Pant Nagar (U.P.) for general cultivation in the state. Indian Agricultural Research Institute has also released 'Pusa Sada Bahar' chilli variety resistant to CMV, TMV and leaf curl virus in 1989.

Table 1: Identified resistant/tolerant source against major pests of chilli in India, since 2000

S. No	Biotic stress and causal organism	Name of line and reference
1	Anthracnose (*Colletotrichum* spp.)	Bhut Jolokia (Gerg *et al*., 2013); PBC80 (VI046804), PBC81 (VI046805), PBC932 (VI047018); LLS, Breck-1, Breck-2, Jaun (Kaur *et al*., 2011)
2	Bacterial wilt (*Psedomonas solanacearum*)	AVPP0102 (PP0107-7011), PBC66 (VI037518), PBC67 (VI037519), PBC384 (VI037548), PBC385 (VI039374), PBC535 (VI037556), MC-4
3	Phytophthora blight (*Phytophthora capsici)*	GKC29, PI201234, IC364063
4	Chili/pepper leaf curl virus (ChiLCV)	BS35, GKC29, Bhut Jolokia (Kumar *et al*., 2006b; Kumar *et al*., 2011), CHUH-4 (Mondal, 2013), Pepper Line Nos. 59 & 86
5	Chilli veinal mottle virus (ChiMoV)	Individual plant selections from: PBC495 (VI037455), PBC521, PBC370 (VI037453), PBC569 (VI046889), PBC371 (VI039369), Tiwari (Erect), 9852-131 (AVPP9807), Punjab Gucchedar, Perennial, Punjab Surkh, Pusa Sadabahar, Pant C1, Perennial HDV (Reddy and Reddy, 2010)
6	Cucumber mosaic virus (CMV)	Perennial, PBC495 (VI037455), VC246, VR42, VR55 (Reddy and Reddy, 2010), AVPP9812 (PP9852-10)
7	Peanut bud necrosis virus (PBNV)	EC121490, IC119611 (Kalloo *et al*., 2005) [18]
8	Nematode (*Meloidogyne javanica*)	EC402105, EC402113, EC405253, NIC19969, IC214965, IC214985, IC215012, EC391083, EC391087, EC378632, EC378688 (Pandravada *et al*., 2010)
9	Powdery mildew (*Leveillula taurica*)	Arka Harita, Arka Suphal, PBC167 (VI046819)
10	Thrips	Caleapin Red, Chamatkar, P46-A, X1068, X743, X1047, BG4, X226, X230, X233 (Kalloo *et al*., 2005) [18]
11	Yellow mites (*Polypagotarsonemus latus*)	Jwala, RHRC Erect, AEG77 (Desai *et al*., 2007)
12	Aphid	LEC-28, LEC-30, LEC-34, 'Kalyanpur Red', x 1068 (Anon, 1972-76, Tewari *et al*.,1985) [59]
13	Southern root knot	Charleston Hot (Dukes and Fery, 1997)

Evolutionary Background

Four of the five domesticated species have evolved from conspecific wild ancestors (Pickersgill, 1971) [45]. The wild ancestor of *C. pubescens* remains uncertain: *C. pubescens* crosses readily with wild *C. cardenasii* and *C. eximium*, and shares the same chromosome end arrangement with these taxa, but differs from them in some significant morphological and molecular characters.

Although all the domesticates include spectacular variation in fruit characters, founder effects associated with domestication have imposed an evolutionary bottleneck which has restricted variation in less visible characters. Selection within the various domesticated species for different uses, for example for consumption as a spice versus consumption as a vegetable, or consumption fresh versus consumption dried, has led to a further partitioning of the genetic diversity within each domesticate. A given named type of pepper will thus include only a limited subset of the intraspecific diversity. Founder effects associated with intercontinental migrations have reduced diversity still further in the areas to which the species have been introduced.

This applies particularly to *C. annuum*. Examples of founder effects associated with domestication include karyotype diversity in *C. annuum* (the wild peppers vary much more in karyotype than the domesticated peppers; Pickersgill, 1971) [45] and polymorphism versus monomorphism in wild versus domesticated *C. baccatum* for a nuclear gene which interacts with the cytoplasm of *C. chinense* (Pickersgill, 1989) [44]. Founder effects are also apparent at the molecular level. Lefebvre *et al*. (1993) [28], in a study of RFLPs, found that cultivars of bell pepper (all of European or North American origin) were much more similar to one another than were small-fruited accessions of *C. annuum*, which included pungent and non-pungent European, Mexican, Indian and Ethiopian accessions.

Loaiza-Figueroa *et al*. (1989) [30] studied isozyme-coding loci and found that the total genetic diversity (inter- as well as intra-specific) for wild Capsicum was 0.282, but for domesticated Capsicum was only 0.176. In both wild and domesticated peppers, genetic diversity between populations was considerably greater than genetic diversity within populations. These data conform to expectations for a predominantly inbreeding species. Almost all species of Capsicum are self-compatible (the exception is *C. cardenasii*) but protogynous, with a degree of stigma exertion that varies with genotype. Actual measurements of out crossing under field conditions range from 2% to over 90%, depending on locality, environment, and spacing between plants (Quagliotti 1979; Pozo Campodonico 1983; Tanksley, 1984) [49 47, 58]. The lowest of these values was obtained from widely spaced plants, comparable to plants in wild populations or individual plants of different types of pepper in house gardens in Latin America. In these situations, most pollination is likely to be geitonogamous. In Capsicum, as in other facultative inbreeders, genetic diversity will be collected more efficiently by sampling many different populations extensively rather than by sampling a few populations intensively (Marshall & Brown, 1981) [32].

Objectives in capsicum breeding and sources of useful characters

Variability and genetic diversity of peppers are wide, allowing alternatives to several new gene rearrangements. On that basis, the methodology employed will depend of the feature that aims to achieve in pepper genetic breeding (Padilha *et al*., 2015) [42]. The main objectives of peppers genetic breeding are characteristics such as productivity, disease and pests resistance, fruit characteristics (bioactive compounds, fruit color, pungency, flavor), and abiotic stresses viz., drought, salinity (Manzur *et al*., 2014) [31].

Before undertaking any breeding programme for specific objective, it is necessary for the breeder to have sufficient knowledge of basic information regarding the nature of inheritance of various traits in terms of additive and non-additive genetic variance, which could help him in planning the hybridization and selection procedure effectively to get desirable results. The conventional method of breeding though significant and productive in its own right, imposes restriction on chance of recombination rates, retains tight and undesirable linkages, restricts the number of desirable alleles at various loci than can be accumulated in the line selected in the advanced generation and utilizes only a part of fixable gene effect (additive, additive x additive etc). Thus, routine breeding methods as pedigree and pure line selections are in effective and inadequate to explore the full range of genetic variability and the estimations were mostly biased due to linkage and epistasis for complex characters like yield, quality and yield contributing characters. Genetic information available so far in chilli crop is mainly concerned with combining ability studies. But studies on nature and magnitude of gene action for various yield and quality characters is lacking. A few reports are available on the estimation of additive and dominance effects only, but an epistatic effect has been assumed to be negligible and thus ignored.

Breeding objectives in Capsicum spp.

Major

1. Higher yield
2. More pungency (capsaicin) and oleoresin in hot chilli
3. Zero pungency (capsaicin) and more antioxidant in sweet pepper
4. Resistance to anthracnose, virus complex, fruit rot and bacterial wilt etc.
5. More dry powder from green fruit

Minor

1. More number of fruits per plant
2. Higher fruit weight and larger size
3. Uniform fruit shape, size and color in sweet pepper
4. Earliness
5. Wider adaptability
6. Improved nutritional quality
7. Longer shelf life

Main goals of chilli peppers breeding programs

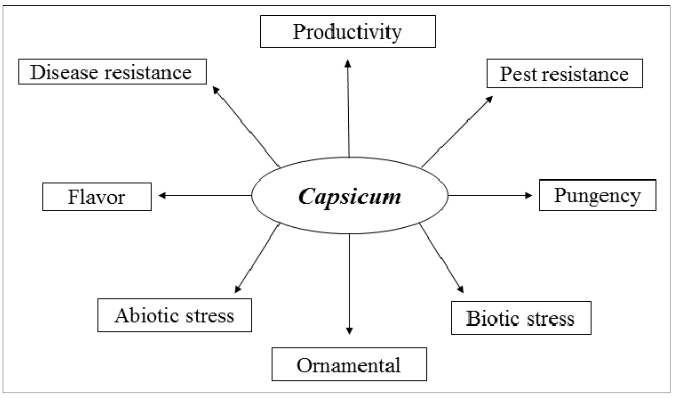

Fig 2: Henrique Kuhn Massot Padilha and Rosa Lía Barbieri, 2016 [15]

Table 2: Breeding objectives for major quality traits in various market types of chilli

S. No	Market type	Important fruit quality traits
1	Fresh market (green, red)	Colour, pungency, shape, size, flavour, exocarp thickness
2	Fresh processing (sauce, paste, canning, pickling)	Colour, pungency, flavour, pericarp thickness
3	Dried spice (whole fruit, powder)	Colour, pungency, flavour, dry matter, low crude fiber
4	Oleoresin extraction	Essential oil (colour, pungency)

Breeding behaviour and Genetics

The breeding behaviour of cultivated pepper was well understood besides recognition of 5 species of Capsicum *viz*., *C. annum*, *C. fruitescens*, *C. pubescens*, *C. pendulum* and *C. Chinese*

Table 3: Breeding behaviour of capsicum species

S. No	Crossing Behaviour	Characteristics
1	*C. annum* x *C. fruitescens*	About 2 % of the seeds were viable when fruitescens was used as female parent. The F1 plants ranging from completely pollen sterile to partially fertile were obtained. Backcross to both parents had been obtained between both F2 and back cross plants showed much pollen sterility. The L gene for tobacco mosaic resistance was successfully transferred from frutescens to annum. The transfer of resistance to the tobacco etch virus from fruitescens has also been reported.
2	*C. annum* x *C. chinese*	Crosses can be made in either direction but are much easier when *C. annum* is used as the female parent. Only an occasional successful cross was obtained in the other direction. The F1 plants ranged from completely pollen sterile to moderately fertile and backcross to both the parents were obtained. Considerable sterility occurred in F2 and back cross plants but gene interchange would be made with ease.
3	*C. annum* x *C. pendulum*	No viable F1 seeds but F1 plants could be obtained by culture of partially developed embryos. The F1 plants were highly self-sterile but an occasional F2 plant had been obtained. It appears probable that genes can be transferred from one species to the other but with difficulty.
4	*C. annum* x *C. pubescens*	Completely cross sterile. Crosses are rarely resulted in fruits and those obtained were without seed.
5	*C. fruitescens* x *C. chinese*	Crosses would be obtained in either direction although with considerable difficulty when *C. chinese* was used as the female parent. The F1 plants were completely to moderately self-sterile. Backcrosses to both the parents were obtained.
6	*C. fruitescens* x *C. pendulum*	Crosses were made in either direction, but more readily when pendulum was used as the Female parent. The F1 plants were highly sterile and viable F2 seeds were very rarely formed. Backcrosses to each parent resulted in only an occasional viable seed.
7	*C. fruitescens* x *C. pubescens*	No fruit had ever been obtained from repeated pollination in both directions.
8	*C. Chinese* x *C. pendulum*	Crosses were made with some difficulty with C. pendulum as the female parent. A few F2 seeds were obtained but none were viable. A limited no. of back crosses was successful.
9	*C. chinese* x *C. pubescens*	Fruits were formed when *C. chinese* was used as the seed parent. The fruit at maturity contained many seeds with fully developed embryos but without endosperm. Such embryos could be grown only on artificial media. The F1 plants were completely sterile and could not be backcrossed to either parent.
10	*C. pendulum* x *C. pubescens*	No successful crosses could be obtained.

Table 4: Capsicum cross breeding chart

Flower	Male Parent	Female Parent										
		Baccatum	**Praetermissum**	**Frutescens**	**Chinense**	**Annum**	**Galapagoense**	**Chacoence**	**Tovarii**	**Pubescens**	**Eximium**	**Cardensii**
White	baccatum	HF	PF	NG	NG	NG	-	NG	-	-	-	-
	praetermissum	PF	HF	-	IV	IV	-	-	-	-	PF	-
	frutescens	NG	-	HF	PF	NG	-	-	-	-	-	-
	chinense	NG	NG	PF	HF	PF	-	NG	-	-	-	-
	annum	NG	IV	PF	PF	HF	IV	IV	-	-	-	-
	galapagoense	NG	-	-	IV	NG	HF	EC	-	-	-	-
	chacoence	IV	IV	-	NG	NG	-	HF	-	-	-	-
Purple	tovarii	NG	I	IV	EC	-	-	IV	HF	-	NG	-
	pubescens	IV	IV	EC	IV	-	-	IV	-	HF	HF	NG
	eximium	NG	PF	NG	IV	IV	-	IV	NG	HF	HF	HF
	cardensii	NG	IV	NG	-	IV	-	IV	-	HF	HF	HF

(Reproduced from Figure 3, Genetic Resources of Capsicum, International Board for Plant Genetic Resources, 1983 (Crop Genetic Resources Centre, Plant Production and Protection Division, Food and Agriculture Organization of the United Nations)

NG = F1 hybrids germinate norminally EC = F1 hybrids raised by embryo culture IV = fruits / seeds set, but F1 seeds inviable PF = F1 hybrids partially fertile HF = F1 hybrids highly fertile = no data, perhaps “does not cross”

Breeding strategy/methods

Conventional methods

1) Introduction
2) Pure line selection
3) Pedigree method
4) Backcross method
5) Heterosis breeding
6) Distance hybridization

Non-conventional methods

1) Marker assisted breeding
2) Tissue culture
3) Mutation breeding

Capsicums are diploid and predominantly perform self-pollination. Capsicum genus has perfect flowers where male and female reproductive structures are in the same flower (Allard, 1960) [2]. They are closely related to potato, tomato, eggplant, tobacco and petunia, which are also examples of Solanaceae. Many members of this family have the same number of chromosomes (2n = 2x = 24) as well as domesticated species of peppers, although genome size varies drastically from a genus to another. Some wild species have (2n=2x=26). In comparison level, the size of C. annuum genome (3.48 GB) is around three to four times larger than tomato size (*Solanum lycopersicum*). The average exon/intron length is 286.5 bp/541.6 bp; Number of genes is around 34.900; Total length of transposable elements 2.34 Gb (76.4%). The hot pepper genome shared highly conserved syntenic blocks with the genome of tomato, its closest relative within the Solanaceae family (Kim *et al*., 2014). There is a list of known genes can be useful to pepper breeders. The list started with 50 genes in 1965, nowadays there is the total of

292 different genes, such as dw-1 (dwarf, plants with 15 ot 20 cm in height), Ef (early flowering), me-2 (*Meloidogyne* spp. resistance) and others (Bosland and Votava, 2012) [6].

The main classical methods utilized in chili pepper breeding are listed in Table 5. Mass selection, Pedigree method (or Genealogical method), Single Seed Descent - SSD method, Backcross, Recurrent Selection and Hybridization are those more utilized (Coon *et al*., 2008; Kulkarni and Phalke, 2009; Nsabiyera *et al*., 2013; Manzur *et al*., 2014) [9, 23, 38 31]. The choice of the best method or combination of them depends mainly on the type of inheritance (monogenic, oligogenic, or polygenic) from traits to be improved (Lee *et al*., 2013) [38].

Mass selection was successfully utilized by indigenous peoples of Tropical America, whereby seeds of the best plants were saved for the next growing season. This method should be used for populations with genetic variability and selected in environments where the traits express themselves and for those of high heritability (Nsabiyera *et al*., 2013) [38]. The pedigree method involves keeping records of matings and their progeny. This includes making single plant selections and self-pollination (Oliveira *et al*., 2015) [14].

The SSD (single seed descent method), which does not need selection during the breeding process, is also utilized in the development of recombinant inbred lines (RILs). Advancement of generations can be performed in greenhouses (Ulhoa *et al*., 2014) [62]. Moreira *et al*. (2009) [34] utilized this method to obtain lines resistant to bacterial spot. Recurrent selection involves selecting individuals from a population followed by intercrossing to form a new population (Singh *et al*., 2014) [57].

Backcross is used particularly for traits controlled by one or few genes, which involves selection of individual plants and successive crosses to a recurrent parent (Prakash *et al*., 2014; Bosland and Votava, 2012) [6]. Hybridization is an important factor in evolution of plants as a source of new genetic combinations and as a mechanism of speciation. Hybridization and pedigree breeding with simple selection methods can be used to improve most traits controlled by both additive and non-additive genes (Nsabiyera *et al*., 2013; Moreno *et al*., 2015) [38].

Mutation breeding has not been a major breeding method for the development of ornamental peppers. However, it may be a means of producing novel mutants of ornamental interest (Neil O Anderson, 2006) [36]. Spontaneous or artificially induced mutations can also have commercial value. MuMex Pinata a sport from Early Jalepeno was released for the home gardener because the mutated tra gene causes the fruit to ripen from a lime green to yellow, to orange and finally red (Votava and Bosland, 1998) [64]. Thus, the plant will produce multi-coloured fruits for the gardener. Mutations can be induced by ioniziung radiation or via chemical mutagens. Bhargava and Umalkar (1989) [4] used bith gamma radiation and chemical mutagens to produce an array of pericarp mutations. Alcantara *et al*. (1996) [1] describe optimal conditions necessary for seed mutagenesis in *C. annum* using the chemical mutagen, ethyl methyl sulphonate (EMS). They produced several foliage mutants. Somoclonal variations may also result in novel phenotypes. Ornamental pepper somoclonal variants have not been reported, but investigations in this area are limited.

Hybrid ornamental peppers are highly uniform and protect the proprietary rights of the developer. Within capsicum, several systems to produce hybrid seed are possible, including the use of genetic male sterile plants and cytoplasmic male sterile plants. Practical use of male sterility in hybrid pepper production is limited by a number of factors. The production of today's ornamental pepper hybrid is reliant on making hybridizations between the two parents by hand; a very labour intensive and expensive process. Through back cross breeding, high genetic variability was determined in F2 and backcrosses by three cluster analyses, showing that parents 01 and 132 differ for the evaluated traits. According to the relative importance of traits, those that most contributed to genetic divergence were number of seeds per fruit, number of fruits per plant, days to flowering and days to fruiting (Nascimento *et al*., 2015) [14].

Non-allelic recessive genes, ms1, ms2 and ms3 condition genetic male sterility in pepper (Shifriss, 1973) [55]. A homozygous recessive state for either gene is sufficient to produce male-sterile plants. Meiosis proceeds normally, but microspore degeneration occurs soon after the tetrad stage, resulting in non-fertilize pollen. Additional ms loci have been reported, but allelic tests are lacking among described mutants (Daskalov and Poulos, 1994). Production of male-sterile parent is an inefficient process because 25% or 50% of the plants, dependent on the presence of ore of two forms of the recessive genes, must be identified and rouged from the population of seed parents in a production field. Closely linked markers have not been identified to facilitate elimination of fertile plants in the seedling stage. Nonetheless, sterile plants are easily identified at anthesis. Due to the inefficiency of hybrid production using genic male sterility, its use in hybrid pepper seed production is very limited. Molecular marker technology may aid in the development of improved ornamental pepper cultivars. Molecular markers have proven invaluable for understanding the genetic make-up of agricultural crops. Molecular markers are commonly used to examine genetic diversity, systematic, phylogeny, and in fingerprinting cultivars for intellectual property protection purposes (Lefebvre *et al*. 2001; Livingstone *et al*., 1999) [27, 21]. They are used un combination with other markers to construct genetic maps, and are used in linkage studies. Plant breeders can use markers linked to a desired trait in marker-assisted selection (MAS). Selection via molecular markers eliminated the need for costly and sometimes and sometimes inefficient screenings, and speeds up the process of cultivar development.

Table 5: Main classical techniques used in Capsicum breeding programs

Technique name	Principle	References
Mass selection	Seeds of the best plants were saved for the next growing season; oldest method	Nsabyera *et al*., 2013.
Pedigree method	Keeping records of matings and their progeny. This includes making single plant selections and self-pollination	Oliveira *et al*., 2015 [14].
SSD (Single seed descent)	This method involves the advance of generations without selection, it is also utilized in the development of recombinant inbred lines	Ulhoa *et al*., 2014 [62].
Recurrent selection	Selecting individuals from a population followed by intercrossing to form a new population	Singh *et al*., 2014.
Backcross	Used particularly for traits controlled by one or few genes, which involves selection of individual plants and successive crosses to a recurrent parente	Prakash *et al*., 2014.

Hybridization	Genes of one specie or variety move into another through the process of crossing	Moreno *et al*., 2015.
Mutation	Spontaneous or artificially induced mutations	Neil O Anderson, 2006 [36]

The chili peppers are best known by the range of their fruit shapes and colors. Despite their flowers show different colors, they are small, around 1 cm, to be attractive as an ornamental to consumers.

Advantages

1. High variability present in nature for quality and yield contributing characters.
2. Characters like fruits per plant, pricarp thickness, fruit size, fruit weight and oleoresin content can be used for selection.
3. Heterosis can be manifested using diverse germplasm.
4. Easy and more hybrid seed production can be possible through proper exploitation of male sterility system.
5. Mutation can be employed to create new useful mutant for crop improvement.
6. In vitro cloning is more successful when cotyledon leaf was used as an explants.
7. Abiotic stress tolerant germplasm present in nature.
8. Disease resistant cultivar can be developed through crossing and backcrossing with resistance germplasm.

Future Strategies

More emphasis should be given on breeding varieties resistant to biotic stresses. For the development of a new variety, besides using modern technologies; the conventional breeding is still durable and easy in long term breeding programme. More emphasis should be given to utilize wild relatives for development of pre bred lines so that as and when resistance source require these lines can be utilize successfully against certain biotic stresses. However, the botanical distance between wild and cultivated relatives act as a barrier in successful hybridization programme for transfer of desirable resistant genes.

- Genesis of varieties with less pungency and consumer preference.
- Exploitation of male sterility and chemical hybridizing agents in developing new hybrids.
- Introduction of heat and drought tolerance germplasm as a strategy for climate change.
- Development of location specific varieties.
- To develop a varieties which can maintain as such capsaicin content even after a longer storage period?
- Developments of varieties with higher antioxidant and oleoresin content.
- Breeding for ornamental plant type.

In this context, present day molecular biological techniques open the scope for better exploration of wild cultivars.

References

1. Alcantara TP, Bosland PW, Smith DW. Ethyl methane sulfonate induced mutagenesis of *Capsicum annuum*. J Hered, 1996, 239-41.
2. Allard RW. Principles of Plant Breeding. John Wiley & Sons Inc, New York, 1960, 485.
3. Barbara Pickersgill. Genetic resources and breeding of Capsicum spp. Euphytica. 1997; 96:129-133.
4. Bhargava Y, Umalkar G. Productive mutations induced in *Capsicum annuum* by physical and chemical mutagens. Acta Horticulturae. 1989; 253:264-265.
5. Boiteux LS, De Ávila AC. Inheritance of a resistance specific to tomato spotted wilt tospovirus in *Capsicum chinense* 'PI 159236', Euphytica. 1994; 75(1-2):139-142.
6. Bosland PW, Votava EJ. Peppers: Vegetable and Spice Capsicums J. Atherton and A. Rees (eds), CABI Publishing, 2012, 199.
7. Bosland P, Votava E. Peppers: Vegetable and Spice Capsicums. Cambridge: CABI Publishing. 2000.
8. Bosland PW, Votava EJ. Peppers: Vegetable and Spice Capsicums, 2012.
9. Coon D, Votava E, Bosland PW. The Chile Cultivars of New Mexico State University. Research Report. 2008; 73:1-8.
10. Desai HR, Bandania KA, Rai AB, Patel AJ. Assessment of yield loss and resistance to yellow mite Polypagotarsonemus latus (Bank) in chilli. Vegetable Science. 2007; 34:46-50.
11. Doganlar S, Frary A, Daunay MC, Lester RN, Tanksley SD. A comparative genetic linkage map of eggplant (*Solanum melongena*) and its implications for genome evolution in the Solanaceae. Genetics. 2002; 161:1697-1711.
12. Doganlar S, Frary A, Daunay MC, Lestervand RN, Tanksley SD. Conservation of gene function in the Solanaceae as revealed by comparative mapping of domestication traits in eggplant. Genetics. 2002; 161:1712-1726.
13. Dukes PD, Fery RL. Charleston Hot: a southern root knot nematode resistant yellow fruited caynne pepper with a compact plant habit. Hort Sci. 1997; 32:947-948.
14. Francisco de Assis de Oliveira, Sergio Nascimento Duarte, José Francismar de Medeiros, Edna Maria Mendes Aroucha e Nildo da Silva Dias. Quality in the pepper under different fertigation managements and levels of nitrogen and potassium. Revista Ciência Agronômica. 2015; 6(4):764-773.
15. Henrique Kuhn, Massot Padilha, Rosa Lía Barbieri. Plant breeding of chili peppers (*Capsicum*, *Solanaceae*) – A review. Australian Journal of Basic and Applied Sciences. 2016; 10(15):148-154.
16. Hoang NH, Yang HB, Kang BC. Identification and inheritance of a new source of resistance against Tomato spotted wilt virus (TSWV) in Capsicum. Scientia Horticulturae. 2013; 161:8-14.
17. http://junglerain.com.au/chilli-info/breeding-chillies
18. Kalloo G, Srivastava U, Singh M, Kumar S. Solanaceous vegetables. In: Dhillon BS, Tyagi RK, Saxena S and Randhawa, eds. Plant Genetic Resources: Horticultural Crops, Narosa Publishing House, New Delhi, India. 2005, 19-33.
19. Kaur N, Singh DJ, Singh KD. Physiological and biochemical traits analysis of Capsicum annuum L. germplasm for resistance *to Colletotrichum capsici*. Journal of Cell and Plant Sciences. 2011; 2:12-21.
20. Kenyon L, Sanjeet K, Wen-Shi T, Jacqueline dA Hughes. Virus Diseases of Peppers (*Capsicum* spp.) and Their Control. Advances in Virus Research. 2014; 90:297-354.
21. Kevin D, Livingstone VK, Lackney, James RB, Rik Van Wijk, Molly Kyle Jahn. Genome Mapping in Capsicum and the Evolution of Genome Structure in the Solanaceae. Genetics, 1999; 152:1183-1202.

22. Kim S, Park M, Yeom SI. Genome sequence of the hot pepper provides insights into the evolution of pungency in Capsicum species. Nature Genetics. 2014; 46(3):271-278.
23. Kulkarni M, Phalke S. Evaluating variability of root size system and its constitutive traits in hot pepper (*Capsicum annuum* L.) under water stress. Scientia Horticulturae. 2009; 120:159-166.
24. Kumar S, Kumar S, Singh M, Singh AK, Rai M. Identification of host plant resistance to pepper leaf curl virus in chilli (Capsicum species). Scientia Horticulturae. 2006; 110:359-361.
25. Lawrence Kenyon, Sanjeet Kumar, Wen-Shi Tsai, Jacqueline d' A. Hughes. Virus Diseases of Peppers (Capsicum spp.) and Their Control. Advances in Virus Research. 2014; 90:297-354.
26. Lee JM, Jahn MM, Yeam I. Allelic relationships at the pvr1 locus in *Capsicum annuum*. Euphytica. 2013; 194(3):417-424.
27. Lefebvre V, Goffinet B, Chauvet JC, Palloix A. Evaluation of genetic distances between pepper inbred lines for cultivar protection purposes: Comparison of AFLP, RAPD and phenotypic data. Theoretical and Applied Genetics. 2001; 102(5):741-750.
28. Lefebvre V, Palloix A, Rives M. Nuclear RFLP between pepper cultivars (*Capsicum annuum* L.). Euphytica. 1993; 71:189-199.
29. Livingstone K. Comparative mapping in the Solanaceae. Ph.D. Thesis, Cornell University, Ithaca, NY. 1999.
30. Loaiza-Figueroa F, Ritland K, Laborde Cancino JA, Tanksley SD. Patterns of genetic variation of the genus Capsicum (Solanaceae) in Mexico. Pl Syst. Evol. 1989; 165:159-188.
31. Manzur JP, Oliva-Alarcón M, Rodríguez-Burruezo A. In vitro germination of immature embryos for accelerating generation advancement in peppers (*Capsicum annuum* L.). Scientia Horticulturae, 2014; 170:203-210.
32. Marshall DR, Brown AHD. Wheat genetic resources. In: L.T. Evans & W.J. Peacock (Eds). Wheat Science - Today and Tomorrow. Cambridge University Press, Cambridge. 1981, 21-40.
33. Mondal CK, Acharyya O, Hazra P. Biochemical basis of plant defense for leaf curl virus of chilli (Capsicum annuum). Proceeding XV EUCARPIA Meeting on genetics Genetics and Breeding of Capsicum and Eggplant, Turin, Italy, 2013, 315-322.
34. Moreira SO, Rodrigues R, Araújo ML, Araújo ML. Desempenho agronômico de linhas endogâmicas recombinadas de pimenta em dois sistemas de cultivo. Ciênc. Rural. 2009; 39:1387-1393.
35. Nascimento MF, Nascimento NFF, Rêgo ER, Bruckner CH, Finger FL, Rêgo MM. Genetic Diversity in a Structured Family of Six Generations of Ornamental Chili Peppers (*Capsicum annuum*). Proc. XXVth Int. Eucarpia Symp. – Section Ornamentals "Crossing Borders" Eds. J Van Huylenbroeck and E. Dhooghe. ISHS. Acta Hort, 2015, 1087.
36. Neil O Anderson. Flower Breeding and Genetics: Issues, Challenges and Opportunities for the 21st Century, Editors: Anderson, Neil O. (Ed.); Springer link publications, 2006.
37. Ngoc Huy Hoang, Hee-Bum Yang, Byoung-Cheorl Kang. Identification and inheritance of a new source of resistance against Tomato spotted wilt virus (TSWV) in Capsicum. Scientia Horticulturae, 2013;161:8-14 ·
38. Nsabiyera V, Ochwo-ssemakula M, Sseruwagi P, Ojewo C, Gibson P. Combining ability for field resistance to disease, fruit yield and yield factors among hot pepper (*Capsicum annuum* L.) Genotypes in Uganda. International Journal of Plant Breeding. 2013; 7(1):12-21.
39. Oliveira FA, Duarte SN, Medeiros JF, Mendes EM, Aroucha, Dias NS. Quality in the pepper under different fertigation managements and levels of nitrogen and potassium Revista Ciência Agronômica. 2015; 46(4):764-773.
40. Oliveira FA, Nascimento SD, Medeiros JF, Edna Maria Mendes, Aroucha, e Nildo da Silva Dias. Quality in the pepper under different fertigation managements and levels of nitrogen and potassium. Revista Ciência Agronômica. 2015; 46(4):764-773.
41. Olmstead RG, Palmer JD. Implications for the phylogeny, classification, and biogeography of *Solanum* from cpDNA restriction site variation. Systematic Botany. 1997; 22(1):19-29.
42. Padilha HKM, Pereira ES, Munhoz PC, Vizzotto M, Valgas RA, Barbieri RL. Genetic variability for synthesis of bioactive compounds in peppers (*Capsicum annuum*) from Brazil. Food Science and Technology, 2015; 35(3):516-523.
43. Pandravada SR, Varaprasad KS, Reddy KJ, Rao ES. Screening and identification of sources of resistance against root-knot nematode (*Meloidogyne javanica*) in chilli (*Capsicum annuum*) germplasm. Indian Journal of Agricultural Sciences. 2010; 80:92-94.
44. Pickersgill B. Genetic resources of Capsicum for tropical regions. In: S.K. Green (Ed). Tomato and Pepper Production in the Tropics, Asian Vegetable Research and Development Center, Taipei, 1989 1-9.
45. Pickersgill B. Relationships between weedy and cultivated forms in some species of chili peppers (Genus Capsicum). International Journal of Organic Evolution. 1971: 25:683-691.
46. Po Po Than, Haryudian Prihastuti, Sitthisack Phoulivong, Paul WJT, Kevin DH. Chilli anthracnose disease caused by *Colletotrichum* species. J Zhejiang Univ Sci B. 2008; 9(10):764-778.
47. Pozo Campodonico O. Estimates of natural cross-pollination in Serrano pepper (*Capsicum annuum* L.). Capsicum Newsletter. 1983; 2:113-115.
48. Quagliotti L, Ottaviano E. Study of variability in the capsaicin content of the berries in different cultivated populations of pepper. Genet Agrar. 1967; 21:249-264.
49. Quagliotti L. Floral biology of Capsicum and Solanum melongena. In: JG. Hawkes, RN. Lester & A.D. Skelding (Eds). Biology and Taxonomy of the Solanaceae, pp. 399–419. Academic Press, London, 1979.
50. Rahim A, Samraj J. Agric Res. J Kerala. 1974; 12(1):105.
51. Reddy KM, Reddy MK. Breeding for virus resistance, In: Kumar R, Rai AB, Rai M and Singh HP eds., Advances in Chilli Research, Studium Press Pvt. Ltd., New Delhi, India, 2010, 119-132.
52. Saini SS, Rathan RS. Himachal J Agric. Res. 1971;1(1):1-2
53. Sanjay K, Sanjeet K, Major S, Mathura R. Identification of host plant resistance to pepper leaf curl virus in chilli (*Capsicum* species). Scientia Horticulturae. 2006; 110(4):359-36.
54. Santos RMC, Nascimento NFF, Borém A, Finger FL, Carvalho GC, Nascimento MF. *et al*. Ornamental pepper

breeding: could a chili be a flower ornamental plant. Acta Hortic. 2013; 1000:451-456.

55. Shifriss Chen. Additional spontaneous male-sterile mutant in *Capsicum annuum* L. Euphytica. 1973; 22(3):527-529.
56. Singh J, Kaur S. Development of multiple resistances in chilli pepper. Proceedings 3rd International Conference held from 20-23 March 1990 at Kuala Lumpur, Malaysia, 1990.
57. Singh P, Cheema DS, Dhaliwal MS, Garg N. Heterosis and combining ability for earliness, plant growth, yield and fruit attributes in hot pepper (*Capsicum annuum* L.) involving genetic and cytoplasmic-genetic male sterile lines. Scientia Horticulturae. 2014; 168:175-188.
58. Tanksley SD. High rates of cross-pollination in chilli pepper. Hort Science. 1984; 19:580-582.
59. Tewari GS, Deshpande AA, Ananad N. Chilli pepper genotypes resistant to thrips (*Scirtothrips dorsalis* Hoct). Capsicum News. 1985; l(5):49.
60. Thakur MR, Singh J, Singh H, Sooch BS. Punjab Lal- A new multiple resistant chilli variety. Prog. Fmg. 1987; 23(9):11-16.
61. Than PP, Haryudian P, Sitthisack P, Paul WJ Taylor, Kevin D Hyde. Chilli anthracnose disease caused by *Colletotrichum* species – Review. Journal of Zhejiang University Science B. 2008; 9(10):764-778.
62. Ulhoa, AB, Telma NP, Raimundo NS, Carlos FR, Rosana Rodrigues, Messias GP, Francisco JB, Reifschneider. Molecular characterization of inbred lines of yellow Jalapeño pepper, Hortic. Bras. 2014; 32(1).
63. Véronique Lefebvre, Goffinet B, Chauvet JC, Palloix A. Evaluation of genetic distances between pepper inbred lines for cultivar protection purposes: Comparison of AFLP, RAPD and phenotypic data. Theoretical and Applied Genetics, 2001; 102(5):741-750.
64. Votava EJ, Bosland PW. Numex pinata jalapeno chile. Hort Science. 1998; 33:350.