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FOCUS

Garden pea improvement in India

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ABSTRACT

Garden pea (*Pisum sativum* L. var. *hortense*) is an important legume vegetable grown for its fresh, shelled green seeds rich in proteins, vitamins and minerals. At present over 1000 germplasm lines are available in India. Improvement of garden pea in the country was initiated during the 1940s in IARI and later in several other agricultural universities/ ICAR institutes. Currently, 27 early-varieties and 59 mid-season varieties are under cultivation in india. Initially, focus was on developing early-maturing varieties with high yield and quality. Subsequently, emphasis was laid on developing mid-season varieties having resistance to powdery mildew and other major diseases like *Fusarium* wilt and rust. Besides, varieties with resistance to bruchids and the leaf miner are also available. In the present paper, an attempt has been made to review current status of improvement of garden pea in India, covering its genetic resources, variability, heritability, genetic advance, heterosis and combining ability, G x E interaction, male sterility, breeding for biotic and abiotic stresses, mutation breeding and biotechnological applications. In recent years, there has been an increase in demand for varieties suited to *kharif* and *early summer* seasons, with resistance to powdery mildew, rust, *Fusarium* root wilt/rot and stemfly and also for processing and export. Therefore, future thrust in the improvement of garden pea would be on developing varieties tolerant to biotic and abiotic stresses (mainly high temperature), and also for processing and export.

Key words: Garden pea, *Pisum sativum*, genetic resources, breeding, varieties, resistance

INTRODUCTION

Garden pea (*Pisum sativum* L. var. *hortense*) belongs to the family Leguminosae (*Fabaceae*) is also called sweet pea is a choice vegetable grown for its fresh shelled green seeds rich in protein (7.2 %), vitamins and minerals. The green seeds are used as vegetable or can be used after processing (canning, freezing and dehydration). India is ranking second next to China both in terms of area and production (FAO, 2012). In India, it is grown in an area of 0.42 million ha with the production of 4.01 million metric tonnes and productivity is 9.5 t/ha. Garden pea is a cool season crop mainly grown during winter season in plains and during summer season in hills. Major area of garden pea is in temperate and subtropical regions of the country. It is also grown in some cooler parts of southern India. Garden pea is cultivated on a large scale in the states like Uttar Pradesh, Madya Pradesh and Jharkhand. It is also grown in Himachal Pradesh, Punjab, West Bengal, Haryana, Bihar, Uttarakhand, Jammu and Kashmir, Odisha, parts of Rajasthan and Maharashtra (Fig 1). In south it is grown in Karnataka and in the hilly regions like Ooty and Kodaikanal in Tamil Nadu. Uttar Pradesh is the leading state in the area (1.8 lakh ha) and production (18.8 lakh tonnes) followed by Madhya Pradesh (22.8 thousand ha; 5.34 lakh tonnes). Jammu and Kashmir is the leading state in productivity (20.8 t/ha) followed by Jharkhand (14.8 t/ha) Table 1 & 2 (NHB, 2013).

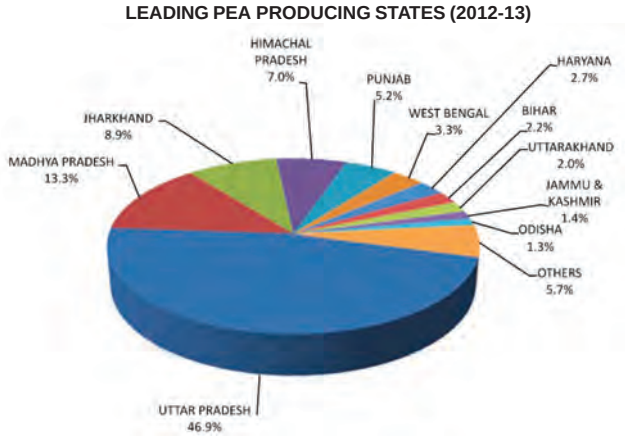

Fig 1. Garden pea area per cent share in different states in India.
Source : NHB, 2013

Table 1. State-wise area, production and productivity under pea (NHB, 2013).

Area (in 1000 ha), production (in 1000 tonnes) and productivity (t/ha)			
State	Area	Production	Productivity
Uttar Pradesh	175.01	1877.93	10.7
Madhya Pradesh	53.45	534.00	10.0
Jharkhand	24.13	358.22	14.8
Himachal Pradesh	23.67	280.23	11.8
Punjab	20.33	208.17	10.2
West Bengal	21.80	132.11	6.1
Haryana	15.08	107.54	7.1
Bihar	10.02	88.71	8.9
Uttarakhand	11.65	78.29	6.7
Jammu & Kashmir	2.79	58.08	20.8
Odisha	5.89	52.76	9.0
Others	57.10	230.10	4.0
Total	420.90	4006.17	9.5

Source: NHB, 2013

Origin

Pea (*Pisum sativum* L.) is one of the world's oldest domesticated crops (Ambrose, 1995; Zohary and Hopf, 2000). Vavilov (1928) considered Central Asia as a primary centre of origin and North East as a secondary centre of origin. Garden pea originated in the region comprising Central Asia, mediterranean countries and Ethiopia. It is native to Syria, Iraq, Iran, Turkey, Israel, Jordan, Ethiopia, Lebanon and has been cultivated in Europe for several thousand years (Nasiri *et al,* 2009). According to Blixt (1970), the Mediterranean is the primary centre of diversity with secondary centers in Ethiopia and the Near East. Smykal *et al* (2012) has reported that its area of origin and initial domestication lies in the Mediterranean, primarily in the Middle East. The wild representatives of *P. sativum* extend from Iran and Turkmenistan through Anterior Asia, northern Africa and southern Europe (Makasheva, 1979; Maxted and Ambrose, 2000; Maxted *et al,* 2010). Lamprecht (1956) reported that *Pisum sativum* (L.) originated in medieval times through a mutation to white flower and large seeded from cultivated form of *Pisum arvense* (L.). Purseglove (1974) regarded *P.elatius* a wild species in Russia as an ancester of *P. sativum*. The genus *Pisum* contains the wild species *P. fulvum* found in Jordan, Syria, Lebanon and Israel; the cultivated species *P. abyssinicum* from Yemen and Ethiopia, which was likely domesticated independently of *P. sativum*; and a large and loose aggregate of both wild (*P. sativum subsp. elatius*) and cultivated forms that comprise the species *P. sativum* in a broad sense (Jing *et al,* 2010; Ellis *et al,* 2011, Smykal *et al,* 2011; Upadhyaya *et al,* 2011).

Table 2. Major pea growing areas in different states (NHB, 2013).

State		Districts/location
Andhra Pradesh	:	Chittoor, Rangareddy, Medak
Assam	:	Darrang, Kamrup, Nagaon
Bihar	:	Patna, Nalanda, Bhojpur, Gaya, Muza Harpur, Vaishali, Samastipur, Katihar
Chhattisgarh	:	Raipur, Baloda Bazar, Durg, Bemetara, Rajnandgaon, Janjgir-Champa, Bilaspur, Korba, Raigarh, Surguja, Surajpur, Koriya, Balrampur
Haryana	:	Ambala, Yamunanagar, Kurukshetra, Kaithal, Karnal, Panipat, Sonipat, Gurgaon, Jind
Himachal Pradesh	:	lahul & spiti (Keylong, Kazza), Kinnaur (Kalpa, Sangla Nichar Valley, Chango, Pooh), shimla (Rohroo, Theog, Shogi, Mashoba), sirmour (Pacchad, Sangarh, Rajgarh)
Jharkhand	:	Ranchi (Ratu, Mandar), Ramgarh, Hazaribagh, Palamu
Karnataka	:	Kolar, Bengaluru, Mysore, Tumkur, Hassan, Chikkaballapur
Madhya Pradesh	:	Shajapur, Jabalpur, Ujjain, Dewas, Gwalior, Morena, Hoshangabad, Vidisha, Sagar
Maharashtra	:	Pune, Parbhani, Thane, Jalna, Nandurbar, Chandrapur, Buldhana
Manipur	:	Imphal Valley
Mizoram	:	Aizawl, Lunglei, Saiha
Nagaland	:	Kohima, Wokha, Mokochung, Zunheboto, Tuensang, Phek, Mon, Dimapur
Odisha	:	Angul (Kishorenagar), Sambalpur (Sasan)
Punjab	:	Hoshiarpur (Hoshiarpur 1, Hoshiarpur 2, Chabbewal), Amritsar (Verka, Jandiala Guru, Majitha, Rayya), Patiala (Sanaur, Rajpura, Ghannaur, Patran), S,B,S, Nagar (Nawan Shahr, Bala, Chaur)
Rajasthan	:	Jaipur, Alwar, Jodhpur, Udaipur
Uttar Pradesh	:	Lalitpur, Jalaun, Jhansi, Mohoba, Sultanpur, Hamirpur, Azamgarh, Basti, Allahabad, Pratapgarh, Etah, Mirzapur, Jaunpur, Kabir Nagar, Ambedkar Nagar, Sonbhadra, Faizabad, Barabanki, Raebareli, Sitapur, Siddharth Nagar, Gonda, Balia, Kanpur-Nagar, Kanpur-Dehat, KanshiRam Nagar
Uttarakhand	:	Almora, Chamoli, Champawat, Dehradun, Nainital, Tehri, Udham Singh Nagar, Uttarkashi
West Bengal	:	Nadia, Hoogly, 24 parganas

Classification

The genus *Pisum* is a member of the family Papilionaceae tribe *viciae* and is composed of two species, *P. sativum* L. and *P. fulvum* Sibth & Sm. *Pisum sativum* is further divided to include five subspecies, namely, *sativum*, *elatius, humile, arvense* and and *hortense*. The two sub species namely *arvense* and *hortense* are treated as varieties under species *sativum* (Govorov, 1928; Nasiri, 2009). Based on crossability and cytogenetical evidences, the number of species within the genus *Pisum sativum* includes the following sub-species (Simmonds, 1979) namely,

Pisum sativum L. var. *hortense* (garden pea), *Pisum sativum* L. var. *arvense* (field pea), *Pisum sativum* L. var. *macrocarpum* (whole pod edible pea), *Pisum sativum* var. *elatius* (wild form), *Pisum sativum* var. *syriacum* (wild form). A distinctive Ethiopian form *Pisum abyssinicum* has been recognized as a species (Smartt, 1990).

Description

Pea is an annual herbaceous plant, with angular or roundish hollow stems covered with a waxy bloom. In leafy types, leaves consist of one or more pairs of opposite leaflets borne on petioles together with several pairs of tendrils (which are essentially modified leaves) and a single or compound terminal tendril. Leaflets are broad and ovate with distinct ribs, and are slightly toothed or entire. Stipules are large, ovate and are irregularly toothed at the base. In semi-leafless types, the leaflets are replaced by tendrils but the stipules are still present. While in leafless types, the leaflets are also replaced by tendrils (*afila* type) but the stipules are rudimentary. *Afila* types have better standing ability than the leafy types because tendrils of adjascent plants intertwine. The plants have tap roots with numerous lateral roots. Inflorescence is a receme comprising one or two self-fertile flowers arising from axil of leaf. The flowers are zygomorphic and are hermaphrodite. Calyx consists of five green sepals and corolla has five petals. Flower colour ranges from white, pink, lavender, blue to purple. The diadelphous and roecium consists of 10 stamens (9 + l) with short filaments. Nine of these filaments at the lower portion are fused to form a staminal tube and surround the ovary. The 10^{th} stamen remains free. The gynoecium is monocarpellary. The ovary is superior, unilocular with marginal placentation, style short, curved, stigma flattened. Ovules upto 13 are arranged alternatively. The fruit is a pod containing several seeds, flattened when young but becoming round or nearly round later, and dehisce along the sides. The seeds may be round, dented or wrinkled. Seed colour ranges from creamy white to brown and may be mottled (Kalloo, 1993; Peter and Kumar, 2008).

Reproductive biology and Cytology

Pea is a self pollinated crop with cleistogamous flowers. Anthesis and anther dehiscence take place in the morning (5 to 8 am). Stigma of pea is receptive to pollen from several days prior to anthesis and one day after flower opening. Pollen is viable from the time anthers dehisce. Pollination occurs 24 h before flower opening. Pollen on the stigma germinates in about 8--12 h and fertilization occurs 24-28 h after pollination (Peter and Kumar, 2008). Outcrossing is generally less than 1%. Peas are diploid and the chromosome number is 2n=2x=14 (Yarnell, 1962). The standard karyotype of pea was described by Levitskii (1934) and Blixt (1959). Karyotype comprises seven chromosomes; five acrocentric and two sub-metacentric. Acrocentric chromosomes are distinguishable on the basis of arm length and centromere (Ellis and Poyser, 2002).

Genetics

Knowledge of gene action in plant breeding helps in the selection of parents for use in the hybridization programmes and also in the choice of appropriate breeding procedure for the genetic improvement of various quantitative characters (Sharma *et al*, 2013a). Pea genetics has been an object of study since early days (Knight, 1799; Mendel, 1866) and pea was the original model organism used in Mendel's discovery of the laws of inheritance, making it the foundation of modern plant genetics (Smykal *et al*, 2012). Vilmorin and Bateson (1912) were probably the first to study the linkage in peas. Genetic studies of several morphological, physiological, quality and resistance attributes have been reviewed by several workers and Lamprecht (1948) gave the first presentation of seven linkage groups (Blixt, 1974). According to Blixt (1974), around 169 genes have been assigned on different chromosomes or linkage groups. Most of the genes have been assigned by Lamprecht, based on dihybrid combination derived from analysis of F_2 generations. The linkage map of pea consists of over 200 loci (Kaloo and Bergh, 1993). The list of genes are given in Table 3 & 4.

1) Inheritance of qualitative characters

Pea has been extensively studied for the genetics of qualitative traits. Significant contributions on qualitative genetics of pea have been made by several scientists. Among them H. Lamprecht, L.M. Monli, S.J. Wellensick and Blixt have contributed enormously. Yarnell in1962 has listed several genes controlling various qualitative attributes and such genes are present in all the seven linkage groups (Kaloo and Bergh, 1993). Blixt (1974) has given a list of 324 qualitative genes. A partial listing of genes useful in breeding programme has been compiled by Gritton (1980) and Kumar *et al* (2006).

Amin *et al* (2010) have compiled the genes which govern various qualitative traits. Three single recessive genes, *cry*, *la* and *le* influence internode length and plant height. Each gene governs these characters along with other two genes. Similarly branching is controlled by two single recessive genes, *fr* and *fru* in presence of each other. A

Table 3. Gene action for various traits

	Character	Gene	Description
1.	Plant height	*cry*	Influences internode length; plant height along with *la* and *le*
		la	Internode length and plant height along with *cry* and *le*
		le	Internode length and plant height along with *cry* and *la*
2.	Wax (bloom)	*wa*	Without wax on pods, upper and lower stipules surfaces and underside of leaflets
		wb	Pods without wax, little wax on rest of plant
		wel	Wax absent from all parts of the plant
3.	Branching	*fr*	With *fru* determines number of basal branches
		fru	With *fr* determines number of basal branches
		ram	Increases number of branches
4.	Leaf and stipule	*af*	Leaflet converted into tendril
		lat	Double leaflet and stipule area
		tl	Leaves with extra leaflets and no tendrils
5.	Colour	*A*	Absence of anthocyanin
		d	Green leaf axil; dependent on '*a*' for manifestation of colour
		pa	Dark green immature seed and foliage
6.	Inflorescence, number of flowers	*fn*	With *fna* determines number of flower on the inflorescence; rearly influenced by environment
		fna	With *fn* determines number of flowers on the inflorescence, greatly influenced by environment
7.	Fasciation	*fa*	Stem fasciation with *fas*
		fas	Stem fasciation with *fa*
8.	Flower colour	*b*	Flower pink; dependent on '*a*' for manifestation of colour
		ce	Flower rose; dependent on '*a*' for manifestation of colour
9.	Seed	*com*	Sides of seeds flattened
		di	Small dimpled depressions in seed; observable only with *r* seed
		r	Seed cotyledons wrinkled
		rb	Seed cotyledons wrinkled
		gty	Gritty seed surface
		i	Green cotyledons; produces yellow cotyledons
		pl	Hilum black with *a* or *b*
10.	Pod	*bt*	Apex of pods blun
		con	Affects curvature of pods
		n	Pod wall thick
		p	Reduces or eliminates sclerenchymatous membrane on inner pod wall
		v	Same as *p*
		gp	young pod yellow

(Source: Amin *et al*, 2010)

Table 4. Gene list in pea

Gene	Phenotype	Class
Aat-m	mitochondrial aspartate aminotransferase	Physiological characters
ac	abnormal corolla	Flower and generative apparatus
Aldo-p	aldolase	Physiological characters
bcm	res. Bean Common Mosaic Virus	Physiological characters
beg	begoniaerubrum	Flower and generative apparatus
calf	cabbage leaf	Complex mutants
ch3	chlorina	Chlorophyll mutations
chi2	chlorotica	Chlorophyll mutations
chi23	chlorotica	Chlorophyll mutations
crd	crispoid	Foliage and emergences
cyv1	res.CYVV	Physiological characters
den	deminutio	Seed characters
Est2	esterase	Physiological characters
Est4	esterase	Physiological characters
fn	flower number	Flower and generative apparatus
Fum	fumerase	Physiological characters
Gal2	beta-galactosidase	Flower and generative apparatus
gfc	green flowers	Flower and generative apparatus
k	keeled wings	Flower and generative apparatus
mifo	minute-foveatus	Seed characters
mo	res. BV2, PV2	Physiological characters
orp	orange pod	Pods
pal	pallens	Seed characters
Pgm-p	plastid phosphoglucomutase	Physiological characters
ppd	photoperiod response	Physiological characters
Ppi3	-Not defined-	Physiological characters
pwv	res. PWV-K	Physiological characters
rms3	ramosus	shoot system
rug3	rugosus	Seed characters
s	chenille	Seed characters
smb2	res. BV2, PV2	Physiological characters
ster	female sterility	Physiological characters
stpr	abnormal generative organs	Flower and generative apparatus
str	brunneostriata	Seed characters
sym14	nodulation resistance	Root system
sym22	nodulation resistant	Root system
ve	ventriosus	Seed characters
vi2	viridis	Chlorophyll mutations

(Source: Peter and Kumar, 2008)

single recessive gene, *ram* is responsible for increasing the number of branches. The characters of leaves, leaflets, stipules and tendrils are governed by single recessive gene. The leaflets are converted into tendrils by the gene, *af*, double leaflet and stipule area, *lat*, tendrils present on acacia leaves, *tac* and leaves with extra leaflets and no tendrils, stem fasciation is controlled by two single recessive genes *fa* and *fas* along with each other. The wax or bloom trait is inherited by single recessive gene, such as *wa* for absence of wax on pods, upper and lower stipule surfaces and underside of leaflets, *wb* for pods without wax, little wax on rest of plants and *wel* for absence of wax from all parts of plant. The colour of plant and its parts, like foliage, flower, and seed are also governed by single recessive genes, like for absence of anthocyanin in plants, flower and seed, *ch-l* for light yellow green plant, *d* for green leaf axil, *pa* for dark green immature seed and foliage and *vm* with effect

similar to *pa*. The number of flowers on the inflorescence is controlled by two different recessive single genes, *fn* and *fna* in the presence of each other. The gene *b* is for pink flower and *ce* for rose coloured flowers and both are dependent on the dominant *a* for manifestation of colour. Single recessive genes determine various seed characteristics, like flattened seed sides (*com*), dimpled seed (*di*), wrinkled seed cotyledon (*r, rb*), gritty seed surface (*gty*), and green cotyledons (*i*), and black hilum by dominant gene *pi* along with *ar* and *b*. Single recessive gene, *it* increases pod width by 25%; the dominant gene *Con* effects curvature of pods, dominant *bt* for blunt apex of pods and recessive *n* for thick pod wall. Tough and leathery pods that dehisce readily at maturity are due to the presence of a dominant single gene, '*p*' and '*v*'are responsible for reducing or eliminating sclerenchymatous membrane on inner pod walls. The purple pod colour is governed by two dominant genes *pu* and *pur*, along with the dominant gene *a* and yellow colour of young pods by a recessive gene *gp*.

Singh *et al* (1986a) in a 10 × 10 diallel analysis reported that non-additive gene action was predominant for protein content. The persistence of SCA component for protein component indicated that additive × additive component was predominant. Mean degree of dominance indicated over dominance for protein content. Negative correlation coefficient (r) between parental order of dominance (Wr + Vr) and parental measurement (Yr) for protein content indicated that the dominant alleles contributed positively for the expression of this trait. Regression coefficient for protein content significantly differed from unity, suggesting the presence of non-allelic interaction of genes. The regression line passed below the origin, suggesting over dominance for protein content. Rastogi (1988) reported the presence of high non-additive genetic variance (H1 and H2) as compared to additive genetic variance (D) in a diallel analysis of ten parents for vitamin C content of garden pea seed in F_1 generation. The ratio of H2/4H1 was very near to the expected value of 0.25. KD/KR ratio in the parents was more than 1 revealing the predominant role of dominant alleles. The scatter of parental arrays suggested that the parents such as GC - 66 and Bonneville contained greater number of dominant genes for higher vitamin C content. Rastogi *et al* (1989) found significant non-additive components in case of protein content in pea seed.

2) Inheritance of quantitative characters

The highly heritable polygenic characters are plant height, earliness, number of pods per plant, pod length, seeds per pod and 100 seed weight. Pod yield has low heritability. Number of branches, earliness, number of pods per inflorescence, number of pods per plant, number of seeds per plant, seed weight and number of days to maturity and plant height had direct effect on yield. The gene action, degree of dominance, and inter allelic gene effects were studied for different plant characters. Seed yield per plant had additive genetic variance and positive epistasis. Plant height and days to flowering was controlled by non additive genes with partial dominance and over dominance (Amin *et al*, 2010). Genetics of few quantitative traits is given in Table 5.

Pod yield exhibited low heritability, whereas number of pods per plant exhibited high heritability. High estimates of heritability were recorded for plant height, pod length, seeds per pod and weight (Singh and Singh 1989a). Nandpuri *et al* (1973) reported a high genetic advance for number of pods per plant, plant height and 100 seed weight. Yield was positively correlated with number of pods per plant and number of seeds per pod, seed weight, branches per plant and number of clusters per plant. Number of clusters and number of pods per plant (Kalloo and Dhankar, 1977) and number of seeds per pod and harvest index, Tewatia *et al* (1983) had direct effect on yield.

Narsinghani *et al* (1982) reported that additive genetic variance in pea was significant for seed yield per plant, while epistatic gene action was positive for number of pods and

Table 5. Genetics of quantitative traits in pea

Trait	Inheritance / Gene action
Plant height	High Heritability, Over dominance, Partial dominance, High genetic advance
Days to flowering	Non-additive gene action, Partial dominance, over dominance
Earliness	Dominant genes; High heritability
Late	flowering Recessive genes; High heritability
First node bearing flower	Dominant gene action; Partial dominance
Number of pods per plant	High heritability; Epistatic gene action positive; High genetic advance
Pod length	High heritability
Number of seeds per pod and test weight	High heritability; Additive gene action and High genetic advance for 100 seed weight
Seeds per plant	Epistatic gene action positive; Additive, dominance and Over dominance
Pod yield	Low heritability
Cold resistance	Intermediate dominance, Polygenic, many recessive genes

(Source: Amin *et al*, 2010)

seeds per plant. There was a positive additive dominance and over dominance for seeds per plant. The monogenic system for days to flowering was observed by Ram *et al* (1981) but non- additive gene action was noted by Singh *et al* (1986a). Kumar and Agarwal (1982) concluded two types of genes, dominant genes for earliness and accumulation of recessive genes for late flowering. Higher narrow sense heritability has been obtained for this character by Singh (1979). Dominant gene action for first node -bearing flowers had been shown by Singh *et al* (1980) but Singh *et al* (1986a) obtained partial dominance. The difference in gene action observed in these studies can be attributed to genotypic differences.

Srivastava and Singh (1988) found both additive and non-additive gene effects to be important in genetics of seeds per pod in peas but non-additive gene effects were more prevalent than additive effects. Gupta and Lodhi (1988) evaluated nine cultivars of garden pea in a half diallel analysis for days to pod formation and days to maturity and observed the preponderance of both additive as well as non-additive gene effects for both traits. The complete dominance was observed for days to pod formation and over-dominance for days to maturity. The ratio of KD/KR (Ratio of dominant allele and recessive allele) revealed excess of dominance alleles for both the traits. Symmetry of distribution of positive and negative genes in the parents was indicated only for days to maturity. Positive correlation for days to pod formation showed importance of recessive alleles favouring delaying of pod formation, while negative association for days to maturity indicated importance of dominant alleles for late maturity. Singh and Ram (1988), observed that additive and non-additive gene action predominated for days to flower, green pods per plant, 100 green pod weight, pod length, shelling percentage, number node at which appear of first flower, primary branches per plant, plant height and green pod yield in diallel analysis of garden pea. Genetic components of variation analysis supported these conclusions.

Singh and Singh (1989b) studied genetics of earliness in terms of flower initiation and days to maturity in F_1 of 12 parents in a diallel cross in garden pea. The additive and non-additive components of genetic variance were significant for these characters. Karmakar and Singh (1990) observed that the analysis of variance for combining ability has revealed the role of additive as well as non-additive gene action in controlling the characters seed yield per plant, pods per plant, and seeds per plant, plant height and days to flowering. However, non-additive gene action was predominant for these characters.

Rana and Gupta (1994) carried out genetic analysis of green pod yield and found that it was influenced by over dominance. Sarawat *et al* (1994) found that both additive and non-additive gene effects were important in the expression of grain yield, branches per plant, pods per plant, seeds per pod, plant height and onset of flowering. Kumar and Bal (1995) predicted over dominance for yield, number of pods per plant, 100 seed weight and partial dominance for other. The degree of dominance indicated over-dominance for all the traits except pod length and seeds per pod. Sirohi *et al* (1995) found that additive x dominance and dominance x dominance types of non-allelic interactions were important in the inheritance of traits like days to flowering, days to maturity and plant height. Singh *et al* (1997) carried out genetic analysis to detect epistasis and to estimate components of genetic variance. Significant estimates of both additive and dominance components were observed for all the traits, except for pod length. The direction of dominance was positive and significant for days to flowering, plant height, number of pods per plant and seed yield indicating the isodirectional nature of dominance. Raj *et al* (1998) studied genetics of yield and it's components in garden pea. The characters like pod yield per plant, number of seeds per pod and number of pods per plant showed either significant additive or dominance or both gene effects along with (i), (j) or (I) types of epistasis in one or more cases. Sharma *et al* (1999) observed the presence of both additive and non-additive type of gene action in pea. Singh and Sharma (2001) recorded in a diallel analysis of 8 parents for five characters that additive gene effects were significant and positive in two crosses for plant height, number of pods per plant, number of seeds and pod yield per plant, Almost all the F_1 crosses had positive dominance gene effects for plant height, number of pods per plant, number of seeds per pod, pod length and pod yield per plant and a higher magnitude than that of additive gene effects. In diallel analysis of 10 parents for earliness, Sharma *et al* (2003a) reported that the additive (D) and non-additive (H1) components of genetic variance were significant for earliness. The degree of dominance was in partial dominance range in F_1 and over dominance range in F_2. The ratio of H2/4H1 revealed the symmetrical distribution of negative and positive alleles among the different parents. The ratio of KD/KR was more than unity in F_1 indicated excess of dominant alleles in the expression of these traits.

Ranjan *et al* (2005) estimated the variance ratio to determine the importance of additive and non-additive genetic variances. The variance ratio was less for days to flowering, plant height, branches per plant, days to maturity,

pods per plant, seeds per pod and seed yield per plant. Sood and Kalia (2006) conducted inheritance studies on seven economic traits viz., days to 50% flowering, days to first picking, pods per plant, seeds per pod, pod yield per plant and shelling percentage in a diallel set of eight parents excluding reciprocals in garden pea. From 28 F_1 crosses as well as their F_2's, prevalence of over dominance was observed for most of the traits in both the generations. Non-additive gene action appeared to be more predominant for the inheritance of most characters studied. Dominant alleles were more frequent in parental lines for the inheritance of most of the characters. Low to medium narrow sense heritability indicated presence of non-additive gene action for most of the traits except for pod yield. Dhillon *et al* (2006) reported additive and non-additive gene effects governed the inheritance of all the studied characters. The additive gene effects were more pronounced for days to flower initiation, node at which first pod appears, number of branches per plant, plant height, number of pods per plant, pod length, days to marketable maturity and shelling percentage, whereas the non-additive gene effects were more pronounced for number of seeds per pod, dry matter content and total green pod yield per plant.

Sharma and Sharma (2012) observed the prevalence of over dominance for most of the traits except for node number at which first flower appear. However, additive and dominance genetic variance were highly significant for days to 50% flowering and days to first harvest. For green pod yield per plant the regression line was linear and slope of regression varied significantly from unity suggesting the prevalence of non-allelic interactions. Low estimates of narrow sense heritability indicated the presence of non-additive gene action for most traits except for days to 50% and days to first harvest. These characters also exhibited medium to high level of heritability and the selections in segregating generation could be effective for evolving early maturing types.

Sharma and Bora (2013) reported higher values of heritability in broad sense and genetic gain indicating that the additive gene actions are important in determining the characters viz. plant height, days to first picking, 100 green pod weight, green pod yield and days to 50% flowering revealed. Therefore, selection programme based on these characters would be more effective in improving yield parameters of garden pea. Combining ability analysis for six physiological characters in pea revealed that leaf area and chlorophyll-a/b ratio was governed by additive gene action, while, both additive and non-additive gene action were important for controlling total chlorophyll, chlorophyll-a, chlorophyll-b content and specific leaf weight, as found by Sirohi and Singh (2013).

3) Inheritance of disease resistance

Single dominant genes confer resistance to several diseases like enation mosaic virus (*En*); near wilt, *Fusarium oxysporum* f. p*isi* race 2 (*Fnw*); fusarium wilt, *Fusarium oxysporum* f. *pisi* race 1 (*Fw*); brown root of peas, *Fusarium solani* f. sp. *pisi*; rust, *Uromyces fabae;* Downy mildew, *Perenospora pisi* and bacterial blight, *Pseudomonas syringe* pv. *pisi* race 1, pea root rot, *Aphanomyces euteiches.* Resistance to pea seed borne mosaic virus (*sbm*), powdery mildew (*er1, er-2*), bean yellow mosaic virus (*mo*), top yellow virus, pea streak virus, pea mosaic virus (*pmv*), and bean virus is controlled by recessice genes. Resistance to *Ascochyta* blight (*Ascochyta pisi*) is governed by duplicate factors or single dominant genes (Amin *et al*, 2010, in Kalloo, 1993) (Table 6).

Table 6. Genetics of disease resistance in pea

Resistant to	Inheritance
Enation mosaic virus	Single dominant gene, *en*
Single dominant gene, *fnw*	*Fusarium oxysporum* f.*pisi* Race 2, Near Wilt
Single dominant gene, *fw*	*Fusarium oxysporum* f.*pisi* Race 1, Fusarium wilt
Single recessive gene, *sbm*	Pea seed borne mosaic virus
Single recessive gene, *er*	Powdery mildew (*Erysiphe polygoni*)
Single recessive gene, *er-2*	Powdery mildew (*Erysiphe polygoni*)
Monogenic, dominant	Brown root of peas, *Fusarium solani* f. sp. *pisi*
Monogenic, dominant	Rust, *Uromyces fabae*, resistance dominant
Monogenic, dominant	Downy mildew, *Perenospora pisi*
Duplicate factor or Single dominant gene	Ascochyta blight, (*Ascochyta pisi*)
Single recessive gene (*mo*)	Bean yellow mosaic virus
Monogenic recessive	Top yellow virus
Single recessive gene	Pea leaf roll virus
Single recessive gene	Pea streak virus
Single recessive gene (*pmv*)	Pea mosaic virus
Single recessive gene	Bean virus 2

(Source: Amin *et al*, 2010)

Varieties

There are three groups of varieties namely early, mid season and late. The early group varieties are dwarf and attain pod maturity in 40 to 45 days and generally two harvests can be done. The duration is 60- 70 days. The early varieties have the advantage in the market as they get better price. Further, early life cycle also helps farmer to quickly switch over to second crop. Due to their compact

GARDEN PEA VARIETIES

Early Season group

AP-3 (Kalyanpur)

Arkel (IARI)

VL-7 (VPKAS, Almora)

Mid Season group

Arka Ajit (IIHR)

Arka Karthik (IIHR)

Araka Pramodh (IIHR)

Arka Priya (IIHR)

Azad P1(CSAUA&T, Kanpur)

Whole pod edible (Snap Pod) group

Arka Apoorva (IIHR)

Arka Sampoorna (IIHR)

Oregon Sugar

Swarna Tripti (RCER, Ranchi)

plant habit more number of plants could be accommodated per unit area and thereby increasing the yield. Details of early varieties are given in Table 7. The mid season varieties attain pod maturity in 60 to 65 days and the duration is 90 days. Generally, three harvests can be done and pod yield is 10 to 12 t/ha (Table 8). In late varieties plants are tall (4 to 5ft) and needs staking. Pod maturity is 90 days and duration is 120 days (Table 9). The popular varieties and recommended areas for this cultivation are given in Table 10.

Table 7. Details of early varieties

SN	Variety	Source	Trait	Remarks
1.	Ageta	PAU, Ludhiana	Plants are small, erect and green in colour. It is suitable for early sowing. First flower appears in about 25 days after seed sowing and it takes about 6 weeks for first picking. Two picking are done. Average green pod yield is 50-55 q/ha.	*Fusarium* wilt resistant
2.	Alaska	Introduction from England	Early, smooth-seeded green pea Pods are light green and appears singly with 5-6 small, bluish-green. 55 days to maturity.	-
3.	AP 3	Kalyanpur	Early maturing variety (50-55 days), Pods are long (9-9.5cm), dark green, 7-8 green seeds per pod, shelling percentage is 47%. Pod yield 7 t/ha in 60 -65 days.	-
4.	Arkel	IARI, New Delhi	Early maturing variety. Plant height is 45 cm. Pods are dark green, 8.5 cm long, 7-8 green seeds per pod, incurved towards the sutures. First picking in 55-60 days. Recommended in 1978. Pod yield 7.5 t/ha in 50 -55 days. Shelling percentage is 40%.	Suitable for both fresh market and dehydration.
5.	Asauji	IARI, New Delhi	Flowering in 30-35 days after sowing and blossom appear in 6-7 nodes. Pods are produced singly. Pods are about 8 cm long, curved, dark green, narrow and appear round when fully developed, Each pod contains seven seeds. Pods give high shelling percentage (45%).	-
6.	Early Badger	Introduction from USA	A dwarf wrinkled seeded variety. Pods are ready for picking in 60-65 days after sowing. First blossom appears in 10-11th node; pods are yellowish green and borne singly, 7.5 cm long with 5-6 bold and sweet seeds.	Good caning variety; *Fusarium* wilt resistant
7.	Early Superb	Introduction from England	Yellowish green foliage. It flowers in about 45 days and first blossom appears at 8-10th node. Pods are borne singly; these are dark green, curved with 6-7 smooth seeds. Shelling percentage is 40%.	-
8.	Harbhajan (EC 33866)	JNKVV, Jabalpur	Developed at Jabalpur by selection from the exotic genetic stock. It is very early and first picking can be taken in 45 days of sowing. Plant type resembles that of field peas; pods are small with yellow, round and small seeds. Average pod yield 3 t/ha.	-
9.	Jawahar Matar 3 (JM 3)	JNKVV, Jabalpur	Developed through hybridization of T19 x Early Badger followed by selections. Plant height 70-75 cm with bushy growth habit; flower colour white. First picking 50 days, pods 7 cm long, light green, roundish-oval in shape with 4-5 wrinkled seeds. Shelling percentage (45%).	-
10.	Jawahar Matar 4 (JM 4)	JNKVV, Jabalpur	Developed at Jabalpur through advanced generation selections from the cross T19 x Little Marvel. Plant height 65 cm, foliage and stem are green. First picking after 70 days. Pods are green, medium in size (7cm) with 6-7 green, wrinkled and sweet seeds. Average pod yield 7 t/ha with 40% shelling.	-
11.	Jawahar Peas-4 (JP4)	JNKVV, Jabalpur	This powdery mildew resistant and wilt tolerant variety for hillocks was developed at Jabalpur through advanced generation selections from a triple cross Local Yellow Batri × (6588 × 46C). Plants attain height of around 75 to 80 cm on hillocks and about 1 m in plants; medium size pods with 5-6 bold, green seeds. First picking after 60 days in hillocks and 70 days in plains. Average pod yield 3-4 t/ha in hillocks and 9 t/ha in plains.	Powdery mildew resistant
12.	Jawahar Peas 54 (JP 54).	JNKVV, Jabalpur	Developed at Jabalpur through advanced generation selection from a double cross (Arkel × JM5) × ('4bc' × JP 501). Plants are dwarf and vigorous. Pods are round to oval shaped, 5 cm long, curved (sickle shaped) and enclosing 8-9 big, wrinkled, greenish-yellow seeds. Shelling percentage is 45. Average pod yield 7 t/ha. Recommended for zones IV, V, and VII.	Powdery mildew resistant variety.
13.	Kashi Kanak	IIVR, Varanasi	It is an early maturing variety developed through selection. It has plant height 50-55cm, foliage dark green, pod straight, light green, length 7-8 cm filled with bold seeds. First picking at 55-58 days after sowing, green pod yield 60-80 q/ha.	-

Table 7. Contd.

SN	Variety	Source	Trait	Remarks
14.	Kashi Mukti (VRP22)	IIVR, Varanasi	Early maturing powdery mildew resistant variety developed through pedigree selection from the cross No. 7 x PM-5. Plant height is 50-53 cm and 50% flowering at 35-36 days after sowing. Pods are 8.5-9 cm long, attractive filled with 8-9 bold soft textured seeds, shelling percentage 48-49, Yield 9.0-11.0 t./ha. Recommended for U.P., Punjab, and Jharkhand.	Powdery Mildew Resistant
15.	Kashi Nandini (VRP 5)	IIVR, Varanasi	Early maturing variety developed through pedigree selection from the cross P 1542 x VT-2-1. Plant height 47-51 cm, flowers appear at 32 days after sowing, bears7-8 pods per plant. Pods are 8-9 cm long, attractive, length 8-9 cm, well filled with 8-9seeds, shelling 47-48%, yield 110-120 q/ha. Recommended for J&K, H.P., Uttrakhand, Punjab, Tarai region of U.P., Bihar, Jharkhand, Karnataka, Tamil Nadu and Kerala.	It is tolerant to leaf miner and pod borer
16.	Kashi Udai (VRP 6)	IIVR, Varanasi	Early maturing variety developed through pedigree selection from the cross Arkel x FC-1. Plant height is 58-62 cm and 50% flowering at 35-37 days after sowing. Plants have dark green foliage and short internodes with 8-10 pods per plant. Pods are attractive, length 9-10 cm, filled with 8-9 bold seed, shelling percentage 48; yield 10- 11 t/ha. Recommended to UP.	-
17.	Little Marvel	Introduction from England.	A dwarf wrinkled seeded variety. It is bred in England from the cross Chelsea Gem x Suttons Alaska. Foliage dark green; first blossom appears at 9-10th node in 40 days after sowing. Pods 8 cm long bore singly, thick, shinny,dark green, straight and broad containing 5-6 sweet seeds.	-
18.	Lucknow Boniya	-	Dwarf white-seeded cultivar, flowers in 40 days. The pods are borne singly, small, narrow, green, and 4-5 seeded when fully developed.	-
19.	Matter Ageta 6	PAU, Ludhiana	Dwarf, high yielding variety developed at Ludhinana through pedigree selction from the cross Massey Gem × Harabona. Plants are dwarf (40 cm), erect, vigorous and quick growing; foliage green and 1-2 pods are borne in a bunch; first picking within 50-55 days after sowing; pods are long with 6-8 round green seeds; average pod yield 6 t/ha with 44% shelling.	It is tolerant to high temperature
20.	Meteor	Introduction from England.	Plants are 35-40 cm tall, dark green foliage; pods are produced singly, dark green, 8.7 cm long with seven smooth seeds. Shelling percentage is 45%.	-
21.	Pant Matar 2 (PM-2)	GBPUAT, Pantnagar	Developed at Pantnagar through pedigree selection from the cross Early Badger × IP3 (Pant Uphar). Plant height 50-55 cm; fruit setting starts from 6th node. Pods are green, relatively small in size than Arkel, with 6-8 sweet and wrinkled seeds. First picking starts 60-65 days after sowing. Average pod yield 7-8 t/ha.	
22.	Pant Sabji Matar-3	GBPUAT, Pantnagar	Early maturing variety developed through pedigree selection from a cross of Arkel & GC 141. Plants are dwarf with dark green foliage. The pods are long well filled with 8-10 seeds. Average pod yield 9-10 t/ha.	
23.	Pant Sabji Matar-4	GBPUA&T Pantnagar	Early variety (70 days to green pod picking) and resistant to powdery mildew. It is leafless type. Yield is 90 q/ha. J&K, H.P., Hills of U.P., Punjab, Tarai region of U.P., Bihar and Jharkhand	Resistant to mildew powdery
24.	Pant Sabji Matar-5	GBPUAT, Pantnagar	Pant Sabji Matar-5 is an early-maturing variety whose plant is dwarf. Pods are long, well-filled and slightly curved towards the tip. The seeds are green and wrinkled at maturity. The first green pod picking can be done within 60 to 65 days and seed maturity is recorded in 100 to 110 days after sowing. Its green pod yield potential is 90-100 quintals per hectare. The variety is suitable for cultivation in Kumaon hills and the plains of Uttarakhand.	Resistant to powdery mildew
25.	VL-Ageti Matar-7 (VL-7)	VPKAS, Almora	Developed at VPKAS, Almora through advanced generation selection from the cross Pant Uphar x Arkel. Plants are dwarf with green foliage and white flowers. Pods are light green, attractive, medium in size (about 8 cm) containing 6-7 seeds. The seeds are light green, dimpled bold and very sweet with high TSS (16.8%). Average yield 10 t/ha with 42% shelling. Suitable for pea growing areas of Uttaranchal, Uttar Pradesh and Bihar, Uttarakhand.	
26.	VRP 2	IIVR, Varanasi	Plants 50 cm tall. Pods straight and medium sized. First harvest in 55-58 Yield 10 t/ha.	

Table 8: Details of mid season varieties

SN	Variety	Source	Trait	Remarks
1.	Alderman	Introduction from USA	Plants are tall (150 cm); pods are more or less straight, big (9-10 cm) and borne singly with 8-10 very sweet, shiny seeds.	Suitable for freezing.
2.	Arka Ajit	IIHR, Bangalore.	Developed by back cross method of breeding using Bonneville, Freezer 656 Erygel and IIHR209 followed by pedigree method. Plants medium tall, Pods 8 cm long with 8 very sweet seeds. Pods mature in 65 days. Shelling percentage 55. Pod yield. 10t/ha in 90 days. Seeds medium bold and light green. Released by CVRC and recommended for UP, Rajasthan and Karnataka.	Resistant to powdery mildew and rust.
3.	Arka Apoorva	IIHR, Bangalore.	A whole edible, dual purpose, midseason pea variety; resistant to powdery mildew and rust; Pods green, crisp, sweet, can be used as salad at immatureand medium mature stage; seeds are bold, sweet and dark green; TSS 12; pod yield 11 t/ha in 90 days.	Moderately resistant to powdery mildew and rust.
4.	Arka Karthik	IIHR, Bangalore.	This is a mid season variety developed at IIHR and released at the Institute level during 2001. It is resistant to both powdery mildew and rust and suitable for freezing. Pod yields 11 tonnes per ha. in 90 days. The pods are 10.5 – 11.0 cm long, seeds bold, light green and sweet.	Resistant to powdery mildew and rust
5.	Arka Pramodh	IIHR, Bangalore.	Mid-season pea variety; pods are medium long (8.0 cm) and slightly flattish round, mature in 65 days; seeds are bold, round, dark green and very sweet; resistant to powdery mildew and rust; pod yield 12 t/ha in 90 days	Resistant to powdery mildew and rust
6.	Arka Priya	IIHR, Bangalore.	Mid-season variety; pods are round, medium long (8 cm), mature in 65 days; seeds are round, medium bold, dark green and very sweet; resistant to powdery mildew and rust; pod yield 12 t/ha in 90 days.	Resistant to powdery mildew and rust
7.	Arka Sampoorna	IIHR, Bangalore.	It is a whole pod edible mid season pea variety developed at IIHR. Pods mature in 55 days. Pods are light green, medium long, with less parchment in the pod walls and medium sweet and crisp. The pods are edible at any stage of development. Seeds are medium bold, sweet. Pod yield 8 t/ha in 85 days.	Powdery mildew and rust
8.	Azad P-1	CSAUA&T, Kanpur.	Plant height 80-90 cm, foliage dark green, days to flowering 40-45 days. 4 pickings. 8 – 9 t/ha.	-
9.	Azad P-2	CSAUA&T, Kanpur.	Developed through advanced generation selection from the cross Bonneville×6587. Plants are tall (130-150 cm), erect with light green foliage and white flowers. Pods smooth, dark green, 8-10 cm long, narrow, very tightly filled, 8-10 seeds per pod, 30-40 pods per plant, shelling percentage 50-55%. First harvest 75 days after sowing. Average yield 12t/ha. in 90 – 95 days.	Resistant to powdery mildew.
10.	Azad P-3	CSAUA&T,Kanpur.	Early maturing variety. First picking in 70 days after sowing. Pods are well filled, bold, green, attractive, straight and medium size. Yield 8 t/ha.	-
11.	Azad P-4	CSAUA&T, Kanpur.	Medium tall, small pods, resistant to Powdery mildew. Average yield 80-90 q/ha. Punjab, Tarai region, of U.P., Uttarakhand, Bihar, Jharkhand	-
12.	Azad P-5	CSAUA&T, Kanpur.	Medium tall, well branched foliage green, flower white, pod medium long smooth and light green seed brown and wrinkled. Pod yield	-
13.	Bonneville	IARI New Delhi	Introduced variety from USA. Plant medium tall (60 cm), flowers are mostly borne in doubles; pods are light green, straight, big (9 cm) with 6-7 well-filled, sweet, bold and wrinkled seeds. 65-70 days for first flowering. Shelling percent 45. Average pod yield 9 t/ha.	-
14.	DPP-9411	HPKV, Palampur	Developed through recombination breeding at HPKV, Palampur and identified for release through AICRP-VC in 2002. Plants are medium tall (67.6 cm) with deep green dense foliage. Pods are deep green, straight, well-filled, medium-sized 6-7 cm long and contain 7-8 bold grains per pod, sweet with TSS 16.5°B. It has marketable maturity in 130 days in the hills and it is resistant to powdery mildew. Recommended for J&K, H.F and Uttaranchal and has yield potential of 100-105 q/ha.	
15.	Hara Bona	Punjab	Medium tall, days to first picking 45-50 days. Node to first fruiting 6-7. Pods 7-8 cm long, dark green, 5-6 seeds per pod. Escapes powdery mildew and pea rust owing to earliness.	-

Table 8. Contd.

SN	Variety	Source	Trait	Remarks
16.	Hisar Harit	HAU, Hisar	Developed at Hisar through bulk-pedigree method of selection from the cross Bonneville × P23. Plant semi dwarf, first picking after 60 days, foliage green; single to double podded; pod well filled and sickle shaped, large and green. Pod length 6.8 cm; seed green dimpled after drying. Average pod yield 10 t/ha.	-
17.	Jawahar Matar 1	JNKVV, Jabalpur	Identified in 1975 for the zones I, IV, VII. Developed at Jabalpur through advanced generation selections from the cross of T19 × Greater Progress. Plant height 65-70 cm, bushy, foliage green, flower white with two flowers per axil. Pods straight with beak like outgrowth at the lower end and big (8 - 9 cm) with 8-9 big, sweet and wrinkled seeds. Average pod yield 10-12 t/ha with 52% shelling.	-
18.	Jawahar Matar 2	JNKVV, Jabalpur	Developed at Jabalpur through advanced generation selection from Greater Progress × Russian-2. Pods dark green, big, curved with 8-10 sweet seeds. Seeds are wrinkled, green and bigger in size.	-
19.	Jawahar Matar-4	JNKVV, Jabalpur	Mid season variety derived from T 19 x Little Marvel. Plants 50-60 cm tall. Foliage green. Pods green, 7 cm long. Mature seeds green and wrinkled. Recommended for zone number IV and VII. Average yield 12 t/ha.	-
20.	Jawahar Matar 15	JNKVV, Jabalpur	This duel variety was developed at Jabalpur through advanced generation selections from the triple cross (JMI × R 98 B) × JP 501 A/2. Plants are dwarf (50 cm), having compact internodes and bigger pods containing 8 seeds. Average pod yield 13 t/ha.	Resistant to powdery mildew and fusarium wilt
21.	Jawahar Peas 54	JNKVV, Jabalpur	Developed at Jabalpur through advanced generation selection from a double cross (Arkel × JM5) × ('4bc' × JP 501). Plants are dwarf (45-50 cm) and vigorous, pods are big, incurred towards sutures (sickle shaped) and enclosing 8-9 big, wrinkled, greenish-yellow seeds. Average pod yield 7 t/ha.	Powdery mildew resistant
22.	Jawahar Peas 71	JNKVV, Jabalpur	A progeny of double cross (Arkel x JP 829) x (JP 501 x JM 1) belongs to mid-season group. The plants are 50 cm in height and the pods are medium sized (7 cm) with 6-7 ovules. Average pod yield 12 t/ha. The seeds are green, wrinkled and bigger (100 seed weight 17 g).	Powdery mildew resistant
23.	JP 83	JNKVV, Jabalpur	Mid season variety developed through double cross (Arkel x JP 829) x (46 C x JP 501). Plants dwarf. Pods big and curved with 8 green and sweet ovules. Yield 12-13 t/ha.	Powdery mildew resistant
24.	Kashi Shakti	IIVR, Varanasi	This is a medium maturing variety developed through pedigree selection from the cross Hara Bona x NDVP-8. Plant height is 90-98 cm and 50% plants bear flowers at 54-56 days after sowing. Plants have dark green foliage with 11-12 pods per plant. Pods are 10-10.5 cm long, attractive, filled with 7.5-8.5 bold seeds, shelling percentage 48-49; yield 14-16 t/ha.	-
25.	Kashi Samridhi (VRPMR-11)	IIVR, Varanasi	Developed from the cross FC-1 x PM-5, Semi-determinate, plant ht. 65-75 cm. Foliage dark green, short internode length. Good attractive and well filled green smooth pods, 13-14 pods/plant, average pod weight is 5-6 g. 7-8 bold seed/pod, round in shape. Recommended for States of Uttar Pradesh, Bihar and Punjab. Late (90-100 days), Resistant to shattering, Avg. pod yield 10.2-13.0 t/ha	Resistant to PM, tolerant to leaf miner and pod borer.
26.	Khapar Kheda	Maharashtra	It is a local selection. Plants are tall growing. A popular double-podded cultivar and flowers in 65-70 days. Pods are small and seeds are wrinkled. Pods are 5-6 cm long and 4-5 seeded when fully developed. Average green pods yield 5 to 6 t/ha.	-
27.	Lincoln	IARI Katrain introduced from USA	Medium tall, plants bear double pods of 8-9 cm length and sickle shaped. Pods are dark green. Mature seeds wrinkled, dark green, sweet, 8-9 grains/ pod, First picking 85-90 days. Shelling percentage is 46. Fresh seeds are sweet. Yield 6.8-10 t/ha. Long shelf life.	Good for canning

Table 8. Contd.

SN	Variety	Source	Trait	Remarks
28.	Matter Ageta 6	PAU, Ludhiana	Dwarf, high yielding variety developed at Ludhinana through pedigree selection from the cross Massey Gem × Harabona. Plants are dwarf (40 cm), erect, vigorous and quick growing; foliage green and 1-2 pods are borne in a bunch; first picking within 50-55 days after sowing; pods are long, 12 to 15 pods per plant with 6-8 round green seeds. Shelling per cent 44. The grains are sweet and taste is better, the seed is smooth, dented and light green with high dry matter, chlorophyll and crude protein. Average pod yield 6 t/ha.	Tolerant to high temperature. suitable for processing.
29.	Mithi Phali	PAU, Ludhiana	Plants are dwarf, gives high green edible pod. Yield- 8t/ha.	-
30.	Narendra Sabji Matar-2	NDAU&T, Faizabad, UP	Plant height 70-75 cm, days to flower 50-54 days. Recommended for cultivation in Punjab, Uttar Pradesh and Bihar. Moderately tolerant to powdery mildew, rust and major pests under field conditions.	-
31.	Narendra Sabji Matar 4	NDAU&T, Faizabad, UP	Developed at NDUA&T, Faizabad. Plant tall (70-75 cm) and green in colour. Mature grains are wrinkled, 7-9 per pod and green in colour. Recommended for UP. Average pod yield 10-11 t/ha.	-
32.	Narendra Sabji Matar 6	NDAU&T, Faizabad, UP	Developed through hybridization CKS-123 x Arkel followed by pedigree selection at NDUA&T, Faizabad and notified by CVRC (Notification no. 597 CE) dated 25.04.2006. Plants are green, 45-55 cm tall, flowering starts in 30-35 days, early maturity, first green pod picking in 60-70 days after seed sowing. Pods are 8 cm long filled with 7-8 green sweet seeds. Recommended for Punjab, U.P., Bihar, and Jharkhand. Average pod yield 8.5-9.5 t/ha.	-
33.	Ooty-1	HRS, TNAU, Ooty	Developed at TNAU through pure line selection from the accession PS 33. It is a dwarf type, yield potential of 11.9 t/ha in 90 days of crop duration.	Resistant to white fly.
34.	P-8	PAU Ludhiana	7-8 seeds per pod, less sweet. Shelling 47.3%. Days to flowering 72. Mature seeds green wrinkled. Susceptible to powdery mildew. Identified in 1985.	-
35.	Palam Priya	HPKV, Palampur	Pedigree selection from the cross Bonneville x P 388. Plants are medium tall (60-67 cm), vigorous with dark green foliage and branching habit. The pods are borne in double and are smooth, straight, light green, long (8-9 cm) well filled (7-8 seeds/pod) with 60 % shelling. Its green peas contain 15-16 % TSS. The seeds become wrinkled upon maturity with light bluish green colour. On an average it gives 4-5 green pod pickings in hills with an average pod yield of 12.5- 15 t/ha.	Resistant to powdery mildew, tolerant to leaf minor
36.	Pant Uphar	GBPUAT, Pantnagar	Developed at Pantnagar through selection. Pant height 70-75 cm with relatively thin leaflets of light green in colour; flower white and two buds are borne per axil; pods are round and 7-8 cm in length with yellowish and wrinkled seeds. First picking starts 75 to 80 days after sowing. Average pod yield 10 t/ha with 52% shelling.	Tolerant against pea stem fly.
37.	PC-531	Ludhiana	Mid season variety. Pod maturity in 65-70 days. Pods dark green, long (8-9cm), round and shelling 50%. Average pod yield is 10 t/ha in 90 days.	
38.	Perfection New Line	It is an introduced variety from USA	The plant is vigorous and medium tall and flowers are borne in doubles; pods are about 8 cm long, dark green with 6-7 light green, sweet and wrinkled seeds. First picking starts after 85 days. It is a high yielding variety. Average pod yield is 10 t/ha.	-
39.	Punjab 87	PAU, Ludhiana	Pant height 75.5 cm, leaves dark green and 1 to 2 pods per axil. Pod maturity in 100 -120 days. Pod length 9.3 cm. Seeds bold, wrinkled and average seeds per pod 7.6. Pod yield 10 to 12 t/ha.	-
40.	Punjab 89	PAU, Ludhiana	Pant height 92 cm, vigorous having more number (28-30) of well filled pods per plant. The pods are dark green, long having 9-10 sweet grains per pod with 55 % shelling. Pods are borne in doubles. It takes 85-90 days for first picking. Average green pod yield 15 t/ha.	-

Table 8. Contd.

SN	Variety	Source	Trait	Remarks
41.	Phule Priya	MPKVV, Rahuri	Suitable for rabi season. Pods are straight, green, tender, sweet, 8-10 greens per pod. Average pod yield 10-10.5 t/ha. Recommended for Maharashtra	Tolerant to powdery mildew.
42.	Pusa Pragati	IARI, New Delhi	Introduction from Germany in 1983. Pods long (10 cm), green with 9 seeds per pod; first picking 60-65 days; Yield 7 t/ha. Released in 1987.	Resistant to powdery mildew.
43.	Swarna Mukti	HARP, Ranchi	A mid season variety. Recommended for cultivation in Jharkhand, Bihar and Rajasthan Yield : 20-25 t/ha	Resistant to powdery mildew.
44.	Swarna Rekha	HARP, Ranchi	Early maturing selection from local material of Bihar. It matures in about 120 days. Plants are semi-spreading type with white flowers. Seeds are round, smooth and creamy in colour with black hilum. It is suitable for green pods and dry seeds as well. Its average yield is 8-10 t/ha of green pods and 1.5-2.0 t/ha of dry grains.	-
45.	Swarna Tripti	HARP, Ranchi	Recommended for cultivation in Jharkhand, Bihar and West Bengal. Yield: 24-28 t/ha.	Snap pea
46.	Sylvia	IARI Katrain	Introduced from Sweden. Plants are tall; first blossom appears at 14^{th} to 16^{th} node after 60 days of sowing. Pods are borne singly, yellowish in colour, long (12 cm) and curved without parchment type pericarp. Pods are sweet and have general appearance of a medium sized French bean pod.	Whole pod edible snap pea
47.	Type 19	Department of Agriculture, Varanasi,U.P	Selection from a sample of Varanasi district of UP. It matures in 120 days. It has dark green foliage and white flowers. Seeds are wrinkled and greenish white. Pods are ready for picking in about 75 days. Average green pod yield 7-10 t/ha. 45% shelling.	-
48.	Vivek Matar-3	VPKAS, Almora	Developed at Almora through pedigree selection from the cross Old Sugar × Early Wrinkled Dwarf 2-2-1. Plant height 67 cm, determinate in habit with light green foliage, white flower and bear two pods in a bunch; pods are light green, 6.8 cm long, straight with 5 wrinkled seeds. First picking starts 100 days after sowing. Average pod yield 10 t/ha with 46% shelling. Identified in 1987 for zones I, IV, VII.	Tolerant to powdery mildew and wilt
49.	Vivek Matar-6	VPKAS, Almora	Developed at Almora through hybridization of Pant Uphar × VL Matar-3 and subsequent selections in advanced generations. Plants are dwarf, vigorous with dark green foliage and white flowers. Pods are light green, straight, medium sized (6-7 cm) and completely filled with 6 semi-wrinkled seeds of greenish white colour. First picking starts 125-130 days after sowing. Average yield 10-11 t/ha. Notified in 1997 by CVRC. Recommended for Uttarakhand Hills, H.P., Delhi, Haryana and Rajasthan.	Moderately tolerant to cold and moisture stress
50.	VL-8	VPKAS, Almora,	Plant height 65-70 cm, pods light green, pod aturity 135-140 days. Pod yield 11 – 12 t/ha. Notified in 1997 by CVMRC. Recommended for Uttarkhand, Himachal Pradesh and Jammu and Kashmir.	Tolerant to powdery mildew and white rot.
51.	Vivek Matar 10	VPKAS, Almora	Plant height 62 – 65 cm. Pods curved, dark green pods; fresh seeds, green and sweet; pod maturity 125-130 days. Pod yield 9 – 11 t/ha. Notified in 2008 by CVRC for Uttarakhnad, H.P., J&K, UP.	Resistant to white rot, wilt, leaf blight and moderately resistant to powdery mildew and tolerant to pod-borer.
52.	VRP 2	IIVR, Varanasi	Plants 50 cm tall. Pods straight and medium sized. First harvest in 55-58. Pod yield 10 t/ha.	-
53.	VRP 3	IIVR, Varanasi	Mid season variety which flowers between early and mid season. Pod Yield 8 t/ha.	-
54.	VRP-7	IIVR	Mid season variety. Pod maturity in 65-70 days. Pods dark green, long (8-9cm) and shelling 50%. Average pod yield is 9-10 t/ha in 90 days.	
55.	Madhu		Plant height 130-150 cm, foliage yellowish green days to flowering 50-55 days, pods 12-15cm long, light green, smooth surface, 2-2.5 cm broad, 20.25 pods per plant and 5-6 seeds per pod.	-

Table 9. Details of late varieties

SN	Variety	Source	Trait	Remarks
1.	NP 29	IARI New Delhi	Plants are medium-tall with green foliage. First blossom appears at 14-16th node after 80 days from sowing, pods are ready to harvest after 100 to 110 days of sowing. Pods are borne in double, green, straight, 7.5 cm long with 6-7 seeds. Shelling percentage 50.	Suitable for dehydration purpose.
2.	Punjab 88	PAU Ludhiana	Developed at Ludhiana through selections from the hybrid progeny of the cross Pusa 02 × Morrasis-55. Plant height 75.5 cm, vigorous, erect with dark green foliage; one or two flowers per axil. Flowering after 75 days and first picking 100-120 days after sowing. Pods are dark green, long (8-10 cm) and slightly curved at centre with 7-8 green less sweet seeds. Pod yield 10-12 t/ha with 47% of shelling. Notified in 1980.	
3.	Vivek Matar 9	VPKAS Almora	Plant height - 60-70 cm, pods are dark green, long, pod maturity 130-140 days. Pod yield 9-11 t/ha. All pea growing areas of Uttarakhand Hills Uttaranchal. Notified in 2006 by SVRC.	Tolerant to powdery mildew and white rot
4.	Vivek Matar 11	VPKAS Almora	It was developed by hybridization between 'Azad Pea 1' × 'PRS-18-6-4-5-1'. Plants are 50-60 cm tall. Pods curved, dark green mostly double pods; Pod length 8-9 cm, fresh seeds green and sweet; pod maturity 132-135 days. Pod yield 9-11 t/ha. Notified in 2010 by SVRC for Uttarakhand, H.P., J&K, UP.	Tolerant to powdery mildew

Table 10. Popular varieties and recommended area/s for their cultivation (NHB, 2013)

Name of variety	Recommended area/s
IARI, New Delhi	
Bonneville	All over India
Arkel	All over India
Pusa Pragati	All over India
IIHR, Bengaluru	
Arka Ajit	Punjab, Tarai region of U.P., Rajasthan, Gujarat, Haryana, Delhi, Karnataka, Tamil Nadu and Kerala
IIVR, Varanasi	
Kashi Nandini	J&K, H.P., Uttrakhand, Punjab, Tarai region of U.P., Bihar, Jharkhand. Karnataka, Tamil Nadu and Kerala
Kashi Uday	Uttar Pradesh
G.B.U.A.&T., Pant Nagar	
Pant Uphar	U.P. and Uttarakhand
Pant Matar-2	J&K, H.P., Hills of U.P., Punjab, Tarai region of U.P., Bihar and Jharkhand
Pant Sabji Matar-3	J&K, H.P., Hills of U.P., Punjab, Tarai region of U.P., Bihar and Jharkhand
Pant Sabji Matar-4	J&K, H.P., Hills of U.P., Punjab, Tarai region of U.P., Bihar and Jharkhand
Pant Sabji Matar-5	J&K, H.P., Hills of U.P., Punjab, Tarai region of U.P., Bihar, Maharashtra and Jharkhand
Phule Priya	Maharashtra
TNAU, Coimbatore	
Ooty 1	Tamil Nadu
Pole type Ooty 1	Tamil Nadu
CSAUAT, Kanpur	
Azad P-3	U.P.
Azad P-2	Punjab, Tarai region of U.P., Uttarakhand, Bihar, Jharkhand
Azad P-4	Punjab, Tarai region of U.P., Uttarakhand, Bihar, Jharkhand
Azad P-5	Punjab, Tarai region of U.P., Uttarakhand, Bihar, Jharkhand

Germplasm status

Though large number of garden pea germplasm is available in different agricultural universities, the exact status of germplasm is presently not available. NBPGR, New Delhi is having large number of vegetable germplasm collection including peas. Recently IIVR has been recognized as the nodal center for maintenance of vegetable germplasm collection at the national level and is presently maintaining 425 pea germplasm (IIVR, 2014). Table 11 roughly indicates the status of pea germplasm. A cursory look at the figure makes one to assume that more than 1200 pea germplasm is currently available in the country. However, the possibility that there might be duplications in these collections is not ruled out. Inter institutional co-ordination at the national level between both ICAR institutes and the agricultural universities which hold these valuable germplasm will help in systematic conservation, cataloguing and documentation of all the available accessions including core collections for specific traits. This will facilitate their exchange and effective utilization in the breeding programmes.

The following table shows the lines which are superior for earliness and for certain pod traits (Kumar *et al*, 2006; Amin *et al*, 2010).

Trait	Superior accessions
Earliness	Asauji, Lucknow, Bonia, Hans, EC 3
No. of pods per plant	PLP-496, 279, 69, 5, 26, 50, 69, 179, 279, 496, AP-3,
Long pods	EC 109171, 109176, 109190, 109195, AP-1, AP-3,
Bold pods	EC-41 03, 6185, 95924, AP-3

Table 11. Germplasm reported from different centres

Sl. No.	No. of germplasm accessions	Name of the Center	Reference
1.	105	Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan.	Jarial and Sharma (2005)
2.	80	G.B. Pant University of Agriculture & Technology, Pantnagar.	Gupta and Singh (2006)
3.	120	N.D. University of Agriculture & Technology, Faizabad.	Singh and Gautam (2007)
4.	50	PAU, Ludhiana	Kumar *et al* (2007a)
5.	54	Institute of Agricultural sciences, Banaras Hindu University, Varanasi.	Yadav *et al* (2010)
6.	317	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur.	Banyal *et al* (2011)
7.	120	IIHR, Bangalore	IIHR (2013)
8.	425	IIVR, Varanasi	IIVR (2014)

Table 12. Accessions resistant to diseases.

Disease/pathogen	Source of resistance	Reference/s
***Fusarium* root rot** (*Fusarium solani f.*sp. *pisi)*	PI 140165, PI 183910, 194006, 210257, 223385	King *et al* (1981)
Damping-off (*Pythium ultimum*)	ACs 140165, 1890, 19404 Minnesota 494 A II	Kraft and Roberts (1970) King *et al* (1981)
Powdery mildew (*Erysiphe pisi*)	Continental, JP 501, VP 7906, PH1-1, HWVP 1	In: Kalloo (1993)
	EC 326, 42529, 109190, 109196, T 10, P 185, P 288, PC 6578, B 4048, P 6587, P 6588, BHU 159, IC 4604,	Amin *et al* (2010)
	PMR-17, PMR-19, KS-245, KS-221, JP-501, JP-9, N0 23, NDVP-250, P-19, EC-269291, JP-20	Pandey *et al* (1999)
	EC598655, EC598878, EC598704, IC278261 and IC218988	Rana *et al* (2012)
Rust (*Uromyces fabae*)	JP Batri Brown 3 and 4 PJ 207508, 222117, EC 109188, Ec 42959, IC 4604, PJ 207508,	Narsinghani *et al* 1980 Amin *et al* (2010)
Wilt (*Fusarium oxyporium* f.sp. *pisi*)	New Era Kala Nagni, LMR 20, LMR 110, Jp 501 Early Perfection, Bonneviella, PL 43, 124, 6101, Glacier	Hagedorn (1953) Kalloo (1993) Amin *et al* (2010)
***Fusarium* root rot** (*Fusarium oxyporium)*	Dia, Nike, K 7589, R 4006, Helia	Rybnikova and Rudikova (1990)
***Ascochyta* blight**	Kinnauri'	Rastogi and Saini (1984a)
(*Ascochyta pisi)*	K 1632, 3055, 5072, 5117	Vladimirtseva *et al* (1990)
Pea root rot (*Aphanomyces euteiches)*	PI 166159, 167250, 169604, 180693, 180868,	Rastogi and Saini (1984b)
	Minnesota 494	King *et al* (1981)
Pea enation mosaic virus	Pi 193586, PI 193835	Stevenson and Hagedorn (1971)
Pea seed-borne Mosaic virus	Psb, Mv-Pam, Psbmv-P4 X 78122, 78123, 78124, 78125, 78126, 78128	Provvidenti and Alconero (1988) Muehlabawer (1983)
Bacterial blight (*P. syringae* pv. *pisi)*	Onward and 3080	Taylor (1972)
Bean yellow	Bonneville	Schroeder and Provvidenti (1971)
Mosaic virus	Wisconsin Perfection	Hagedorn (1951)
Pea leaf-roll virus	Rando, Novette, Starlett	Paszkiewicz (1983)
Pea mosaic virus	Perfection type America Wonder, Gem,	Schroeder and Provvidenti (1966)
	Dwarf White Sugar, Little Marval	Amin *et al* (2010)
Bean virus 2	New Era, Wisconsin, Perfection	Johnson (1957)

Source: (Kalloo 1993; Amin *et al*, 2010)

Genetic variability

Sharma and Bora (2013) reported that the genotypic coefficient of variances (GCA) varied from 8.14 (pod length) to 33.35 (green pod yield per plant). The estimates of GCA were found highest for green pod yield per plant (33.35), followed by plant height (26.82) and number of green pod per plant (21.02), respectively. Kumaran *et al* (1995a), Vikas and Singh (1999a), Singh *et al* (1996), Sureja and Sharma (2000) and Kalloo *et al* (2005) also reported high estimates of genotypic variability for yield and its contributing traits. Kumar *et al* (2010) reported maximum phenotypic coefficient of variation (42.69%) for number of pods per plant followed by yield per plot (38.76%). It was moderate for duration of availability of green pods (18.02%). Comparatively low phenotypic coefficient of variation was shown by 100-green seed weight (13.58%), days to 50% flowering (5.18%) and days to first picking (4.28%). Guleria *et al* (2009) reported significant varietal variations in the mature dry seeds of pea genotypes for total protein (14.95% to 22.44%), albumins (3.30% to 6.35%), globulins (7.97% to 10.53 %), glutelins (1.15% to 3.05 %) and prolamins (0.46% to 1.50 %). Rathp and Dhaka (2007), the magnitude of genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) were comparatively higher for seed yield per plant, dry matter yield, plant height and number of pods per plant as compared to other characters. These findings are supported by earlier workers (Dhobal 1996; Singh Vikas *et al, 1*996*;* Kumar *et al,* 1998; Tyagi *et al,* 1997). According to Olivia *et al* (2010) the analysis of variance revealed highly significant differences for days to first flower, length of internodes, days to first green pod harvest, length of pods, number of pods/plant, pod yield/ plant, seed yield per plant, plant height, 100 seed weight, shelling percentage and protein content, except breadth of pods which was significant at 5% level.

Heritability and Genetic advance

Kumaran *et al* (1995a), Vikas and Singh (1999), Singh *et al* (1996), Sureja and Sharma (2000) and Kalloo *et al* (2005) reported high estimates of broad sense heritability were recorded for plant height (97.84%), days to first green pod picking (95.80), 100 green pod weights (94.69%), green pod yield per plant (93.10), and days to 50% flowering (92.25%), whereas remaining characters revealed moderate heritability. The high genetic advance as percent of mean along with high heritability was obtained for green pod yield per plant (66.28), plant height (54.67), number of green pod per plant (38.28), 100 green pod weight (32.07). Similar findings were also reported earlier by Kumar *et al* (2000), Mahanta *et al* (2001) and Chaudhary and Sharma (2003). Pallavi *et al* (2013) recorded highest heritability 99.97% for days of flowering. Heritability estimates were moderate for node of first flower (78.27%); followed by 100-seed weight (68.25%), plant height (65.84%), and number of primary branches per plant (53.50%). Similar to this investigation, Joshi and Thomas (1987) observed high heritability for 100-seed weight and plant height. High heritability was also found for plant height at maturity by Narsinghani and Saxena (1991). Nandi *et al* (1995) reported moderately high genetic advance and heritability for plant height, 100-seed weight and pod length. Lenka *et al* (1998) also indicated that seed yield and 100-seed weight are all heritable traits. High genetic advance coupled with high heritability was observed for plant height and 100-seed weight. It indicated genotypic variation for these traits was probably due to high additive gene effects and thus early generation selection for highly heritable characters is expected to give better results. Raffi and Nath (2004) also reported the additive gene effect for pods per plant, 100-seed weight, plant height and yield per plant. Kumar *et al* (2010) reported maximum genetic advance was exhibited by pods per plant followed by biological yield per plant and plant height with their high magnitude of genotypic coefficient of variability and heritability indicating the presence of additive effects for these characters. Sharma *et al* (2009b) estimated heritability ranged from 49.25% in shelling percent to 95.95% in pod breadth. High heritability along with more genetic gain was expressed by pod breadth (94.95% & 63.16%). Total phenols (g/100g) of leaves (94.37% & 84.30%) and high heritability with moderate genetic gain was recorded for number of pods/ plant (93.41% & 25.39%), node number at which first flower appears (94.93% & 23.68%) and pod yield per plant (79.17% & 22.96%) indicating presence of additive genes in governing these traits and the selection based on the phenotypic performance of the plants could prove to be very effective in the improvement of these characters which could be retained in further generations. Kumarai *et al* (2008) recorded highest heritability for shelling percentage (93.1%) followed by nodes to first flower (87.7%), 100 seed weight (87.4%), number of pods per plant (85.3%), seed vigour index (85.0%) and pod length (80.1%). Moderate heritability estimates were recorded for rest of the traits viz., number of seeds per pod (78.0%), plant height (77.5%), total soluble solids (76.2%), pod yield per plant (73.3%) and powdery

mildew intensity (74.1%). High heritability coupled with moderate genetic gain was observed for nodes to first flower, number of pods per plant, 100 seed weight and seed vigour index. These results indicated that an effective selection for this trait could be done. Similar inferences were drawn by Kumaran *et al* (1995a). Moderate heritability and genetic gain was observed for number of seeds per pod, which was in conformity with Singh and Saklani (1973). Singh (1995), Dhobal (1996) and Gupta *et al* (1998) reported that high heritability coupled with high genetic advance over the mean was observed for plant height, dry matter yield, 100 seed weight and grain yield per plant indicating the preponderance of additive gene effect and desired improvement in these characters can be brought through direct selection of these component traits. Mahanta *et al* (2001) also observed high heritability coupled with high genetic advance for seed yield per plant, pods per plant, plant height, seeds per pod and 100 seed weight, suggesting additive gene effects. The findings also get supported by Kumar *et al* (1998). Pod length and number of seeds per pod exhibited high heritability with low genetic advance indicating non-additive genetic effects.

Yadav *et al* (2010) reported that heritability (h^2) value was highest for plant height (96.70) followed by seed yield per plant (96.20), 100-seed weight (95.90%) and seeds per pod (90.60). High heritability estimates for these characters were also reported by Sureja *et al* (2000), Chaudhary *et al* (2003), and Singh *et al* (2006). The genetic advance (GA) expressed as percentage of mean, was maximum for seed yield per plant (72.00%) followed by pods per plant (55.39%) and 100-seed weight (47.96%). The minimum GA value was recorded for days to maturity (10.41).The results are in harmony with Tyagi and Srivastava (2002), Vikas *et al* (1999). Seed yield per plant, 100-seed weight, plant height and pods per plant exhibited high heritability along with high genetic advance. Akhilesh *et al* (2007) and Sharma *et al* (2003b) also reported this estimates of heritability for different traits. The studies further revealed the medium value of heritability for number of seeds per pod, shelling per cent, number of primary branches, number of pods per plant, 100 seed weight and seed yield per plant. These findings are in agreement with those of Singh *et al* (2003). The high value of genetic advance in per cent of mean was recorded for plant height, length of internodes, length of pods, days taken to first flower, number of pods per plant, number of seeds per pod, number of primary branches, shelling percent, seed yield per plant and pod yield per plant. Singh *et al* (2003) and Akhilesh *et al* (2007) have also reported that estimate of genetic advance for different traits showed that high heritability with high genetic advances was recorded for length of pod, length of internodes, plant height and days to appearance of first flower.

Correlation and Path analysis

According to Kumarai *et al* (2008) the genetic correlation coefficients were higher than their respective phenotypic correlation coefficients for most of the associations, which may be attributed to the low effect of environment on the character association. Pod yield per plant was positively and significantly correlated with number of pods per plant, 100 seed weight and seed vigour, which suggested the possibilities of improving pod yield per plant improvement of these characters. Similarly plant height had significant positive correlation with number of pods per plant and 100 seed weight. Maximum positive direct effect on pod yield was shown by number of pods per plant, followed by number of seeds per pod. Among the various indirect effects on pod yield, high positive indirect effects via number of pods per plant were recorded for the traits viz., 100 seed weight, plant height, total soluble solids, seed vigour, and nodes to first flower. High positive indirect effect was also recorded for pod length via number of seeds per pod. High negative indirect effect was observed for powdery mildew severity via number of pods per plant, for total soluble solids via number of seeds per pod, for shelling percentage via nodes to first flower, for 100 seed weight via plant height and for nodes to first flower via shelling percentage.

Sharma *et al* (2009b) reported that the path coefficient revealed that at genotypic levels, number of pods per plant (0.7921) exhibited highest significant and positive direct effect on pod yield per plant, followed by node at which first flower appears (0.0393) and plant height (0.0046). High positive indirect effects *via* pods plant were recorded for traits viz. total phenols (0.4581), plant height (0.1396) and node at which first flower appears (0.1084). Thus the results showed that number of pods per plant total phenols, node at which first flower appeared and plant height were the most appropriate characters to select for high green pod yield in garden pea. Present findings lend credence to (Kumaran, *et al* 1995b, Shah and Lal 1990, Sharma and Kaali 1998).

According to Yadav *et al* (2010) the seed yield per plant showed significant and positive correlation with pods per plant, 100-seed weight and plant height. 100-seed weight

had significant and positive correlation with pod length and plant height. Number of seeds per pod was strongly associated with plant length. Pods per plant were positively and significantly associated with number of primary branches. The trend of correlation coefficients revealed positive and highly significant association of yield per plant with plant height, pods per plant and 100 seed weight. Srivastava and Singh (1989), Vikas *et al* (1999) and Kumar *et al* (2003) earlier reported a similar trend. The correlation analysis revealed positive and highly significant association of the traits viz., days to flowering and days to maturity, pod length and seeds per pod, pods per plant, seed yield per plant and 100 seed weight with pod length and seed yield per plant. For path coefficient the direct and indirect effect of yield contributing traits on yield revealed that the maximum positive direct effect was exhibited by pods per plant followed by 100-seed weight, days to maturity and pod length. High direct effects for above traits were also reported by Kumar *et al* (2003) and Arya *et al* (2004). The high positive direct effect of number of pods per plant on yield per plant resulted from strong and positive correlation between them. The pod length had positive direct effect on seed yield (0.058) but it had relatively low correlation with yield per plant. The correlation between seeds per pod (0.001) and seed yield was positive (0.044) due to positive indirect effect via pod length, 100-seed weight, days to maturity and number of primary branches. Finding of path analysis indicated that pods per plant, seed weight and days to maturity had high direct effect towards seed yield accompanied with moderate to high correlation with yield per plant.

According to Rathp and Dhaka (2007) the path coefficient analysis revealed that direct and indirect effects at genotypic level were higher than corresponding phenotypic effects. Highest positive direct effect on seed yield per plant was exhibited by number of pods per plant (0.61), 100-seeds weight (0.26 g) and dry matter yield per plant (0.24 g). Highest indirect positive effect was observed via number of pods per plant (0.61), dry matter yield (0.16 g) and harvest index (0.23). Number of pods per plant, pod length, number of pods per node, dry matter yield per plant, number of seeds per pod, harvest index and 100-seed weight showed significantly positive correlation with seed yield per plant. It was observed that seed yield per plant is directly affected by number of pods per plant, harvest index and number of pods per plant while it is indirectly affected via number of pods per node, 100-seed weight, plant height and number of branches per plant.

Heterosis

An improvement in yield of self-pollinated crops like garden pea is effected mainly through selection of genotypes with desirable traits in the recombinant inbred populations resulting from the hybridization of parental lines. Heterosis has been recognized in pea since the early studies of Mendel (1866). In India, although heterosis in pea was reported, the cleistogamous nature of flower and non availability of male sterility system restricts its application in production of commercial hybrids (Sarawat *et al*, 1994; Singh *et al*, 1994; Tyagi and Srivastava, 2001) However, the phenomenon of heterosis is helpful in prediction of potential crosses which are likely to give transegressive segregants (Ganesh *et al*, 2008).

Heterosis for seed yield ranged from 30 to 56% depending on the environment and was greater in poor environments compared to the better environments. This effect is primarily due to increases in the number of pods per plant (Sarawat *et al*, 1994). Ganesh *et al* (2008) estimated heterosis over better parent for seed yield and related traits in 16 crosses. Significant average heterosis over better parent was observed for plant height, pods per plant and seed yield per plant. Heterosis for seeds per pod and seed weight was negative or low. Heterosis for seed yield per plant and pods per plant was mainly due to over dominance. Brar *et al* (2012) observed that the cross P-1 and Arkel x C-96 showed maximum significant heterosis for early flowering and can be exploited for early yield. Katiyar (1994) also revealed significant heterobeltiosis for days to 50% flowering and the cross combination C-308 x C-400 exhibited maximum significant positive heterosis (40.97%) over better parent and also recorded high sca effects for plant height. These findings are in in agreement with those of Srivastava *et al* (1986) and Mishra *et al* (1993).

The cross combination(s) MA- 6 x C-400 for pod length; Arkel x C-400 for number of pods per plant; JM-5 x C-96 and NDVP-10 x C-400 for shelling percentage exhibited highest significant maximum positive heterosis. The cross-combinations P-1 x PB-89, KS-268 x PB-89, PMR-19 x C-400 for number of grains per plant, and KS-268 x C-400, P-1 x C-400, MA-6 x C- 400 for green pod yield per plant, exhibited significant and positive heterosis (Brar *et al* 2012). Bisht and Singh (2010) reported that the yield and related traits were most heterotic characters, whereas, number of green pods per plant, number of primary branches per plant, number of nodes per main stem, green

pod yield, dry seed yield, showed high heterosis over mid parent, better parent or standard parent. E-6 × Arkel and E-6 x VL-7 were the best combinations over the standard checks for days to first flowering. Singh and Santhoshi (1989) reported that heterosis in yield was due to more number of primary branches per plant.

Awasthi *et al* (2009) reported negative significant heterosis and heterobeltiosis for earliness. Sood *et al.* (2006) reported that Matar Ageta-6 x JI-2436 exhibited heterobeltiosis for earliness and green pod yield.

According to Karnwal and Kushwaha (2010) among all 28 crosses, high heterotic response for pods per plant was exhibited by the cross DARL-403 × Pant Uphar. Whereas, DARL-403 × Pant Uphar F_1 showed highest magnitude of heterosis for primary branches. The highest heterosis response for nitrogen fixing (nodules per plant) was expressed by the cross DARL- 403 × VP-316. While, highest heterosis for nodules volume per plant was exhibited by two crosses DARL-403 × VP-316 and Arkel × Punjab Ageta. Heterosis for nodules dry weight per plant was exhibited by the cross Azad P-3 × Pant Uphar.

According to Sharma and Sharma (2013a), only 15 crosses out of 28, revealed significant positive heterobeltiosis and highest magnitude of heterosis was recorded in PB-89 x PSM-3. The highest economic heterosis was recorded in PB-89 x PSM-3. Heterosis for pod yield per plant was also reported Pandey *et al* (2006). The cross combinations Green Pearl x DPP 9411 and Azad P1 x Sugar Giant with high heterosis for pod yield and related traits were reported by Sharma *et al* (2007). Bora *et al* (2009) reported significant and highest heterosis for pod length, number of green pods per plant and for green pod yield per plant and several other characters. Among parents DVP-2, VRP-6 and PMR-32 were observed to be top performing parents for pod yield and its contributing traits. However, for quality traits Pusa Pragati, PMR-32, VRP-6 and DVP-2 were best. The F_1 hybrid DVP-2 x Pusa Pragati had manifested significant high heterosis for quality as well as yield and its contributing traits.

Sharma *et al* (2007) observed that the cross combinations Green Pearl x DPP 9411 and Azad P 1 x Sugar Giant showed high heterosis and *sca* effects for pod yield and related traits. Green Pearl x Sugar Giant combination was the most promising for early flowering and green pod picking. For most of the traits including pod yield per plant, both additive and non-additive gene actions were of prime importance. According to Sharma and Bora (2013) The cross VRP-5 x Arkel revealed significant highest heterosis for pod length over better parent and standard check, respectively. The cross combination PMR-32 x Snow pea revealed significant positive heterosis for number of green pods per plant pod yield per plant over better parents. Mishra (1998) and Shah and Mohammed (2005), also reported significant heterosis for number of pods per plant, and Shah and Mohammod (2005) and Singh and Mir (2005) for green pod yield per plant. The manifestation of heterosis for these pod weight had also been reported earlier by Sharma e*t al* (1998) and Kumar e*t al* (2000). Patil *et al* (2011) observed that green pod yield per plant exhibited high amount of heterosis over superior parent. The cross combination of Azad P- 5 x KS-150 exhibited maximum heterosis over superior parent Rao and Narsinghani (1987) observed the highest heterosis over the better parent in the cross Kinnauri x R 701 It was also observed the parents having highest genetic divergence did not produce heterosis of the same magnitude. On the other hand, the crosses possessing lowest D^2 values produced different heterotic effects. This means that the parent of the same cluster can also produce different heterotic values. Awasthi *et al* (2009) observed that the crosses, EC 328758 x *Swarnamer* showed positive significant heterosis for seed yield. Similarly, Ram *et al* (1986), Tyagi and Srivastava (1999), Kumar *et al* (2000) and Sharma *et al* (2007) observed heterobeltiosis for seed yield pods per plant. Misra (1998), Gupta *et al (*1998) and Pathak and Jamval (2002) concluded that while cross EC 328758 x *Swarnamer* exhibited positive significant heterosis for pods per plant and seed yield per plant and EC 269396 x *Pusa Pragati* for early maturity.

Combining ability studies

The combining ability analysis is the most important and efficient tool in choosing the desirable parents for hybridization programmes. The nature and magnitude of two kinds of combining abilities, i.e. general combining ability (gca) and specific combining ability (sca) helps the breeder in adopting appropriate breeding methodology (Bisht and Singh, 2010). Combining ability analysis on the basis of diallel mating system is one of the most appropriate methods to identify the best combiners, which can be utilized for hybridization programme. It gives information about the nature of gene action and the relative magnitudes of fixable (additive) and non-fixable (non-additive/dominance) genetic variations (Borah, 2009).

The concept of combining ability was proposed by Sprague and Tatum (1942). They partitioned the genetic variances into two components (i) variance due to general combining ability (GCA) and (ii) variance due to specific combining ability (SCA). The GCA is defined as the average performance of parental lines or strains in a set of cross combinations. Whereas in SCA certain cross combinations relatively show better or low performance on the basis of average performance of the parental lines.

Singh *et al* (1972) evaluated the progeny of a diallel set excluding reciprocals for yield and the yield contributing traits and reported that both GCA and SCA variances were significant for all the traits. The GCA effects were prominent in characters such as plant height, pod length and pod width, where as in number of pods per plant and number of seeds per pods, SCA effects were more. Das and Kumar (1975) observed that both GCA and SCA variances were predominant for yield, number of branches, number of pods and seeds per pod, while SCA variances were higher for seed yield per plant. Venkateswarlu and Singh (1981) reported that both general and specific combining ability were important for plant height, primary branches, pods/ plant, 100-seed weight and seed yield/plant. The mean squares from diallel analysis of the F1 crosses showed that the variances due to both GCA and SCA were highly significant for all the character studied.

Singh *et al* (1986a) had reported tht both general and specific combining ability mean squares were significant for all the traits studied and varieties Rachna, P-29 and P-185 were the best general combiners followed by HFP-4 and Dola. In general, a positive relationship was recorded between SCA effects. EC-33866 was found to be good general combiners for protein content. Srivastava *et al* (1986) observed that the best general combiners were also best specific combiners. Gupta and Lodhi (1988) evaluated nine cultivars of garden found that parents EC-109189, T-163, EC-09196 and P-23 were good general combiners for days to pod formation and days to maturity. Cross combinations EC -109189 × T-163, EC-109189 × P-23, EC-109189 × EC-109196, T-163 × EC-109196 and T-163 × P-23 showed significant negative SCA effects and thus, were promising for selecting early genotypes. Singh and Singh (1989b) studied genetics of earliness and days to maturity in a diallel cross and suggested that both additive and non-additive genetic variance were controlling these characters. The parents EC-33866, A-474-228, GC-322 and Sel-2 were good general combiners. The performance of parents was positively associated with their GCA effects. The SCA effect was found for early flowering in EC-33866 x ED followed by Sel-2 × T163.

Karmakar and Singh (1990) reported that in a diallel experiment that JP-169 was the best general combiner for yield and its components followed by VP-7802. The genotype VP-8005 was good general combiner for seeds per pod and Arkel for dwarf stature. Glorisa × JP 169 was the best specific combination for yield and yield component characters followed by Arkel × VP-7802 and JP 169 × VP 8005. Arkel × VP 8005. Karnwal and Kushwaha (2010) concluded that, the parents DARL- 403, Pant Uphar and PSM-3 were good general combiner for both pod yield per plant and nitrogen fixing nodules per plant. The five crosses namely VL-9 × Pant Uphar, VL-9 × DARL-403, DARL-403 × Pant Uphar, DARL-403 × VP-316 and PSM-3 × DARL- 403 are important for developing lines with good yield potential and high nitrogen fixation.

Kumar and Bal (1995) reported Bonneville to be the best general combiner. The cross combinations Wando × P-35, Arkel × P-35, Hara Bonna × GC-141, Arkel × GC-141 and Arkel × GC-141 were the best specific combiners for pods per plant, pod length, number of seeds per pod, hundred seed weight and yield per plant respectively. Panda *et al* (1996) were found parents PH-1, HUVP-1, EC-33866 and VL-6 to be good general combiners for green pod yield, number of seeds per pod, days to first picking of green pods and the cross combination HUVP-1 × EC-33866 was the best specific combination for total green pod yield per plant. Singh and Mishra (1996) studied heterosis and combining ability in 6 × 6 diallel set of mid season peas and found cultivar Bonneville was the best general combiner followed by VP-7906. The estimates of SCA effects showed that cross Bonneville × JP-169 performed best for pod length, pod width and grains per pod. However, 10 out of 15 cross combinations (VP-7906 × C-152 being highest) showed negative SCA for days to 50% flowering, which tends towards the earliness. In most of the cases, SCA variances were found to be higher than those of GCA variances for early maturity. Bhardwaj and Kohli (1998) found that the parents VL-3, Lincoln, Kinnauri, Ageta-6 and Arkel were good general combiners for yield and yield traits. They had observed that the crosses showing high estimates of SCA effects usually did not involve both the parents having high GCA effects. Most of the crosses showing significant and positive SCA effects involved high × low general combiners.

Narayan *et al* (1998) studied combining ability from data derived on pod yield and three quality components viz., dry matter content, total soluble solids and protein content and six yield components in pea varieties and their 15 F_1 cross combinations. The cultivar Bonneville was the best combiner for all the quality traits. Sharma (1999) observed that the parents Azad P-1, Palam Priya and VL-7 were the best general combiners, while cross combination VL-7 × DPP-13 showed significant and positive SCA effects for all 5 yield components except grains per pod. Sharma *et al* (2000) carried out combining ability analysis from diallel cross of pea cultivars and found that GCA variance were significant for all characters except pod breadth for which SCA variance was higher. The per se performance of parents and crosses was usually associated with the combining ability effects. Singh *et al* (2001) derived information on combining ability in garden pea involving twenty one crosses and seven parents. The GCA and SCA variances were highly significant for all the traits (days to flowering, days to maturity, plant height, number of primary branches per plant, number of pods per plant and pod length). The SCA variances were predominant in comparisons to GCA variances for all the characters that indicated the greater contribution of non-additive gene action in the expression of these characters. Kumar and Jain (2002) conducted field trial with 8 × 8 diallel analysis in garden pea and observed that variety Arka Ajeet showed highest GCA effects for characters including number of pods per plant and plant height. The cultivar had revealed Bonneville higher GCA for earliness, number of pods per plant and pod yield per plant. Cross combination Arka Ajit × Bonneville had revealed highest SCA for pod yield per plant and number of pods per plant followed by PMR- 20 × KS-136.

Singh and Mishra (2002) derived information on combining ability in 10 × 10 diallel set. The mean sum of squares due to GCA and SCA variances were highly significant for all the characters except seeds per pod. The parents PDP-52 and Azad P-1 were the best general combiners for seed yield per plant. Three cross combinations PDP-23 x PDP-52 in F1 and PDP-33 × PDP-55 and PDP-41 × PDP-55 in F2 had exhibited desirable significant SCA effects for four characters. Dixit (2003) reported that the cross combinations IPF × KPMR and IPF- 98-9 × MS NDP-90-1 showed significant and desirable SCA effects as well as high per se performance for pod yield per plant and number of pods per plant. The cross combination IPF-98-9 × NDP-90-1 showed significant SCA effects and good performance for plant height. Singh and Singh (2003) evaluated F1 and F2 generations of pea in a 10 × 10 diallel set of crosses. The magnitude of SCA effects was recorded higher than GCA effects for all the traits under investigation except days to first flowering and days to maturity.

Zaman and Hazarika (2005) derived information on general and specific combining ability effects. Parent Rachna and HUP-2 were found to be good general combiners for green pod yield and most of the other characters. Azad pea was good general combiner for earliness. The cross combinations Rachna × Azad pea, Rachna × HUDP-6 and Azad pea × HUP-2 exhibited higher and significant SCA effects for yield and majority of the characters. Ranjan *et al* (2005) conducted field trial involving 7 × 7 diallel mating design excluding reciprocals for yield and its components. Parents KPMR-327, KPMR-228, NDP-93 were observed as good general combiner and crosses HUP-15 ×KPMR-327, KPMR-327 × LFP-179 as superior cross combinations for yield contributing characters. Pandey *et al* (2006) reported that combining ability analysis showed significant difference for GCA and SCA variance for all the characters. Parent Lincoln appeared to be one of the best combiners for all the traits including plant height in desired direction. On the basis of combining ability studies general combiners for plant height (dwarfness, UD-1, Lincoln), pods per plant (Pahari Matar, NC-64086), pod length (Lincoln, J-4), seeds per pod (Lincoln, UP-7839), pods yield per plant (Lincoln, NC-64086) and Arkel UD-1 for total soluble solids were identified. Sood *et al* (2006) reported that the varieties Palam Priya and JI-2334 were the best parent for protein content. Bonneville proved to be the best combiner for pod yield per plant, shelling percentage, dry matter content, and protein content, whereas Lincoln and VL-3 were the best combiners for all the traits except shelling percentage and protein content. These parents also produced some crosses with high SCA effects for more than one trait. Bonneville × Lincoln exhibited positive significant SCA effects for all the characters except dry matter content, while as Solan Nirog × Kiannauri recorded significant and positive SCA effects for all traits except pod yield per plant (Raj, 2006). The prevalence of additive and non-additive gene action in the inheritance of yield and quality traits suggested that the suitability of recurrent selection in succeeding generations for the development of transgressive segregants.

Singh *et al* (2007) conducted a field study with 10 × 10 diallel analysis (without reciprocals) in edible podded pea.

The mean squares for general combining ability were observed higher than those of specific combining ability in all the characters. Variety Sugar Bon showed highest GCA for days to 50% flowering and number of branches per plant and the second highest GCA for plant height. Variety Mithiphali recorded highest GCA effects for total and marketable green pod yield per plant. Cross combination Sugar Daddy × JP-19 recorded highest specific combining ability for total and marketable green pod yield per plant followed by Early Snap × Mithiphali. Sharma *et al* (2007) carried out a line × tester analysis involving 10 promising lines and 2 testers having wider genetic base for pod yield and related horticultural traits in garden pea at diverse environments at Kukumseri (dry-temperate) and Palampur (sub-temperate) during summer 2004 and winter 2004 and 2005, respectively. Among the parents, Green Pearl, Azad P 1, DPP 9418-06 and DPP 9411 were observed as good general combiners for pod yield/plant and majority of the component traits. The cross combinations Green Pearl × DPP 9411 and Azad P 1 × Sugar Giant showed high heterosis and SCA effects for pod yield and related horticultural traits. The cross Green Pearl × Sugar Giant was the most promising for early flowering and green pod picking. For powdery mildew incidence, the cross VRPMR 10 × Sugar Giant where both parents revealed high negative GCA effects also showed significant negative SCA effect and heterosis. For most of the traits including pod yield/plant, both additive and non-additive gene actions were of prime importance.

Kalia and Sood (2009) evaluated F_1's and F_2 progenies of eight divergent parents mated in diallel fashion excluding reciprocals for combining ability in green pea for the horticultural characters. However, the SCA variance component was predominant indicating the importance of non-additive gene effects for all the characters except for peas per pod and pod yield which were influenced by additive gene action, suggesting their improvement through pure line selection. Palam Priya was found to be the best general combiner for all traits and is thus the most suited as parent for improving productivity and other desirable traits in garden pea. To ensure further increase in pod yield along with high protein content, cross combinations involving desirable yield components is advocated, with JI 1559 × Matar Ageta 6 as the best combination. To further improve pod yield, inclusion of F_1 combinations with high SCA and parents with good GCA in multiple crosses, biparental mating, or diallel selective mating could be a worthwhile approach.

Singh *et al* (2010) observed higher values of variance due to GCA for days to flowering, days to maturity, plant height, pod length, number of developed ovules per pod, shelling percentage and green pod yield per plant showed presence of additive gene action while it was non additive for number of productive branches per plant and number of pods per plant based on both the generations. Parents 'KS-226', 'KS-225', 'KS-136', 'Azad P-1 and 'Azad P-3' were good general combiners for green pod yield based on both the generations. Cross combinations namely 'KPMR-184 × KS-136', 'Rachna x KS-225', 'KS-195 x AP-3', 'KPMR-184 × Mutant pea' and 'Mutant × KS-136' in F1, 'KS-195 × KS-225', 'KPMR-184 × AP-3', 'Mutant × KS-226', 'KS-226 × AP-1' and 'KPMR-65 × KS-226' in F2 were good as specific combinations for green pod yield. Majority of these crosses fall in the high × low general combiners. The crosses between table × field pea gave higher yield than table × table or field × field pea.

Sirohi and Singh (2013) reported lines HPPC 41, HPPC 77, HPPC 91 and HPPC 94 for leaf area and total chlorophyll content and HPPC 60, HPPC 67 and HPPC 84 for specific leaf weight were good general combiners. While HPPC 67 × HPPC 63, HPPC 69 × Lincoln, and HPPC 94 × Lincoln were the promising crosses for specific leaf weight, chlorophyll-a and chlorophyll-b contents, respectively, on the basis of specific combining ability.

Genotype × environment (G × E) interactions

Genotypes selected in a breeding program, before they are commercially released need to be tested at different locations for few years in order to select superior lines based on the genotype × environment (G × E) interaction and their stability across these situations. To determine the extent of the G × E interaction, a simple regression analysis of stability parameters is used by analyzing parameters of experiments conducted over years and/or locations (Eberhart and Russell, 1966). Rana *et al* (2006) evaluated 28 genotypes of garden pea in six environments for pod yield and quality traits and reported that Azad P-I, DPP9418-06 and Pb-88 were promising and stable genotypes for conducive environment, while the genotype NDVP 9 was suitable for poor environment for pod yield per plant and TSS. In addition to them, DPP 9411 also showed consistent performance over all the environments for pod yield per plant and chlorophyll content. Thus, based on these results, Azad P-I, DPP 9418-06, Pb-88, NDVP 9 and DPP 9411 may be recommended for commercial cultivation in garden pea growing belts of Himachal Pradesh. Sirohi and Gaurav

(2008) reported stability analysis of 30 pea genotypes for 16 characters grown over eight environments. The genotype × environment interaction was significant for all the characters except for pod length and number of seeds per pod indicating varied phenotypic expression of most of genotypes in different environments. The genotype DMR-7, L-116, P-1852 and KPMR-157 were identified as stable genotypes for yield.

Male sterility

In peas, the first instance of male sterile mutant gene acting during pre-meiosis was recorded by Nirmala and Kaul (1991). Here, the anther development and PMC differentiation occurs normally. However, later, their chromatin and nucleolus degenerate and they do not develop a callose wall. Thus, while the gene action is pre-meiotic, the mutant is ameiotic functionally. *Pisum sativum* genome is a rich source of ms genes, 38 recorded by Gottschalk and Kaul (1974) and 8 by Nirmala (1990). The ms genes act differentially at most all the stages of microsporogenesis (Kaul 1988; Kaul and Nirmala 1991; 1993, Nirmala and Kaul 1991, 1993). Though the facets and pathways of ms gene action in *Pisum* mutants are diverse and innumerable, the consequences are the same *viz*. inhibition of the formation, promotion or development of functional pollen grains. Male sterility in pea had not been reported to occur naturally until Singh and Singh (1995) characterized a spontaneous mutant with a single recessive gene conferring male sterility observed in a 'Longittee' cultivar. The plant had white-translucent anthers, and was male sterile. The inheritance of this mutant was studied in a cross involving the mutant and the mother parent and their F_1, F_2, F_3 and BC_1F_1generations. Results suggested that the sterile character was genetic and due to a recessive gene. Prior to this discovery, several male sterile mutants were generated using a variety of mutagenesis treatments (Nirmala and Kaul, 1991). All male sterile genes which have been reported act as recessive traits and nearly all the mutants have full female fertility (Kaul, 1988). Two ms genes (ms-3 and ms-10) exhibited reduced female fertility in addition to male sterility. Many of the male sterile (ms) genes which have been reported act during the post-meiotic stage. Sterility of the male gametophyte occurs through a variety of mechanisms, beginning during pre-meiosis through post-meiotic events; however, most cases of sterility involve post-meiotic events (Kaul, 1988; Kaul and Nirmala, 1989). By EMS, DES and gamma ray treatment in Arkel and Bonneville pea varieties, three male sterile mutants, msg-1, msg-7 and msg-8 were induced in *Pisum sativum* (Nirmala and Kaul, 1991). Sterility in each of these is conditioned by single recessive genes, the three genes being non-allelic. Whereas in one mutant, the ms gene acts during pre-meiosis, in the other two the genes act during post-meiosis. In both the post-meiotic mutants, male meiosis was normal. In both the post-meiotic mutants, micro spores degenerate fully. Male sterility in all the three mutants was complete while female fertility was normal. Kaul and Nirmala (1993) reported, dys-synapsis, involving lack or impaired synaptic pairing, confined only to the male sex was detected in a 0.05% DES induced mutant of *Pisum sativum* variety Arkel. This anomaly is controlled by a single nuclear recessive gene msg4, non-allelic to the other msg genes isolated in *P. sativum* genome. The synaptic anomaly leads to abnormal male meiosis resulting in degenerated microspore formation rendering the mutant total male sterile.

Nirmal and Kaul (1994) have isolated two male sterile mutants msg5 and msg6 from M_2 progeny of 4hr 0.05% EMS and 0.1% DES treated seeds of Bonneville and Arkel, respectively. msg 5 induces male sterility at MI stage and msg6 induces at PII stage.

Methods for breeding

Improvement of pea has been undertaken at several centres in the country. Some of the important centers where garden pea breeding work is in progress are: BHU (Varanasi), CSAUA&T (Kanpur), GBPUAT (Pantnagar), HARP (Ranchi), HAU (Hisar), HPKV (Palampur), IARI (New Delhi), IARI (Katrain), IIHR (Bangalore), IIVR (Varanasi), JNKVV (Jabalpur), NDAU&T (Faizabad), PAU (Ludhiana) and VPKAS (Almora). The improvement of garden pea in India started in around the year 1940. Initially the main emphasis in pea improvement has been on early maturity, yield, and quality. Later on the focus has shifted to the midseason varieties with resistance to diseases. Intensive work has been undertaken on breeding for resistance to diseases (powdery mildew, fusarium wilt and rust) at several centers in the country and for insect pests (bruchus, leaf miner) at JNKVV, Jabalpur. Work on breeding for resistance to leaf miner was taken up at HAU, Hisar (Amin *et al*, 2010). Pea being a self pollinated crop can very well be improved through methods commonly practiced in the improvement of self pollinated crops. These methods tend to follow the systematic sequence of steps developed for utilization to their best advantages. Following methods are mostly commonly used for pea improvement (Kumar *et al*, 2006).

1. Introduction: Most cultivated varieties in India have been introduced from various European countries and the U.S.A. Arkel, Meteor, Early Badger Perfection Newline, little Marvel and Superb are introductions (Kumar *et al*, 2006). Introduction was the main method of improvement followed in earlier days. Cultivar Bonneville still occupies large area. Earlier T 19 was grown for a short duration. Yet another line NP 29 once grown is hardly seen but Lincolin continues to be grown by farmers even today, although at a very few places. The other entries which are grown in small pockets are Early Giant, Greater Progress, Early Superb, Early Badger, Little Marvel, Khapadkheda, Perfection New Line and Wisconsin (Peter and Kumar, 2008).

2. Hybridization: Most of the pea cultivars have been developed by hybridization between an Indian variety and an exotic variety (Amin *et al*, 2010). Hybridization system results in new recombinants and variability in crop plants. Breeding work has led to development, testing, identification, release and notification of many improved garden peas varieties. For evolving varieties through hybridization in pea following procedures are used:

(i) Single seed descent method

(ii) Pedigree method and modifications

(iii) Bulk method

(iv) Back-cross method

2.1. Single seed descent (SSD) method: Single seed descent method is now becoming common in peas. This is particularly useful in those situations where selected better lines are intercrossed. Hybrid (F_1) plants are grown to produce 500 or more F 2 seeds. One seed is harvested from each F_2 plant and the harvested seeds are bulked to plant F_3. This procedure continues till F_5 and F_6 in which phenotypically uniform, superior and stable individual plants with distinct traits are selected for further evaluation for yield and quality. A major advantage of this method is to improve this crop with less resources and the rapid advancement of generation is possible in field and glass house / off season nurse. (Kumar *et al*, 2006).

2.2. Pedigree method: This is a system of breeding in which individual plants are selected in the segregating generations (F_2) from a cross on the basis of their desirability judged individually and on the basis of a pedigree record. Jawahar Mattar series 1, 2, 3, 4, 54 and 83 have been evolved through this method (Peter and Kumar, 2008). Several improved varieties like Arka Priya, Arka Pramodh and Arka Apoorva have been developed through this method at IIHR, Bangalore. Similarly, Vivek Matar 3, 6, 11, Kashi Samridhi, Narendra Sabji Matar 6, Matar Ageta 6 and Jawahar Matar 1 and 2 were developed through this method.

2.3. Bulk method*:* This method was developed by Nilsson Ehle of Sweden in 1908 in a wheat breeding programme. The growing of genetically diverse population of self pollinated crops in a bulk plot with or without mass selection followed by single plant selection in F /F 5 6 generation is known as bulk breeding. Following are the advantages of this method (Newman, 1912).

(i) Large populations could be grown in each generation, thereby increasing the probability of more gene combinations.

(ii) Little work is required to handle anyone cross permitting several crosses to be carried forward.

(iii) Selection from later generations would breed true as in any other comparable method of breeding.

(iv) More generations could be grown each year involving off season nurseries since there is greater role of natural selection. (Kumar *et al*, 2006).

2.4. Back-cross method: In the back cross method, the hybrid and progenies in the subsequent generations are repeatedly backcrossed to one of their parents. The objective of the back cross method is to improve one or two specific traits of a high yielding variety, which is well adapted to the area and has other desirable characteristics. The characters lacking in this variety are transferred to it from a donor parent without changing its genotype, except for the gene being transferred. Since the recipient parent is repeatedly used in the backcross programme, it is also known as recurrent parent. The donor parent, on the other hand, is known as the non recurrent parent because it is used only once in the breeding programme (for producing the F_1 hybrid). Thus, the end result of a back cross programme is a well adopted variety with one or two improved characters. (Kumar *et al*, 2006). The back cross method is mainly used in the disease resistant breeding programme. Varieties like Arka Ajit and Arka Sampoorna which are resistant to powdery mildew and rust were developed through this method at IIHR, Bangalore.

3. Mutation breeding: Mutation breeding is an alternative to conventional breeding for crop improvement. Exposing plant genetic material to mutagens enhances the possibility of isolating genotypes with desirable traits. Induced mutations can create variability in inherited traits in crop plants (Kumar *et al*, 2007b). Induced mutagenesis has been

used to obtain direct mutants or by using these mutants in hybridization (Ahloowalia *et al*, 2004) to overcome yield barriers and to obtain desirable horticultural traits. In peas studies were carried out by Narsinghani (1978) to assess the adaptability and yield potential of some of the induced and spontaneously arisen genotypes. The various mutants and their recombinants with commercial cultivars presently available at Jabalpur and elsewhere are given below (Kumar *et al*, 2006).

Afila: Snoad (1974) introduced the *st* gene (reduced stipule size) and the *af* (*afila*) gene where leaflets get converted into branched tendrils. Plant with the genetic constitution *af af* and *st st* are called "leafless". In afila plants tendrils intertwine and provide mechanical support to adjacent plants and prevent lodging to some extent.

Acacia: The tendrils are converted into leaflets. This tendril less mutant character is also governed by simple recessive gene (AcaCia long, Acacia batri, Acacia purple).

***Eleiofil*:** The leaflets are subdivided repeatedly and multiple leaflets confuse the plants to be of peas till pods are formed. The genetics of this mutant is a double recessive of acacia x afila. The genetic ratio obtained is 9 normal: 3 acacia: 3 afila: 1 pleiofila (Pleiofila tall, Peliofila dwarf, Pleiofila purple).

Earl- flowering mutant: This mutant flower from 4^{th} to 6^{th} node from the base, against 7^{th} to 8^{th} in Arkel, 12^{th} to 13^{th} in Bonneville. These are '46 C' and JP-829.

Fasciated mutants: The genotypes under this group are R- 701, R-71 0, JP-625, JP-67 etc. The inflorescence is not distributed along the stem but the flowers are clustered at the top. The apical part of the stem is band like and broadened. Sometimes the distribution of flowers and pods are over a larger part of the stem region without reduction in the total length and are called relaxed fasciated mutants such as 251A. The mutated attributes have been combined with multi resistant lines and the advance pea recombinants are being tested for resistance and production potential at Jabalpur.

Sharma *et al* (2009a) exposed Arkel and Azad P-1 to mutagens (^{60}Co gamma rays and ethyl methane sulphonate (EMS)) in 2004 to 2006. Treatment with 0.3% EMS was, in general, more effective in inducing desirable mutations at the highest frequency, and 'Arkel' had more positive mutations. Most mutants bred true as they did not segregate in the M_2 generation. Profuse pod-bearing mutants and two mutants with long, slender pods.were isolated 'Azad P-1. Two mutants with short internodes were isolated in 'Azad P-1' treated with 15 kR dose of gamma rays and 0.3% dose of EMS. 26 mutants with dark green pods and 21 mutants with Long pods (pod length between 10 to13 cm) were also isolated from 0.3% EMS-treated 'Arkel' during 2006. Male sterile mutants were recorded in different treatments of gamma rays and EMS; Anthers of such male sterile mutants were shriveled without pollen formation, resulting in no pod set or pods containing no seed.

Sharma *et al* (2010) isolated wilt-resistant mutants in two susceptible pea genotypes, Arkel and Azad P-1, mutagenized either with ethyl methane sulfonate (EMS, 0.2% and 0.3%) or gamma rays (5-22.5 kR) in ^{60}Co gamma cell for three consecutive years. Screening of different mutagenized populations under wilt-sick plots resulted in the isolation of 25 mutants exhibiting complete or enhanced wilt resistance compared to parental genotypes. Five of these wilt-resistant mutants also outperformed the susceptible background genotypes in terms of yield and other horticultural traits.

In general the breeding methods mostly followed in garden pea are pedigree selection, backcrossing and their modifications used for developing varieties resistant to diseases. Kalloo (1993) has reported the use of recurrent selection to develop varieties resistant to common root rot.

Breeding objectives

In India, most of the organizations which work for the improvement of garden pea are targetting to develop high yielding varieties (in early, midseason and tall group) with resistance to biotic and abiotic stresses. Presently, there is also demand for varieties and suitable for processing qualities like freezing, dehydration and canning and export. Thus, the chief breeding objectives in peas are:

1. Breeding for earliness: Early varieties have advantage as they get a better market price though the yield might be less. Early varieties attain pod maturity in 50-60 days. They are usually dwarf in their plant habit and are highly suitable for high density sowing which helps to maximize the productivity and thereby compensate for the lower yield. Arkel, Meteor, PM 2, Early December, Early Badger, VL7, VRP 2, Swarna Rekha, Jawahar Matar 3 and 4 are some of the popular varieties. Besides, several other varieties namely, Hans, EC-3, Lucknow, Asauji, Lucknow, Bonia, EC 3 are also in cultivation. Details of early varieties are given in the Table-7.

2. Breeding for high yield: Mid season and late group of varieties generally give yield above 10 tonnes in about 90 and 110 days respectively. Most of the varieties presently in cultivation are mid season varieties with pod maturity in 65 days. Some of the popular varieties in this category are: Bonneville, Arka Ajit, Arka Karthik, JP 83, Palam Priya, Azad P1, Pant Uphar, Kashi Shakthi, Hisar Harit, Punjab 88, Swarna Rekha, Narendra Sabji Matar 6 and Phule Priya. Details all the midseason varieties are given in the Table-8.

3. Breeding for disease resistance

Major diseases for which resistance breeding work is in progress in India are powdery mildew, rust and Fusarium wilt. Accessions resistant to diseases are given in Table 12.

3.1. Breeding for resistance to powdery mildew

Pea powdery mildew is one of the major constraints in pea production worldwide, causing severe seed yield and quality loss. The resistance is governed by a single recessive gene *er1* in majority of resistant cultivars, but *er2* and *Er3* have also been reported (Sara *et al*, 2010; Srivastava *et al*, 2012). In India, among fungal diseases affecting pea, powdery mildew (PM) caused by *Erysiphe pisi* is the most serious one as it causes yield loss upto 50 - 100% (Kumar and Singh, 1981; Aghora *et al*, 2006). Previous studies by many workers have shown that powdery mildew is governed by a single pair of recessive gene *er.* The simple recessive inheritance has also been confirmed by Mishra and Shukla (1984) and Singh *et al* (1986b). Both in ICAR institutes and in agricultural universities, major focus is on breeding garden pea for resistance to powdery mildew disease. Several improved varieties/lines resistant to PM are available for cultivation. Among these the popular resistant varieties are Arka Ajit, Arka Karthik and Arka Sampoorna (Mohan *et al,* 2012). Recently at IIHR, two powdery mildew resistant varieties, Arka Priya and Arka Pramodh, with pod yield of 12 t/ha in 90 days were developed and released at the institute level (IIHR, 2012). Several other varieties also show very high level of resistance for powdery mildew PMR-17, PMR-19, KS-245, KS-221, JP-501, JP-9, No. 23, NDVP-250, P-19, EC-269291, JP-20 (Pandey *et al*, 1999). Some of the other powdery mildew resistant popular garden pea varieties are: JP-83, JP-71, PRS-4, Azad P-1 and Azad P-4 superior yields, better quality pods, bigger and sweet ovules. (Amin *et al*, 2010; Peter and Kumar, 2008). Sharma and Sharma, (2013b) has reported that six genotypes of pea viz. VP -233, PRP-801, PMVAR-1, VP- 318, VP-316 and PMVAR-5 were found to be resistant to powdery mildew. These resistant genotypes could be used in breeding programs for development of disease resistance. Sharma *et al* (2013b) used three resistant genotypes, Sugar Giant, VRPMR-10 and DPP 9411 in hybridization and developed two high yielding powdery mildew resistant lines DPPMR-09-9 and DPPMR-09-2. Recently at IIHR, SSR marker for powdery mildew resistance has been identified for using in marker assisted breeding (MAB) programme (IIHR, 2012).

3.2 Breeding for rust resistance

Pea rust has been reported to be caused *Uromyces pisi* (Pers.)Wint. and *Uromyces fabae* (Pers.) de Barry. The latter species is prevalent in India (Katiyar and Ram, 1987). Rust is governed by single pair of dominant gene (Aghora *et al*, 2006). Many workers have identified sources of resistance to rust in peas (Pal *et al*, 1980; Singh *et al*, 2004; Vijayalakshmi *et al*, 2005; Kushwaha *et al*, 2006). Varieties developed at IIHR, Arka Ajit, Arka Karthik, Arka Priya, Arka Pramodh and Arka Sampoorna are resistant to rust (Mohan *et al*, 2012; IIHR, 2012). Similarly, varieties developed by JNKVV, Jabalpur JB Batri 3 and JP Batri Brown 4, are resistant to rust. Few other donors for rust resistance are: PJ-222117, BC-1091188, PJ-207508, JP Batri brown-3 and JP Batri brown 5 (Narasinghani *et al*, 1980; Peter and Kumar, 2008).

Combined resistance to Rust and Powdery mildew

Varieties Arka Karthik, Arka Ajit, Arka Priya and Arka Pramodh developed at IIHR, Bangalore have combined resistance to both rust and powdery mildew. Another variety of snap pea, Arka Sampoorna is also resistant to rust and powdery mildew (Mohan *et al* 2012; IIHR, 2012).

3.3 Breeding for resistance to wilt and root rot

***Fusarium* wilt:** Among diseases affecting root, wilt caused by *Fusarium oxysporum* f. sp. *pisi* (Hall) Snyd and Hans is one of the most devastating diseases of pea (Sharma *et al,* 2006; Sharma, 2011). The disease along with root rot has been reported to cause yield losses up to 93% in India (Maheshwari *et al,* 1981). Presently, most of the commercial varieties are susceptible to this disease. Therefore, development of resistant cultivar is the most efficient approach for the management of this disease (Sharma *et al,* 2010). Sen and Majumdar (1974) reported immunity against wilt in Sylvia, Blible Pod, Selectionl, T17, Kalanagani, Grey Giant, Alaska, Canner King, Kelvedon Monarch, etc. Utikar and Sulaiman (1976) observed field resistance against *Fusarium* wilt in Tall White Sugar, Early

Giant and Grey Badger. High resistance against wilt was obtained by Pachhauri *et al* (1981) in lines JM 2, JM 1, GC 468, Sel 23-3-2 and resistance in Pusa Vipasha, Sel 2 pl-2, Kalanagani, Sel 525, GC 66, Lokar, EC 3833, Canner King, Super Alaska, Boach Selection and Sel 5-2-1. The genotype Kalanagani reported to be immune against wilt by several workers (Sen and Majumdae, l974; Ramphal and Choudury, 1983; Pachhauri *et al*, 1981). At JNKVV, Jabalpur, breeding of peas resistant to *Fusarium* wilt and powdery mildew resulted in isolation of resistant donor JP 501 A/2 (Tiwari and Narsinghani, 1985). The genetics of wilt disease resistance found to be monogenic dominant (Narsinghani and Tiwari, 1991). Donors for, wilt resistance are: Early perfection, PL-6101, PL-43, PL-124, Early Giant, Canner King, Bonneville, Silivia, Blible red, T-17, Selection -1, JM-2, JM-I, Pusa Vipasha, Tall white sugar, Lakar, Boach Selecation, Kalanagni, and Early Badger (Kumar *et al*, 2006). Dhar *et al* (2011) tested four early (GP 17, GP 207, GP 447, Pusa Pragati) and four mid season (GP 378, GP 468, GP 471 and GP 473) lines along with highly susceptible variety Arkel in fusarium wilt sick plot and found that lines GP 17, P 207' and GP 473 had high level of resistance (9–26%) besides yield. Sharma and Sharma (2013c) observed that out of the 36 genotype screened, three were highly resistant and 14 were resistant.

Root rot: Fusarium root rot, caused by *Fusarium solani* (Mart.) Sacc. f. sp. *pisi* (F. R. Jones) W. C. Snyder & H. N. Hans affects pea crop around the world (Kraft and Pfleger 2001). Mir (1997) observed that out of the 13 varieties tested, two were resistant (Grey Giant and Early Badger) to *Fusarium solani* f. sp. *pisi*. Varieties Bonneville and Arkel were highly susceptible to the disease.

3.4 Breeding for Bacterial blight

Ascochyta blight complex is a severe disease of peas throughout the world and causes huge losses to growers every year. The disease complex is caused by three *Ascochyta* species: *A. pisi* (teleomorph *Didymella pisi*), *A. pinodes* (teleomorph *Mycosphaerella pinodes*) and *Phoma medicaginis var. pinodella*. According to Rastogi and Saini (1984b), pea blight caused by *Assochyta pinodella* cause considerable damage to the pea crop every year. To ascertain the inheritance of resistance to pea blight and incorporate resistance in the commercial cultivars, crosses were made between Kinnauri resistant to pea blight and four highly susceptible commercial pea cultivars Bonneville, Lincoln, GC 141 and Sel 18. Studies of the F_1's, F_2's, back crosses and F_3's indicated that Kinnauri carries a dominant gene imparting resistance to pea blight.

3.5 Breeding for resistance to viral diseases

Viruses are among the most widespread and destructive pathogens of crop plants causing serious economic losses by yield and quality reduction (FAO, 2011). In pea's pea seed-borne mosaic virus (PSbMV), caused by *potyvirus* is an important viral disease affecting pea transmitted by aphids and causes major yield loss (Coutts *et al*, 2008; Gibbs *et al*, 2008). Pea seed borne mosaic virus (Psbmv) is transmitted through seeds. In India its occurrence was reported in by Thakur *et al* (1984). Symptoms for pea seed-borne mosaic virus disease are stunting, chlorotic flecks, leaf and pod distortion (Kapoor and Singh, 1999). Resistance to the common strains of PSbMV is conferred by a single recessive gene (*sbm*) - (Hagedorn and Gritton, 1973) localized on LG VI (*sbm*-1 locus) (Smykal *et al*, 2010). Hagedorn and Gritton (1973) used PI-93586 and PI-193835 as the sources of resistance to pea seed borne mosaic virus.

Pea enation mosaic virus (PEMV) is transmitted by aphids (Nault *et al*, 1964). Disease symptoms include stunted growth, translucent veins, and blister like lesions, deformed pods and reduced yield (USDA 2009). Eleven accessions (JI 2990 to 3000) from the Norwich Germplasm Collection were screened for Pea enation mosaic virus (PEMV) and were found to be tolerant to the disease though there was some variation in the expression of PEMV symptoms (Schmidt *et al*, 1995). Perfected Freezer-60 has been reported to be its source of resistance (Hagedom and Hampton, 1975). Line PS08 is tolerant to PEMV. Resistance to PEMV is governed by single dominant gene *En* (USDA, 2009). Two markers CNGC (2.5 cM) and tRNAMet2 (1.3 cM) are closely associated with resistance to Pea enation mosaic virus (PEMV) and these markers can be used in marker assisted breeding (Jain *et al*, 2013).

3.6 Breeding for insect resistance

Few of the major insects which cause damage to peas are:

Leaf minor (*Chromatomyia horticola* Goureau)

Aphids (*Acyrthosiphon pisi*)

Pod borer (*Helicoverpa armigera* Hub., *Lampides boeticus* L.and *Etiella zinckenella* Tr.)

Pea stem fly (*Melanagromyza phaseoli* Tryon)

Pea weevil (*Bruchus pisorum*)

Among the pests of this crop, pea stem-fly (*Melanagromyza phaseoli* Tryon), pea leaf miner (*Chromatomyia horticola* Goureau) and pod borer complex (*Helicoverpa armigera* Hub. *Lampides boeticus* (L.) and *Etiella zinckenella* Tr.) are serious, and often cause substantial loss of crop (Mittal and Ujagir, 2005).

Leaf miner: Pea leaf miner caused more than 20% loss in pea yield (Mehta *et al,* 1994). Several varieties have been identified with high and moderate level of resistance to pea leaf miner in India (Mukerji *et al,* 2009). At JNKVV, Jabalpur, JP 179, JP 169-1, JP 747 were found to be resistant to leaf miner (Kalloo, 1993). Similarly at HAU, Hisar, LMR 4, LMR 10 and LMR 20 were identified as the sources of resistance to leaf miner (Kalloo, 1993). Mittal and Ujagir (2005) identified PAlO7 resistant as it had leaf miner infestation index of 0.20 and damage rating of 1 on a scale of 1-4 , compared with infestation index of 0.37 in check c.v. HPF4.

Bruchus: Pea seeds are damaged by pulse beetle (bruchid) (*Callosobruchus chinensis* Linn). Bruchus infestation starts on maturing pods in the field. (Srivastava and Bhatia, 1958). The two pea lines, JP 9 and JP 179 were resistant to bruchus (Kumar *et al,* 2006). The crosses of *Pisum fulvum* with *P. sativum* hold promise for resistance to the pea seed weevil (*Bruchus pisorum*) (Amin *et al,* 2010).

Pea stem fly: The damage by larval stages of the stem fly results in plant wilting and mortality up to 100 % in northern India (Sandhu *et al,* 1975; Singh, 1986). Sources of tolerance to stem fly are: Asauji, GC-141, IP-3 (Pant Uphar), T-163, Dwarf Grey Sugar, T -10, Load Sel and Bonneville (Kumar *et al*, 2006). Mittal and Ujagir, 2005 identified two germplasm viz., P-4039 and P-4107 resistant as they had stem fly damage of 3.12 and 4.97% compared with 13.52% damage in check (HFP4) and ten germplasm proved to be moderately resistant with stem fly damage between 5.99 and 9.56 % and damage rating of 2.

Multiple resistance

A few lines with multiple resistances to diseases and pests were developed at JNKVV Jabalpur. JP 9 resistant to powdery mildew and bruchus and JP Batri Brown 3 and JP Batri Brown 4 resistant to rusts and bruchus (Amin *et al,* 2010). JP-179 highly resistant to powdery mildew, fusarium wilt, bruchus, leaf minor and tolerant to rust and JP-501 A/2 resistant to fusarium wilt, powdery mildew and bruchus (Kumar *et al,* 2006). Varieties developed at IIHR, Bangalore, namely: Arka Ajit, Arka Karthik, Arka Pramodh and Arka Priya were found to be resistant to both powdery mildew and rust.

Snap or sugar snap pea breeding

Whole pod edible pea also known as snap pea or sugar snap pea is so called because the pods are devoid of fibrous parchment layer (Sneddon, 1970) and unlike conventional peas; entire pods are consumed either as salad or after minimal cooking. The pods can be consumed either at the initial stage when seeds just begin to appear and the pods are almost flat (popularly known as snow peas) or in the half maturity stage or even at full maturity stage. Mature pods are tender, succulent and sweet with crisp texture. The pods are rich in protein, minerals and vitamins. Recently, edible podded peas are gaining popularity as about 40% of consumable biomass is saved as no shelling is required (Singh *et al,* 2007). Whole pod edible peas are popular in several western countries like USA and European countries, China, Japan and in South East Asian countries. In India, in the recent years it is becoming popular and there is a tremendous scope for its spread in the upmarket.

According to Simmonds (1979) classified snap pea under *Pisum sativum* L. var. *macrocarpum*. The edible condition results from action of one or both of two independent recessive genes, *p* and *v.* Either gene present in the homozygous condition greatly reduces parchment, while, pods of plants homozygous for both *p* and *v* are considered parchment-free (White, 1917). Howerver, inheritance studies by McGee and Baggett, (1992) revealed that lack of parchment layer trait (fiberlessness) in pod wall is controlled by a single recessive gene *sin-2.*

Oregon sugar poded is a snap pea variety, developed at Oregon state university, USA and has been introduced in India. Smilarly, Sylvia is a snap poded variety introduced from Sweden by IARI Katrain. At IIHR, Arka Sampoorna a whole pod edible pea was developed by IIHR and released in 2001 at the institute level (IIHR, 2014). A. Sampoorna has pod yield potential of 8 t/ha in 90 days and the pods are medium long (7 to 7. cm) and both pod walls and seeds are light green. The seeds are medium sized with intermediate sweetness. Also, it is resistant to powdery mildew and rust. Pan *et al* (2010) reported that Swarna Tripti (IC 548862) was developed through hybridization between a green podded and powdery-mildew-resistant pea line JP 585 and a light-green podded variety Oregon Sugar Podded, followed by

selection in the segregating generations. This variety is ready for harvest in 80-85 days after sowing. Its pods are green, medium long (7.3-7.5 cm). Recently another whole pod edible dual purpose variety Arka Apoorva was developed and released at IIHR (IIHR 2012). Arka Apoorva is a midseason pea line with pod yield potential of 10 t/ha in 90 days. Arka Apoorva gave about 20 % higher pod yield than A. Sampoorna. The pods are longer (9 cm) and broad compared to A. Sampoorna (7 cm) and the seeds are bold, dark green sweet and the whole pods are crisp. It is also moderately resistant to powdery mildew and resistant to rust.

Breeding for higher nutritive quality

Parent 65102 was a good general combiner for protein, tryptophan, ascorbic acid and calcium contents. Cultivar Little Marvel is very sweet and cultivars Li Lincon, Thomas Laxton, and Alderman have excellent canning and freezing quality. These characteristics can be transferred into new high yielding cultivars by systematic breeding programmes (Kumar *et al*, 2006).

High protein content

The inheritance of protein content is polygenically controlled, and also by recessive factors (Cousin et al, 1985). The varieties GC 195 and the local cultivar, Kinnauri have high soluble protein content due to the presence of a very high number of dominant genes (Rastogi *et al*, 1989).

Breeding for processing quality

Freezing, dehydration and canning are the most common processing methods of peas. There is great demand for frozen peas during off season. Wrinkled and dark green peas like Arkel are suitable for dehydration. Peas grown for processing have to attain maturity at the same time. For canning, both round and wrinkled seeded varieties like T 19 and Bonneville are used. However for freezing, wrinkled seeds are used (Amin *et al*, 2010). At IIHR, Bangalore, IIHR 18, a wrinkled bold seeded variety was found to be suitable for freezing up to six months.

Breeding for abiotic stress

Breeding for tolerance to high temperature and resistance to frost: Garden pea is commonly cultivated during winter season in plains. In the recent years there is a demand for varieties suitable for cultivation during off season particularly during early summer due to higher market price. However at present there is no garden pea variety tolerant to high temperature and suitable for cultivation during summer season. Peas grown during summer results in poor growth, poor pod and seed set. IIHR544 (Magadi local) a tall midseason cultivar belonging to *arvense* group is tolerant to high temperature. It is a pulse type cultivar grown around Bangalore during summer (February to April). The pods are small (4 cm long) with four seeds and yield is around 2.5 t/ha. Cultivar early Badger is reported to be tolerant to heat and drought (Choudhury, 1967). Freezer can be good source of frost tolerance and the cv. Alderman which is suitable for hill regions (Yawalkar, 1969) can be used for transferring frost resistant genes into other suitable cultivars.

Biotechnology in pea improvement

Biotechnology tools like marker-assisted breeding, tissue culture, *in vitro* mutagenesis and genetic transformation have potential to contribute in the development of varieties resistant to biotic and abiotic stresses. However, only limited success has been achieved till now.

Molecular marker-assisted breeding

Molecular markers (closely linked to targeted traits) are the powerful genomic tools to increase the efficiency and precision of breeding in crop improvement (Varshney *et al*, 2012). Majority of the work on molecular markers in pea breeding is based on genetic mapping using various DNA markers in segregating populations for specific traits. Traditional mapping approaches have led to the development of marker-assisted selection strategies in pea breeding (Vignesh *et al*, 2011). Several workers have identified molecular markers linked to powdery mildew and rust resistant genes. Molecular markers have also been used diversity analysis in pea.

Use of molecular markers in diversity analysis

Kumari *et al* (2013) analyzed genetic diversity among 28 pea genotypes using 32 SSR markers. Cluster analysis revealed two distinct clusters, I and II with six and 22 genotypes respectively. Cluster II further had two sub clusters with IIA (12 genotypes) and IIB (10 genotypes). Wani *et al* (2013) used randomly amplified polymorphic DNA (RAPD) to estimate diversity among five genotypes of pea (four RAPD primers generated 24 bands, 10 of which were found to be polymorphic.

Molecular markers for powdery mildew

Tiwari *et al* (1998) crossed the resistant cultivar Highlight with *er1*and the susceptible cultivar Radley. F_3 plants were screened with primers, using bulked

segregant analysis and three Operon primers, OPO-18, OPE-16, and OPL-6, were linked to *er1*. Janila and Sharma (2004) has studied powdery mildew resistant cultivar DMR11 and a susceptible line and found that marker OPU-17 was linked to resistant allele and it would increase the efficiency of marker assisted selection for powdery mildew resistance. Katoch *et al* (2010) reported that by segregation analysis of an F_2 progeny of cross Lincoln/JI2480, the leaf resistance (of powdery mildew) in JI2480 was controlled by a single recessive gene *er*2. Through linkage analysis of resistant F2 progeny plants using SSR and RAPD markers it was inferred that marker of *er*2 gene was localized on pea linkage group III (LGIII). A RAPD marker OPX-17_1400, showing linkage to *er*2 was successfully converted to a SCAR marker, ScX17_1400 for usage in breeding. Srivastava *et al* (2012) screened 620 random amplified polymorphic DNA (RAPD) markers and developed a SCAR marker ScOPX 04_{880} which can differentiate homozygous resistant plants from the susceptible accessions and can be used in marker-assisted selection.

Molecular markers rust resistance

Vijayalakshmi *et al* (2005) has identified two RAPD markers linked to rust [*Uromyces fabae* (Pers.) de Bary] resistant gene in pea, viz., *SC10-82*360 and *SCRI-71*1000 flanking the rust resistance gene (*Ruf)*.These RAPD markers were not close enough to *Ruf* for using in maker-assisted selection. However, if the two markers were used together, the effectiveness of MAS would be improved considerably. Rai *et al* (2011) evaluated a mapping population of 136 F6:7 recombinant inbred lines (RILs) derived from the cross between pea genotypes, HUVP 1 (susceptible) and FC 1 (resistant). One major (Qruf) and one minor (Qruf1) QTL for rust resistance on LGVII was identified. The Qruf was flanked by SSR markers, AA505 and AA446 which would be useful for marker-assisted selection for pea rust resistance.

Tissue culture

Sharma and Kaushal (2004) generated and evaluated somaclones of two pea cultivars, Palam Priya and Lincoln for resistance to Ascochyta blight and powdery mildew. Five somaclones of Lincoln and one of Palam Priya showed resistance to *Ascochyta pinodes* but none were resistant to powdery mildew. However, one somaclone (SP6-1) of Palam Priya was resistant to Ascochyta blight and moderately resistant to powdery mildew. Increased PAL and peroxidase activity was observed in somaclones resistant to Ascochyta blight. Sharma *et al* (2010) isolated wilt (*F. oxysporum* f. sp. p*isi*) resistant callus regenerants and evaluated them in wilt sick plots. Only five R2 lines showed wilt resistance compared to parental cultivars.

Doubled haploids

Doubled haploids (DHs) are an important tool for the rapid generation of homozygous breeding lines which helps to accelerate the selection process and thus speed up the breeding of new varieties. In peas, doubled haploidy is still in embryonic stages partly due to problems such as poor regeneration of fertile plants and most protocols are genotype specific posing threats to their wide application (Croser *et al,* 2006).There are many factors such as genotype, donor plant growth conditions, microspore stage, pre-treatment of flower buds and culture medium etc., that affect androgenesis. More often, anthers rather than microspores are cultured, since the extraction and culture methods of pollen grains are laborious process. Gosal and Bajaj (1988) induced callus on anthers from pea. A few heart-shaped stage embryos developed but no regeneration was obtained. Gupta *et al* (1972) attempted for the first time to develop an androgenesis protocol for the pea breeding line 'B22' through anther culture, but no regeneration or confirmation of the ploidy level of callus cells was reported. Subsequent experiments with the same callus resulted in a few roots, shoots and torpedo-shaped embryos after 36 months, again with no confirmation of ploidy level (Gupta 1975). Gosal and Bajaj (1988) successfully induced callus from anthers of the pea cultivar 'Bonneville' as well as the two breeding lines, 'T163' and 'P88'. A few heart-shaped stage embryos developed but no regeneration was obtained. About 90% of the cells were diploid indicating that callus might have developed from maternal anther tissue rather than microspores. For isolation of anthers, buds are harvested when the microspores reach the uninucleate stage. This stage is reached when bud size is 6-7 mm in field pea. Generally, whole flower buds at various stages of development are harvested and used as a source of explants either immediately or stored in darkness at 4ºC (for 2 to 5 days) for cold shock pre-treatment or at 32ºC (for 1 or 3 days) for heat shock before isolation of anthers. For example, field pea buds are pre-treated by placing their stamens in water at 4ºC for 48 hr. Sidhu and Davies (2005) have given detailed protocol for anther culture in var. Mukta, and *Pisum fulvum (Sm)* accession ATC113. They have found that anthers of pea genotypes cultured on B5 medium with nine percent sucrose was the best for callus production.

They also recovered two putative haploid /DH plants were recovered from two genotypes - Gorokh and Pelican. Putative haploid /DH plants were produced only on L2 + Dicamba (2 mg/l) + Casein hydrolysate (1 g/l) + 9% sucrose medium. A plantlet was regenerated from one cultivar. Efforts are on to identify key factors to improve this protocol and to achieve complete regeneration (Sidhu and Davis, 2005). Though the progress made till now by various workers in peas is very limited, the recovery of haploid plants in peas demonstrates that the haploid production may be possible in this crop by microspore or anther culture. Whether any culture conditions can be modified to give consistent haploid production in different pea genotypes needs further investigation. It is important to identify whether these plants are from microspores and therefore haploid or doubled haploid, or from somatic cells of anthers.

Future thrust

1. Systamatic work on the collection, conservation, cataloguing, evaluation and exchange of germplasm.
2. Breeding varieties for resistance to biotic and abiotic stresses (mainly high temperature) and suitable for processing (freezing) to meet the internal demand and for export.
3. Development of male sterile lines, double haploidy procedures to shorten breeding cycle and suitable molecular markers for major diseases like powdery mildew, rust and *Fusarium* wilt/rot and for pea enation mosaic virus.
4. Development of garden peas suitable for cultivation in net house/polyhouse.

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