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CREATING HIGHER GENETIC YIELD POTENTIAL IN FIELD PEA (*PISUM SAVITUM* L.)*

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ABSTRACT

The present status of pea breeding and the yield potential of the existing varieties are discussed along with the possibility and ways to improve the yield levels further. It is argued that most of the major breakthroughs in yield potential were made through the exploitation of major genes controlling qualitative traits. Quantitative genetics has generally failed to make any impact. Genes have been identified which can make significant change in yield levels. These are: af, le, er, I-i, A, Pl in combination with earliness. The ideal plant type is defined as high yielding (preferably also early) dwarf. Areas for the use of biotechnology tools in pea breeding are identified.

Key words: Pea, *Pisum sativum*, yield potential, ideal plant type.

Field peas, also referred as dry peas to distinguish it from the vegetable type, is one of the most important grain legumes occupying an area of more than 10 million hectares in the World (Table 1). About two-thirds of this area is situated in the former USSR and China. The three other significant pea growing nations are France, Australia and India, in that order. Amongst all pea growing nations, France is remarkable in having average pea yields of over 4 tonnes per ha from over half million hectares.

Amongst cool season grain legumes, field pea is not only the most widely grown but potentially the highest yielder (Table 2). Heath and Hebblethwaite [1] have quoted potential yields of 7.5–8.0 tonnes per ha from The Netherlands. There is a large gap between potential yield and the actual yields realised in most pea growing nations. A part of the solution lies in the crop husbandry. However, there appears to be little doubt that pea breeding efforts on a world wide scale have been minimal despite the fact that pea is amongst the crops

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which have been extensively subjected to genetic research. Marx [2] pointed out that the pea breeding programmes around the World are small and restricted, thus providing little chance for rare gene combinations to occur. In this context, it is notable that dry pea is not included in the mandate of any of the International Institutes (ICARDA has a limited variety trial programme) despite being the most widely grown cool season grain legume with the highest yield potential.

Pea (*Pisum sativum*) as a grain legume is among the six major pulse crops cultivated the world over. A comparison of the yields harvested per unit area in the countries where pea is cultivated along with other grain legumes (Table 3) shows that it is the second highest yielding grain legume, next only to broad bean (*Vicia faba*) [3].

Interestingly, the highest average yield of dry pea (28 q/ha) is reported from Egypt. The average productivity in India is 11 q/ha. In comparison, the highest national yield levels in other crops are: faba bean 37 q/ha (USA), rajma 32 q/ha (Germany) and 28 q/ha (Egypt), soybean 26 q/ha (Egypt), chickpea 19.0 q/ha (Egypt), and lentil 17 q/ha (Egypt).

Table 2. World statistics on area, average yield, the highest national average yield (based on countries with sizeable area) of major cool season grain legumes (FAO, 1990)

Crop	Area (million ha)	Mean yield (kg/ha)	Highest mean yield (kg/ha) and country
Field pea	10.0	1,631	6,554 (Austria)
Broad beans	3.2	1,270	3,521 (Germany)
Chickpea	9.9	747	1,475 (Israel)
Lentils	3.0	737	1,425 (USA)

Source: FAO Year book. Production Vol. 43, 1949. FAO, Rome, 1990.

Table 1. Area, production and average yields of field peas (dry peas) in countries with areas above 70,000 ha

Country	Area (x1,000 ha)	Production (x1,000 tonnes)	Average yield (kg/ha)
Ethiopia	125	80	640
Tanzania	70	20	286
Canada	178	274	1,542
USA	71	177	2,479
China	1,300	1,325	1,019
Iran	75	54	720
India	444	426	958
Pakistan	145	71	487
Czechoslovakia	73	178	2,449
Denmark	144	497	3,455
France	634	2,693	4,248
United Kingdom	86	300	3,492
Australia	486	519	1,068
USSR (former)	5,400	8,550	1,583
WORLD	10,084	16,447	1,631

Source: FAO Year book, Production Vol. 43, 1949. FAO, Rome, 1990.

The message of the above statistics is that, like all other pulse crops, pea also gives best performance in Egypt. The reasons are: cultivation under assured irrigation and less damage due to insects and diseases in the desert country.

In contrast, the average yields of India in the same cropping season were miserably low: faba bean 17 q/ha, pea

Table 3. Comparison of yield levels (q/ha) of pea with other pulse crops in the major countries of common cultivation

Crops compared		Countries of common cultivation
Pea 18.4	Faba bean 22.4	India, China, Egypt, USA, USSR
Pea 17.1	Rajma 16.0	India, China, Egypt, Turkey, S. Africa, Tanzania, USA, Sweden, USSR
Pea 16.6	Soybean 14.9	India, China, Egypt, Turkey S. Africa, Tanzania, USA, USSR
Pea 16.5	Chickpea 9.75	India, Egypt, Turkey, Tanzania
Pea 19.3	Lentil 12.0	India, Egypt, USA, USSR

11 q/ha, soybean 8 q/ha, chickpea and lentil 7 q/ha, and rajma 4 q/ha.

An important lesson that can be taken from these observations is that there is enough scope to increase the productivity of all pulse crops, especially in India, provided they are cultivated under normal moisture availability and pest–disease control. This holds particularly true for the pea crop thanks to its inherent high productivity potential.

Among the major pea growing states of India, the yield levels of pea are in the following order: Rajasthan (a repetition of Egyptian situation) 13.37 q/ha, U.P. 12.36 q/ha, Haryana (also arid) 9.80 q/ha, Punjab (unirrigated, hence arid) 9.74 q/ha, and Bihar 7.03 q/ha [4]. All these states have either sufficient moisture availability (e.g. Bihar and eastern U.P.), or the crop is cultivated in relatively dry areas with irrigation.

Madhya Pradesh with 3.47 q/ha is among the bottom ranking states [4]. Although a state with vast arid and semiarid areas, the productivity is low mainly due to nonavailability of irrigation. The poor yields of M.P. are, therefore, understandable. However, pea production in this state can be increased from its second largest area of about 120,000 ha in the country and exceed all other states provided a reasonable crop can be assured with the help of irrigation to the extent necessary.

Thus, the main conclusion from the foregoing discussion is that, given the right crop management, even with the existing varieties the pea productivity can be raised to the level of Egypt (26 q/ha), a country which also falls almost in the same range of latitudes as North India.

At the same time, there are reasons to believe that the yield potential of pea crop can also be increased much above the present level through efficient breeding.

This paper examines the means for raising the yield potential of peas through genetic manipulation. The quality aspects have been excluded as milling quality is easy to achieve and trying to breed for greater protein content in this species, with a narrow range of protein content, may be counterproductive due to negative correlation with yield [5]. We have approached this task by examining direct manipulation of yield and yield components, restructuring of pea plant, i.e. ideotype approach, breeding against abiotic and biotic factors limiting yield, and the role of molecular biology in pea improvement.

YIELD IMPROVEMENT

The pea grain yield is predominantly controlled by additive gene action but nonadditive factors have also been found to play significant role [6]. The heritability of yield varies widely depending on the choice of parents, the environmental conditions, and the efficacy of field plot techniques. Yield stability is another very significant criterion as pea yields are notoriously variable from year to year and season to season. Amongst the logical yield components (number of pods per plant, number of seeds per pod, and seed weight), pods per plant appears to be most closely related to yield [7]. Pods per plant is also highly correlated with the number of seeds per plant which is believed to be a significant determinant of yield [8]. Karup and Davis [9] suggested pods per plant to be a good selection index. Precisely for this reason, "podding intensity" is the most frequent selection criterion for grain yield in pea. However, it is questionable if pods per plant is an easily measurable character. Amongst easily measurable characters, seed weight (i.e. seed size) is unfortunately poorly correlated with grain yield. Pandey and Gritton [7] showed that plant height was highly correlated with yield which may be due to greater number of pods on tall plants. Stelling and Ebmeyer [10] demonstrated that although high heritability of some of the yield components makes them attractive as selection tools, their value was limited due to poor genetic correlation with yield.

The above facts led us to believe that direct selection for yield is probably the best option available to the breeder. Recent studies, however, show that selection for yield in peas in the early generation is not very effective, particularly if based on single plants [10, 11], which may explain why so many pea breeding programmes based on pedigree methods are making slow progress in improving yield. Both the above studies led to the suggestion that single seed descent method (SSD), where earlier generations are used to select for few simply inherited characters, may be more appropriate in peas. McBride et al. [12] provided experimental evidence that in comparison with pedigree method, SSD produced greater range in yield and greater number of lines outyielding the control variety. The more recent breeding programmes in Australia employ early generation yield trials to identify crosses and F_2 derived lines within crosses where greater selection efforts are to be directed in the later generations.

Although male sterility is known to occur in peas and two useful genes, ms2 and ms11, have been identified [13], no results have so far been reported to utilise it in developing outcrossing populations.

RESTRUCTURING THE PEA PLANT: THE IDEOTYPE APPROACH

The "ideotype" concept received impetus from the discovery of two recessive genes affecting pea leaf. The afila (af) gene which converts leaflets into tendrils and the st gene which reduces the size of stipules [14]. The significance of these genes stems from the improved standing ability due to reduced bulk of the plant and the interlocking between vastly increased number of tendrils. The totally leafless plants with afaf stst genotype, however, result in such reduced growth rates that such varieties are unlikely to achieve the productivity levels of the normal leafed varieties. The semileafless plants of afaf StSt genotype, on the other hand, have been shown to be competitive to leafy types [1]. Hovinen [15] in Finland and Brouwer [16] in the Victoria State of Australia have emphasised the need for afila type ideotype. The later work, however, emphasized that semileaflessness alone is not sufficiently effective unless combined with stem strength and high branching ability [17]. Afila type pea lines have been claimed to be more tolerant to water logging [18] and drought [19]. Heath and Hebblethwaite [20], however, found no difference in the water use efficiency between semileafless and leafed lines. Tenorio and Ayerbe [21] also showed that under dryland conditions of Spain, semileaflessness offered no advantage apart from improved harvestibility. Eteve [22] found that semileafless lines suffered greater frost damage than leafed lines. Heath and Hebblethwaite [23] also reported that semileaflessness did not prove to be an advantage against pathogens such as *Mycosphaerella pinodes* and *Pernospora pisi*.

Another character which has received attention is the small rabbit-eared rougue stipule imparting fine foliage appearance in the cultivar Progreta [1]. However, Bertholdsson [23] showed that stipules play a greater role than leaflets in supplying assimilates to roots and cautioned against any reduction the stipule size.

A reduction in the biomass has been implied to offer greater standing ability in a pea crop and a mere 70 cm tall plant is advocated in the ideotype proposed by Heath and Hebblethwaite [1]. Walton [24] working in the dry climate of Western Australia (< 325 mm annual rainfall), however, emphasized the need for medium to tall plants in achieving greater yield. R. French (personal communication) working in the wheat belt of Western Australia found an overall correlation coefficient of $r = 0.809$ between grain yield and dry matter, but it ranged from -0.02 in the good environment to 0.663 in the harsh environment. On the other hand, harvest index was more closely associated with yield in the good environment, implying that whereas dry matter production is more important in the harsh environment, partitioning of assimilates is more important in a good environment.

Whereas the application of the ideotype approach in pea breeding is not questioned, the above discussion cautions against using the popular concepts as selection criteria without carefully examining their value in the agroclimatic conditions to which breeding programme is focussed. Also, the selection for high yield per se should not be overlooked in the quest for "ideotype".

The Indian experience in pea breeding is an interesting example. Attention of the pea breeders in India has been concentrated on three single-gene controlled and easy to detect characters during the last one-and-half decades: tendrilled or afila (gene af, chromosome I), dwarf plant (gene le, chromosome IV), and powdery mildew resistance (gene er, chromosome VI).

All three genes, being nonlinked, can be easily combined, and subsequent selection for other economic traits like maturity duration, seed quality, and yield potential becomes easy.

The dwarf strains are being tested in separate multilocation trials at the same locations where tall-pea trials are also conducted. Therefore, their yield levels are comparable over the two groups of genotypes. Generally speaking based on several years of experience, the dwarf strains have given up to 50% higher yields than the tall genotypes [25]. This is one important area that needs to be explored and exploited further.

The tendrilled character involves transformation of all the leaflets in the main leaf into a multiplicity of branched tendrils. The stipules remain large as usual which, combined with the mass of green tendrils, ensure enough food supply to the pod(s) developing in their axil at each individual node [26]. At the same time, the intertwined tendrils provide mechanical support to the neighbouring plants and delay the lodging of plants even at maturity. An additional advantage with afila plants is that the network of tendrils above the crop canopy prevents bird damage.

The er gene for powdery mildew resistance (PMR) needs no emphasis. This single gene has virtually saved the pea crop in this country which was almost at the point of collapse in the 1970s when the area and production were reduced to almost half. Genetic studies have shown that the er gene is closely linked to another convenient seed marker which gives black hilum (gene Pl). This trait is selection neutral in terms of seed quality and its market preference. Strains combining er–Pl genes are already available, some of them in af, le background. Using such parental lines (af, le, er, Pl), breeding for PMR can be done even at the centres where powdery mildew has erratic occurrence. If the Pl gene is taken along, selection for PMR should not be difficult even in the years when the weather conditions (e.g. prolonged cold in rabi season) do not permit establishment of the disease, making it difficult to distinguish the resistant and susceptible plants in a segregating population.

The Indian workers are already utilizing the af, le, er genes extensively in breeding programmes. For almost 15 years, only PMR varieties are allowed to enter the multilocation trials. Dwarf pea varieties will soon become available in large numbers for commercial cultivation. One tendrilled dwarf PMR variety (af le er) has already been released, and the latest trends in the all-India trials are that more afila strains are reaching the final stage of the three-year testing than the normal leafed types.

With these developments, like many other pulse crops with new plant types (early, dwarf, determinate) becoming available, the pulse production has increased during the recent years [27]. The production of dry pea has shown rapid increase with the PMR varieties spreading to larger areas.

Nevertheless, there are few more areas that need greater attention now than in the past. First of all, the structure of the pea plant is such that it is destined to fall on the ground at one stage or the other. The stem of a pea plant is very thin at the base and its thickness increases as the plant grows. Coupled with huge mass of foliage in the upper tiers and accumulation of massive pods, the plant becomes top-heavy, and the thin base cannot hold it in upright position for long. The tall varieties lodge much earlier in their ontogeny, but ultimately the dwarf genotypes also fall even if carrying afila trait. This is particularly so if the harvesting is delayed and an overmature crop has to wait in the field.

Any genetic system that can make the base of the pea plant anatomically strong and thick enough, which can keep the plant standing erect till full maturity, will undoubtedly boost its yield potential. Such a plant, combined with afila and dwarf characters, could be planted at a very close distance. At high crop densities and with appropriate crop management, the yield levels of this crop per unit area could be increased by 20–25%.

The pea crop in India (like many other countries) has a limited scope because its consumption is highly restricted and the uses of grain not so diversified as, for example, in the case of chickpea. Pea also does not form a staple food item in Indian diet like pigeonpea, mung, urad or lentil—the pulses of daily mass consumption. As a result, the market cannot absorb large production of grain pea. This is evident from the fact that at present, when pulses like urad, mung, rajma, arhar, lentil, and even moth are selling in the wholesale price range of Rs 1500–2000 per quintal, the price of dry peas is hovering around Rs 1000/- per quintal. This is so for the last several years.

Therefore, new uses of dry peas have to be found if the popularity of this crop is to increase. Finding export markets could be a sure way to increase pea production in India.

Two areas are clearly discernible. The green seeded fieldpea (i.e. round, nonvegetable type) is usually about Rs 200–300 per quintal costlier than the white peas. There is need to evolve varieties which, besides af, le, er traits, should also combine the green seeded trait. This character is also controlled by a single recessive gene (i, chromosome I). Its monogenic nature and easy visual scoring make it extremely convenient for selection.

However, the i gene is closely linked to af on the same chromosome I (map distance about 12). Therefore, these two genes will be combined only by raising large segregating populations.

Another aspect of pea breeding could be to develop fodder–forage varieties. This would involve developing varieties meant for green fodder or concentrates in the form of dry grain for cattle and poultry feeds. The biggest convenience in such breeding programmes is that the restrictions imposed on the varieties meant for human consumption are no more relevant. The white (or green) seeded varieties have to be white flowered also, because the dominant A gene produces red flowers. The white and green seed colours are, in fact, due to cotyledon colouration, which is visible even in intact seeds when the seed coat is translucent due to absence of pigment (recessive gene a). The red flowered genotypes produce seed with coloured (red, brown, or opaque deep green) testa. The cotyledon colour cannot be visualized in intact seeds of such pigment-potent genotypes.

However, it is an established empirical observation in many crops, including pea, that the genotypes capable of synthesizing pigments (anthocyanins etc.) are more productive, stable, nutritious, and tolerant to environmental fluctuations. Coloured seed does not impose any restrictions on its use in animal husbandry. Even for human consumption, it does not make any difference once the testa is removed and only split cotyledons are sold as the commercial product (which may be white or green depending on the status of I–i gene).

There is no doubt that the demand for cattle/poultry feeds and fodder will increase manifold in this country in the years to come. In India, the poultry industry has been growing at the rate of 8–10% per annum over the last many years. The picture is even more encouraging in other components of animal husbandry. With increasing population and rising standards of living, consumption of food items from animal sources (milk, meat, eggs, fish etc.) is bound to increase. A cheap pulse like pea could come to rescue in such a situation. If the "high quality" white peas are the cheapest pulse today, the relatively less preferred coloured peas (from human consumption point of view) will sell still cheaper — a situation most favourable in economic terms for animal husbandry.

It is, therefore, essential that the pea breeders should take the challenge, foresee the needs of future, and initiate breeding programmes for dual purpose (feed–fodder) peas as well. It will take decades before varieties suitable for commercial cultivation become available. The chances of success in this area are perhaps even greater, and the grain yield in red flowered peas can be increased by a margin of at least 15–20% over the best white seeded varieties.

Earliness is yet another trait of great economic importance. It must be remembered that yield is the productivity potential per unit area. Therefore, unit of land area is one component of yield assessment, which is not a genetic trait but a part of crop management. Early varieties can be planted with high crop density, and the crop stand can be further increased by selecting dwarf varieties. Perhaps this would be the most ideal situation to maximize yields not only per unit time, but also per unit area. In fact, this could be a general formulation not only for pea, but for most grain crops as well, leguminous and others. The concept of "ideal plant type" can be summarised as follows [25].

IDEAL PLANT TYPE = HIGH YIELDING (EARLY) DWARF

In the pea crop, the future variety development programmes should concentrate on the following major properties:

1. Dwarfism
2. Afila
3. Earliness
4. Shattering resistance
5. Red seed (testa)
6. Green seed (cotyledons)
7. Powdery mildew resistance
8. Strong erect stem

BREEDING AGAINST YIELD LIMITING FACTORS

Abiotic stress. Field peas are very susceptible to waterlogging, freezing temperatures, and water stress. Significance of the semileafless (afila) character in relation to these factors has been discussed earlier. Cold tolerance is being actively pursued in several European countries, particularly those in the CIS (former USSR). Winter hardy pea germplasm lines have been registered in the USA [28]. Cold resistance is also significant in the subtropical and Mediterranean climate where peas are grown in winter and are often subjected to frosty nights. Perhaps the most significant amongst abiotic factors is the moisture stress due to shallow rooting system of this plant. Deeper and more extensive roots have been suggested from UK [1] and Western Australia [29]. However, breeding for deeper root system presents enormous practical problems. The osmoregulation/osmotic adjustment, on the other hand, is a more measurable character and it is shown to be associated with drought tolerance in several crop plants [30]. When plants are subjected to water stress, their osmotic potential tends to decrease. If this decrease does not accompany a change in relative water content, there is full osmoregulation. If, however, the relative water content decreases, this will indicate a higher or lower osmoregulation depending on the magnitude of decrease. Rodriguez-Maribona et al. [31] in Spain showed strong correlation ($r = 0.7–0.9$) between osmoregulation and yield of peas under water stress. Similar work is in progress in Western Australia (R. French, personal communication). It may be some time before a simple technique for measuring osmoregulation in large numbers of breeding lines is developed, but at the present, screening of parental material and advanced lines is a clear possibility.

Disease resistance. Much has been said above about powdery mildew. Among other diseases, root rots caused by *Pythium* spp., *Aphanomyces euteiches* f. sp. *pisi, Fusarium solani* (Mart.) Sacc. f. sp. *pisi* (Jones) Synd. and Hans, bacterial blight caused by *Pseudomonas syringae* pv. *pisi,* downy mildew caused by *Peronospora pisi* Syd., black spots caused by *Ascochyta pisi* Lib., *Mycosphaerella pinodes* (Berk and Blox.) and *Phoma medicaginis* var. *pinodella* (Jones) Boerema, and pea seed borne mosaic virus are most important. Their significance in causing yield damage, however, varies with the agro-ecological condition. Some excellent information and breeding materials are available for various root rot resistances from the work of Dr. J. M. Kraft at the Washington State University [32–34] and from the University of Wisconsin [35]. Resistance is also available against downy mildew [36], powdery mildew [37], bacterial blight [38], and pea seed borne mosaic virus [39]. Amongst the organisms causing black spot disease complex, sources of resistance to *Ascochyta pisi* [40] and *Phoma medicoginis* var. *pinodella* [41, 42] are available and have been used in breeding programmes. However, breeding against *Mycosphaerella pinodes,* which also happens to be the most widely distributed and most destructive, has met with little success. Clulow et al. [43] from the United Kingdom and Nasir et al. [44] from Germany have recently reported genetic analysis of partial resistance. Critical examination of the above two studies in light of the past [45] and recent work in Australia highlights several persistant problems. The level of resistance in parental lines is generally insufficient. There are doubts about the durability of resistance in view of the large pathogenic variation that has been found to occur. Resistance sources are wild pea collections, some of which are species other than *P. sativum,* and they carry many undesirable agronomic traits. Limited experience in handling segregating populations highlights difficulties in selection for resistant plants with desired agronomic traits. Resistance to *M. pinodes* therefore poses the greatest challenge in achieving high yields in the Mediterranean and temperate regions.

Insect pest resistance. Pea and bean weevil (*Sitona lineatus* L.), pea moth (*Cydia nigricana* F.), pea aphid (*Acyrthosiphon pisum* Harris), pod borer (*Helicoverpa armigera* Hub), and pea weevil (*Bruchus pisorum* L.) are some of the world wide insect pests. Their significance, however, varies greatly from region to region. Red legged earthmites (*Halotydeus destructor* Trucker) are most destructive in the southern hemisphere where pasture legumes abound such as Australia. Integrated efforts to identify and breed for insect pest resistance have only been reported on *Sitona lineatus* L. [46] and *Bruchus pisorum* L. [46, 47]. Clements et al. [48] recently reviewed the status and potential of breeding for insect pest resistance in grain legumes and emphasized the need for large multidisciplinary team efforts for identifying resistance mechanism and developing cultivars. Such resources at present are unfortunately scarce for peas which is currently excluded from international institutes where such programmes are flourishing for other grain legume crops. Nevertheless, encouraging results have been reported recently. Transgenics of pea carrying the α-amylase inhibitor gene of common bean have been claimed to be resistant to bruchid weevil [49–51].

NITROGEN FIXATION

A pea crop should freely nodulate and fix atmospheric nitrogen in order to yield to its maximum potential. Hobbs and Mahon [52] studied variation in N_2 fixation and found heritability to range between 0.76–0.85. Whereas breeding specifically for increased nitrogen fixation may not be feasible in many programmes, selection for yield may indirectly improve the selected lines against the native and applied bacterial population. However, care must be exercised when using undomesticated lines as parents in the disease and insect pest resistance programmes as Holl [53] found two recessive genes, sym2 and sym3, responsible for nonnodulating and nonfixing characters amongst wild genotypes collected from Afghanistan.

ROLE OF BIOTECHNOLOGY IN PEA BREEDING

While there is no denial of the fact that the age-old system of field testing and multilocation trials is an essential component of any breeding programme which cannot be bypassed, biotechnology techniques have the potential of increasing the span of coverage, speed, efficiency and precision of plant breeding to an extent which is beyond comprehension at present. Among all leguminous crops, pea is the most suitable candidate to begin with. As the "queen mother" of the science of genetics, among the pulse crops, maximum work on basic genetics, cytology and cytogenetics has been carried out in *Pisum sativum*, which gives tremendous advantage in planning studies on molecular genetics [26, 54, 55]. However, it is known that related plants have a very high level of molecular homology and the molecular markers of one species are equally applicable to other species in a majority of cases. In fact, molecular probes of pea are already being used for RFLP analysis in lentil [56]. The number of RFLP markers for all the chromosomes of pea is increasing rapidly [57–59].

As mentioned above, single genes have been identified in pea which control several economic traits related to plant architecture, disease resistance etc. Establishing linkage of these genes with molecular markers should be the first priority so that marker-based selection can be practiced. By doing so, huge amounts of segregating materials can be screened even before going to the field and segregates for the desired trait can be selected with perfection. Weeden et al. [60] have already produced genetic maps combining molecular markers and genes of economic significance in pea. Further, such molecular markers and genes for morphological and economic traits can be cloned and characterized. They can be employed to identify similar DNA sequences in other grain legumes, and ultimately, used for transformation across the species limits.

The pea plant thus provides a model specimen to not only develop near-ideal varieties in this crop [25, 61], but also to extend the concepts of modern breeding from pea to other crops as well. The opportunities are immense, and the future appears to be bright.

CONCLUSION

Based on the knowledge generated from genetic studies and experience gained from variety improvement programmes in pea, it can be concluded that major advances have been made only through the exploitation of single gene controlled traits. Breeding for quantitative traits remains as vague and uncertain as in all other crops, even though some precision can be added to breeding for polygenic traits with proper planning and use of early screening procedures [62, 63]. It would be advisable to mainly concentrate on identification of major genes of economic value. Genes and their linked RFLP markers must be identified. Such gene sequences can also be used more conveniently to generate genetic variability of transspecific nature which never existed. They can also be conveniently used in combination with biotechnology techniques to make the breeding process efficient and selection more precise.

The future needs of pea breeding will be to develop dwarf nonlodging and disease-free varieties with white and green seed (for human consumption) as well as red seed coat (for feed and fodder purpose). High yielding varieties can be developed following the simple definition of "ideal plant" type as:

Ideal plant type = High yielding (early) dwarf

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