CHAPTER 16

VARIETAL ADAPTATION, PARTICIPATORY BREEDING AND PLANT TYPE

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Abstract: The need for adaptation to environments is modified by a need to yield well across a range of seasons and changing microenvironments that can lead to large genotype environment interactions. These interactions may be linked to specific physiological or other traits of the plant which are under genetic control and may be understood. Consequently, different breeding schemes (e.g., farmer participation or research station directed) may be needed in different situations. Similarly under different agro-ecological situations different types of plants may need to be selected (e.g., well watered vs. rainfed). A range of possible factors that affect the ideal adaptation and approach are discussed in this chapter as a means to better understand the process of lentil adaptation that has taken place and continues to take place around the world

1. INTRODUCTION

Adaptation is the process by which plants/varieties/organisms become more suited to survive and function in a given environment. The history of adaptation of lentil in India is well reflected in naturally existing plant types. The luxuriant growth, profuse production and simultaneous shedding of flowers/immature pods and indeterminate and long duration of growth, low harvest index and photosensitivity are factors that reflect a domestication process aimed at maximum survival rather than maximum production. The term adaptation refers to the relationship between the plant and its environment, and thus, can be used in two ways, i.e., to describe both a process and condition. The process is one of the modifications to suit new environmental conditions, and the condition is the result of that process. In the latter case, the

S.S. Yadav et al. (eds.), Lentil: An Ancient Crop for Modern Times, 255–274.

process may be unknown or ignored and the adaptation describes the present performance of a population in one or more environments. The prevalent practice of cultivating one or more pulses together mixed with cereals and millets speaks of adaptation to subsistence farming (Lal 2001).

A common breeding objective in lentil is to develop cultivars with high and stable yield over a range of production environments. Inevitably breeders must sacrifice performance in some environments in order to attain an acceptable level of overall performance, that is, broad adaptation involves specific sacrifices, and limits are placed on performance in particular environments because of the range of environments, which the breeder must consider. Cultivar stability is yield variability over years at a site and cultivar adaptability is yield variability across sites averaged over years. Lentil breeders must be concerned with both stability and adaptability when selecting among breeding lines. Stability and adaptability should be closely related if genotype × environment interactions are caused by unpredictable environmental variables such as rainfall, rather than by predictable ones, such as soil type differences that vary across sites but not years.

In choosing among possible cultivars, a farmer would be interested mainly in their relative stability at the farm site, or conversely in the relative amount of risk associated with the use of each for a given yield level at that site. Where genetic differences in performance are relatable to factors associated with particular locations, they can be exploited by development of regional breeding or selection programmes if adequate resources exist. However, current resources in India (most Asian countries) do not permit such a proliferation of programmes for the food legumes, in general, and lentils, in particular. Therefore, a strategy to develop broadly adapted cultivars is most appropriate. Given that lentil is generally grown under conditions in which moisture stress is virtually assured in most years, it is likely that cultivars may require broad stability even if they possess narrow adaptation. In certain regions, special problems are encountered like, rust and wilt in north west plain zone (NWPZ) and north east plain zone (NEPZ) of India, wilt in CZ and stem and root rot in rice fallows of northern India. For such regions, regional breeding for narrow adaptations can be more productive. Development of pest and disease resistant varieties is a major objective of all the lentil improvement programmes. An emphasis on protective breeding is not surprising : the problems are economically significant, the objectives are easily defined, and selection can be conducted in discrete programmes. Genetically resistant varieties have many advantages over other forms of control.

2. IMPORTANCE OF ADAPTATION

The phenotype of an individual is the resultant effect of its genotype and the environment in which it develops. Furthermore, the effects of genotype and environment may not be independent. This interplay of genetic and non-genetic effects on the phenotypic expression is called genotype-environment (GE) interaction. Some genotypes perform well in a wide range of environments, while others need specific environments to express their genetic potential. A combination of stability in earliness and high-yielding ability is a very important attribute of any genotype (e.g. L 9–12, LH84–8 and Precoz) to be released for general cultivation as a variety.

Farmers are concerned with the production of particular varieties over time and space. As a result, the central objective of lentil scientists is the improvement of the productivity of lentil in specific environments and improving its adaptation to a range of production environments. This may involve genetic and/or environmental modifications designed to alleviate limits of productivity or adaptation. Genetic improvement involves a modification of the genotype to produce a more appropriate phenotypic expression in particular environments. Agricultural production inevitably involves modification of the environment to relieve a particular stress or limit to productivity. This may either negate or alter the need for genetic modification or change the probability of its success in the short or longer term. In practice, improvements in productivity and adaptation depend upon the manipulation of both the genetics and the environment of the plant, and concurrent manipulation is likely to result in optimum performance. Thus, genetic manipulation is only one aspect of crop improvement, and may not be the most appropriate means of resolution of the primary limit to productivity or adaptation.

Plant breeders have observed that adaptation of lentil cultivars is highly area-specific. Since lentils had been domesticated and then widely disseminated throughout the Mediterranean region, Asia and Europe by the Bronze Age, and now, almost throughout the world, it seems probable that tremendous genetic variation exist within the genus for adaptation to environment (Summerfield 1981). Lentil (*Lens culinaris* Medikus subsp. *culinaris*), an annual diploid ($2n=2x=14$) plant is a grain legume well adapted to cool conditions. It is normally sown after autumn rains in the Mediterranean region, or after the monsoon rains, i.e. onset of winter, in India and Pakistan, and grows throughout the winter (*rabi*) season. The crop is reported to be intolerant to extreme heat and cold, which could be why it is confined to higher elevations in tropical countries such as Ethiopia and Mexico, or is grown during the spring at higher elevations in temperate countries such as Iran and Turkey. The crop tolerates drought better than waterlogged soils. For severely drought prone areas selection for early flowering is required (Silim *et al.* 1993).

Improvement through breeding for larger crop yields always includes a conscious or unconscious attempt to produce varieties or populations that are able to make more productive use of the environments for which they are intended. A breeder can expect the greatest benefit only if resistance attributes for *Ascochyta* blight, fusarium wilt, pests, drought, frost, lodging, etc., are incorporated into genotypes which are physiologically well adapted to particular environments. However, the ways in which the climate of a region determine what species will thrive, and the effects of seasonal and annual vagaries of weather on economic yields, are poorly understood in most crops (Monteith 1977), and in lentils hardly at all. Lentil land races must result from centuries of natural and artificial selection in environments, which embody diverse agro-climates and edaphic conditions at various latitudes and altitudes.

3. VARIETAL ADAPTATION FOR DIFFERENT ENVIRONMENTS

Lentil plants have a broad range of characteristics that may be influenced by genetics and environment and a range of these interactions and how they may affect productivity are discussed below. More detailed description of many factors are included in other chapters. The detection of the genetic difference component of the interaction is improved when plants are grown in environments, which maximize the difference in response between genotypes, i.e. in environments outside the range of conditions to which particular genotypes or populations are adapted. For the identification of lentil genotypes which are well adapted not only to seasonal changes in the aerial environment but also to different seraphic conditions (e.g. hot, dry or saline soils), it is also important to consider the symbiotic association with *Rhizobium*. A nodulated legume can obtain at least part of its nitrogen requirements from symbiotic fixation (Chapter 8). Unfortunately, the symbiotic relationship has frequently been ignored in studies of interactions between genotypes and environment in lentils.

3.1. Effects of Climatic Factors

Lentil genotypes are sensitive to geographical and seasonal differences in photoperiod and temperature. In India, sowing in October produces the largest yields but vegetative growth is terminated progressively sooner, and yields are smaller as sowing is delayed (Saxena and Singh 1977). Nevertheless, a large proportion of Indian crops are not sown until after the harvest of paddy in December. Similar benefits of sowing earlier than farmers would normally do, have been recorded in Syria (Hawtin *et al.* 1979). Crops sown early in India and Pakistan on conserved moisture in soil, may exploit chance showers of rain but, unless resistant genotypes or appropriate chemicals are used, fungal diseases such as *Fusarium oxysporum* (wilt) can negate all other advantages. Under irrigated conditions in north west plain zone of India, timely sown crop (second fortnight of November) results in the best expression of seed yield and its component characters (Solanki and Singh 2000).

The major traits of adaptation for lentil producing large yields in low rainfall Mediterranean-type environment (short season) are early flowering, and pod and seed set before the onset of terminal drought. Early phenology together with rapid ground cover and dry matter production allows greater water use in the post flowering period (Siddique *et al.* 2001). The development of earlier flowering cultivars with greater dry matter production together with improved agronomic packages will increase and stabilize lentil yields in low rainfall environments (Siddique *et al.* 1998). The yield under drought conditions is strongly correlated with early vigour and early pod set which enables the plants to escape drought (Leport *et al.* 2003). Drought tolerance is closely related to the distribution of root systems in the soil. Stem length, root length and lateral root number were highly correlated, both amongst themselves and with yield. The line, ILL 6002, exhibited significantly superior root and shoot traits and yield, and therefore, is a valuable germplasm for breeding drought tolerant cultivars (Sarker *et al.* 2005).

Some lentil varieties produce higher yields in environments, which are conducive to high yields, as expected, whilst others yield better-than-average in poor environments but fail to exploit better conditions (Malhotra *et al.* 1971). In general, varieties which mature relatively early, which are likely to be small-seeded types in India, may be the least stable, but the most desirable in different locations. Sowing date studies reported for lentils tell us little about those characters which contribute to high and stable yields, or otherwise, in different photo-thermal regimes.

Lentil plants are, usually less than 70 cm tall but, if flowering is delayed and crop durations are extended by cool ($<10\,°C$) temperatures, their indeterminate habit can result in excessively tall plants. Branching pattern depends on genotype and on population density. Sparse branching may be associated with bold seeds and deep roots. Variation in both the number and size of a particular plant organ can be analysed in terms of two variables which may or may not be independent: the rate and the duration of growth (Monteith 1977). When the size or number of organs is fixed genetically, a change in growth rate associated with warmer or cooler temperatures may be offset by a proportional change in duration, so that the net effect may be small. However, if the rate of growth is limited by some non-genetic factor(s), such as the supply of C or N, a change in growth rate in association with change in temperature may not be compensated for by differences in growth duration.

Lentil seedlings, owing to hypogeal germination, are less likely to be killed by freezing, wind or insect damage, or grazing, than if germination were epigeal. If the young shoots are damaged, new buds can be initiated from the nodes below ground. Rates of germination, emergence (hypocotyl elongation) and early seedling growth depend markedly on temperature. Lentil seeds can germinate throughout a wide range of temperature, whether in the light or in darkness, or in constant or diurnally-fluctuating regimes. The optimum temperature range varies with genotype and the age and size of seeds. Smaller seeds, which have a greater surface area: volume ratio than larger seeds, can germinate more rapidly than larger ones at cool temperatures (15 to 25 °C). Young plants can withstand a severe frost, but may be killed if this is prolonged, or repeated (Slinkard 1979), or accompanied by desiccating winds. Cold nights can lessen water uptake, hence genotypes adapted to cold conditions may also tolerate the physiological drought (Steponkus 1978). One lentil genotype (WH 2040), introduced into USA from Greece, has been reported to withstand intense cold ($-23\,°C$) at the seedling stage, without the protection of snow cover, and to establish adequate crop stands thereafter (Wilson and Hudson 1978).

In the countries surrounding the Mediterranean sea, the period of vegetative growth in the lentil crop coincides with progressively lengthening days and warmer temperatures. In comparison, crops in the Indian sub-continent will experience at this stage of development shortening days and cool, or even cold (0 to 2 °C) air temperatures (Sinha 1977). Crop growth rates are very low during early vegetative growth, especially when air temperatures are cool (Saxena 1979), and although some genotypes grow more rapidly than others, this species produces only meagre yields per unit of crop time.

Seed set in controlled environments is improved when relative humidity is maintained close to 50% in 16h photoperiods (Muehlbauer 1979) and in a temperature regime of 27° day to 21 °C night. The first (lowermost) fruits to mature usually contain heavier seeds than those which ripen later, although seed size depends also on genotype, the proportion of reproductive load in single-seeded pods, soil fertility and maturation environment. Notwithstanding these additional factors, an acropetal decline in seed size could indicate that pod-filling is limited by the availability of assimilates, N or other nutrients. If yield were limited by sink size, rather than the supply of nutrients, it may be reasonable to expect that later-formed fruits would be equally as well filled as those, which matured earlier (Sheldrake and Saxena 1979).

Sinha (1977) reported that lentils produce seed yields as large as 3.5 t/ha. Variations between genotypes and/or environments have been described by statistical procedures, such as correlation, rather than seeking to explain how environmental variations in time affect the physiological and morphological processes, and hence growth, development and yield (Bunting 1975). Lentil seed yields have been found to be positively associated with branching, the number of flowers and pods per node or per plant and the number of seeds per pod and sometimes, plant height, days to flowering and 100-seed weight (Table 1). For plant height, days to flowering and the number of seeds per pod both types of associations, i.e. positive and negative with final yield have been reported. Some workers have suggested that harvest index may be a useful selection criterion for large yields.

Donald and Hamblin (1976) suggested that it might be useful in plant breeding practice to distinguish between ‘isolation environments’, ‘competition environments’ and ‘crop environments’ and to recognise that plants with different characters will produce large economic yields in each situation. Selecting early generations in an ‘isolation environment’ (well spaced plants) may be the most appropriate for harvest index. It seems prudent that, in seeking adaptation to environment in lentils, evaluate the proposals recently advocated for cereals, not only with respect to the data which are collected as a matter of routine in yield trials but also in more specific studies which, hitherto, have evaluated HI in ‘competition’ and/or ‘crop environments’ (Singh 1977, Solanki and Singh 2000).

The majority of cultivars released so far in lentil are selections from germplasm and not from hybridization programmes. Most of these cultivars are well adapted to only restricted regions, others are more broadly adaptable and some can exploit less favourable environments (Kumar *et al.* 2005, Solanki 2001). Large genotype × environment interactions have been recorded for most characters which contribute to variations in seed yield (Kumar *et al.* 2005, Solanki 2001, Yadav *et al.* 2002), and we can not hope to identify with confidence the main effects and interactions of climatic factors such as photoperiod and temperature on the more responsive components of yield, morphological or reproductive, until these relationships have been studied more carefully. Winter cold has a smaller effect on yield than rainfall, with no consistent overall effect, but with differences over regions (Erskine and El-Ashkar 1993).

Table 1. Associations of different traits with seed yield in lentil (compiled from Huyghe (1998))

Trait	Workers reporting	
	Positive association	Negative association
Days to flowering	–	Joshi *et al.* 2005, Muehlbauer 1974, Singh and Dixit 1970, Wilson 1977
Plant height (cm)	Kumar *et al.* 2002, Vir and Gupta 2002, Solanki *et al.* 2002	Muehlbauer 1974, Singh and Dixit 1970, Wilson 1977
Branches/plant	Kumar *et al.* 2002, Om Vir and Gupta 2002, Solanki 1999, 2006, Solanki *et al.* 2002, Yadav *et al.* 2005	–
No. of flowers/plant	Singh and Singh 1976, Wilson 1977	–
Clusters (Nodes)/ plant	Om Vir and Gupta 2002, Solanki 1999, 2006	–
Pods/cluster (node)	Kumar *et al.* 2002, Om Vir and Gupta 2002, Singh and Singh 1976, Wilson 1977	–
Pods/plant	Joshi *et al.* 2005, Kumar *et al.* 2002, Om Vir and Gupta 2002, Singh and Singh 1976, Solanki 1999, 2006, Solanki *et al.* 2002, Wilson 1977, Yadav *et al.* 2005	–
Seeds/pod	Joshi *et al.* 2005, Kumar *et al.* 2002, Om Vir and Gupta 2002, Singh and Singh 1976, Wilson 1977	Muehlbauer 1974, Singh and Dixit 1970, Wilson 1977
100-seed weight (g)	Om Vir and Gupta 2002, Solanki *et al.* 1992	–
Biological yield/plant (g)	Kumar *et al.* 2002, Om Vir and Gupta 2002, Solanki 1999, 2006, Yadav *et al.* 2005	–
Harvest index (%)	Kumar *et al.* 2002, Solanki 2006, Yadav *et al.* 2005	–

3.2. Effects of Water and Soil Factors

Whether the lentil crop responds favourably to irrigation or not depends largely on local edaphic conditions and rainfall patterns. Irrigation at the branching stage and again at pod formation increased yields in one season, but had no effect in subsequent season when there was well distributed rainfall (Sinha 1977). Irrigation may not be necessary in systems where lentils are grown after the harvest of paddy (Singh and Virmani 1974), and provision for adequate surface drainage may be advantageous in Mediterranean regions where rainfall can be expected during crop growth (Oweis *et al.* 2004). Appropriate plant populations in dry land farming systems should be maintained. While dense populations may intercept radiant energy more effectively than sparse stands, they may also deplete the soil profile of water more rapidly, and so eventually produce smaller economic yields.

Of course, this may not occur with short duration cultivars, which, by maturing rapidly, may avoid substantial stress (Silim *et al.* 1993). Yields are less responsive to row spacing than to sowing density. The narrowest row spacing (0.2 m), generally gives the greatest seed yields, which decrease linearly with increased row spacing (Silim *et al.* 1990).

Pulse crops are often grown on marginal lands under conditions of agronomic neglect (Jain 2005). Lentils are still grown in edaphic conditions which are not very different from those in their native habitats, i.e. dry, coarse-textured, stony hill side sites. Thus selection pressures have continued to be for adaptation to drought, poor fertility and competition with pests, pathogens and weeds. Lentil crops respond to better management, fertilizer and different nutrient applications. Siddique and Loss (1999) reported that there is no effect of sowing depth on crop phenology, nodulation or dry matter production in lentil over locations and cropping seasons. Sowing at depth (4–6 cm) may improve crop establishment where moisture from summer and autumn rainfall is stored in subsoil below 5 cm, by reducing damage from herbicides applied immediately before or after sowing, and by improving the survival of *Rhizobium* inoculated on the seed due to more favourable soil conditions at depth (Siddique and Loss 1999). Brandt (1999), while evaluating the management practices for black lentil green manure for the semi-arid Canadian prairies observed that if green manuring is practiced, early incorporation with lentil leaf strips is the most promising management system. However, even with improved water management practices, green manuring did not demonstrate a consistent advantage over summer fallow, which may be required to offset the added economic costs required to enact this practice.

Lentil productivity is influenced positively by the rate and method of phosphate placement (band placement) in different environments (Tawaha and Turk 2002). The effect of organic materials on soil physical environment and yield sustainability in rainfed rice-lentil sequence found the sole application of FYM as the best followed closely by the conjunctive use of FYM and inorganic fertilizer (Sarkar *et al.* 1995). Neither crop rotation nor tillage practice have a measurable impact on lentil diseases, but epidemics of *Ascochyta lentis* and *Botrytis cinerea* were most severe in treatments with the densest plant stands. The trends of tillage, rotation and environment over years demonstrated that regardless of tillage or crop rotation practices, the annual environment was the most important factor limiting the severity of disease and the prevalence of causal agents in the complex (Bailey *et al.* 2000). Chickpea, lentil and dry pea yielded 76%, 77% and 90%, respectively, of their fallow field yields when grown on stubble indicating that the pulse crops have excellent potential for intensifying cropping systems in the dry semi-arid prairie by replacing summer fallow in crop rotations. The tillage system had no consistent effect on plant densities, which were generally adequate (Miller *et al.* 2001).

The function of plant breeding is to produce varieties that exploit fully the potential of the environment. The breeder's objective should be to produce a variety with a large yield potential, not one with a large yield. To increase lentil yields from rainfed farmlands, involves objectives which include responsiveness to improved agronomic practices; adaptation to the edaphic and aerial environment and to water expectation and storage, nutritional and culinary qualities to meet consumer requirements and preferences. The opportunity to breed a new variety that will be well adapted throughout a wide geographical area occurs rarely, and when it does, it must be followed by diversification to provide varieties which can exploit local potential. Examples of very widely adapted varieties of lentil in several geographical areas with highly stable yields are available; L9-12, a *microsperma* variety, and Precoz, a *macrosperma* variety that possess earliness and high yield potential, is grown in a number of countries around the globe.

4. MULTILOCATION TESTING AND VARIETAL IDENTIFICATION

Multilocation testing is the evaluation of a genotype (introduction or developed through breeding) at a number of locations for its yield stability and adaptability. Multilocation testing of genotypes may be undertaken for one or more years depending upon the objective(s) of the breeding programme. The genotypes which have been observed superior in different station trials for seed yield, pest-disease resistance, lodging resistance, quality characters, etc. and only those with acceptable seed quality are evaluated further in the multilocation trials first in the state and then at the national/international level. The performance of the genotypes tested in multilocation trials in the state decides which genotypes are to be entered in the advanced varietal trials (AVTs). In these trials conducted for at least three years, the genotypes found superior to the existing cultivars (checks) in seed yield, or at par in seed yield but superior in some other trait, are identified for further testing at the farmers' fields. The differential performance of varieties in regional yield trials permits evaluation of the genotype × environment interactions.

With the establishment of the International Research Centres, like ICARDA, ICRISAT, IITA, AVRDC, etc., international yield trials are now conducted with different pulse crops (ICARDA for lentils). Through the international nurseries, it is possible to identify varieties with adaptation to a broad range of environmental conditions, as well as to identify those with adaptation to specific environments. The nurseries also serve to disseminate superior germplasm to breeders in a wide range of locations around the world.

After the identification of a variety 'on-farm trials', also known as 'field verification trials' or 'demonstration trials', are conducted at the farmers' fields. They are unreplicated, large-plot tests, conducted with the identified variety and the local land race or cultivar. These trials are conducted at a large number of locations. Selecting suitable locations for the trials covers a wide range of environments. The objectives of the trials are to grow the newly identified varieties under farmers' conditions to assess the yield and to obtain the farmers' views. New varieties are generally tested for two or three years. If superior in yield and acceptable to the farmers, a new variety will be considered for release. The cultivar is considered for release for commercial cultivation in an area, region, or country, if it is superior to the existing cultivar in yield, or if it has a good yield and is superior in quality or some other special characteristic such as height and lodging resistance, which have implications for mechanical harvesting. At the time of release, the cultivar is named as for instance, Sapna (LH84-8), and the results are published in popular journals (Brouwer 1995, Solanki *et al.* 1992).

4.1. Agroclimatic Zones for Lentil Cultivation in India

For pulse cultivation, India is sub-divided into five zones, i.e. north west plain zone (NWPZ), north east plain zone (NEPZ), north hill zone (NHZ), central zone (CZ) and southern zone (SZ). Lentil is grown in all, except the SZ where it is cultivated sporadically. Among different states, it is mainly cultivated in UP, MP, Bihar and West Bengal, which together contribute more than 80% area and production of this crop. Traditionally, the northern belt has been the area of small-seeded lentils. Several high-yielding varieties resistant to rust have been released for northern hills and plains. During the eighties, concerted efforts were made to develop the bold-seeded varieties and consequently a large number of bold-seeded varieties suitable for northern plains were developed and released, e.g. LH84-8, L4076, K75, DPL15, LH82-6, DPL62, etc. In central parts of India, bold seeded types are preferred. High yielding varieties with tolerance to wilt have been developed for this region e.g. JL3, IPL81, L4076, K75, etc. This crop has a great promise in rice fallows of the northern plains (Singh 2006).

5. FARMERS PARTICIPATION IN VARIETAL DEVELOPMENT

In lentil, to date no new variety has been developed/released through extensive farmer participation. However, for a crop like lentil that is widely grown in developing countries this approach offers many advantages in developing and disbursing better adapted varieties. Farmer participatory approaches for the identification or breeding of improved crop cultivars can be usefully categorized into participatory varietal selection (PVS) and participatory plant breeding (PPB). PVS is a more rapid and cost effective way of identifying farmer-preferred cultivars if a suitable choice of cultivars exists. If this is impossible, then the more resource-consuming PPB is required. PPB can use, as parents, cultivars that were identified in successful PVS programmes. Compared with conventional plant breeding, PPB is more likely to produce farmer acceptable products, particularly for marginal environments (Witcombe 1996).

In most developing countries, only a few farmers in marginal areas have adopted improved cultivars, often because they have not been exposed to acceptable alternatives to their landraces. Alternative approaches for identifying cultivars that are acceptable to resource-poor farmers have been suggested and tried by a number of workers. Chambers (Chambers 1989) reviewed the few examples of providing the farmers with ’a basket of choices’ of varied genetic material none of which used lentil(Maurya *et al.* 1988, Sperling *et al.* 1993, Weltzein *et al.* 1996, Joshi and Witcombe 1996). All of these are examples of participatory varietal selection, since farmers were evaluating near-finished or finished products. In contrast, participatory plant breeding is the selection by farmers of genotypes from segregating generations. There are few examples of PPB in the literature (Sthapit *et al.* 1996). The methods of PVS and PPB have been outlined and their impact on biodiversity has been reviewed by Witcombe *et al.* (1996).

5.1. Participatory Varietal Selection (PVS)

Most cultivars grown by farmers in developing countries like India are old and only a few of the released cultivars are grown widely. One of the main reasons for low cultivar replacement rates is that farmers have inadequate exposure to new cultivars. If adoption rates are to be improved, farmers need to try a wide range of novel cultivars in their fields through their involvement in PVS programmes. The cultivars should be selected not only from the target region but also from other regions or countries. A successful participatory varietal selection programme (PVS) has four phases:

(a) Identification of farmers' requirements

Farmers' requirements have to be identified first so that they can be given more appropriate genetic material to test. This can be done by using several methods, either separately or in combination. The methods include participatory rural appraisal, the examination of farmers' crops around harvest time, and the pre-selection, by farmers, of varieties from trials of many entries, grown either on a research station or on a farm. In areas where there is a diversity of landraces in farmers' fields and where resources allow, the local germpalsm can be collected and grown in a trial, on station or on farm, with recommended cultivars as the control.

(b) Search for suitable released material and advanced lines

A search is made for cultivars that most closely meet the important identified characteristics, particularly those relating to maturity, plant height, agro-ecological niche, and grain quality. Cultivars are selected from new and old releases at any level (national, zonal), and from pre-release material at an advanced stage of testing.

(c) Experimentation on farmers' fields

Various testing and evaluation systems can be employed (e.g. Joshi 1996, Deshmukh 2005) and they vary greatly in the extent of farmer participation (Table 2). One of the simplest methods of PVS used was in rice, where farmers were offered small quantities of seed from various varieties (released, pre-released and advanced lines) to grow under their own conditions without intervention from researchers.

Table 2. Methods of varietal selection with varying degrees of farmer participation [after Witcombe *et al.* (1996)]

Sr. No.	Methods in increasing order of farmer participation	Evaluation includes
1.	Researcher-managed and evaluated on-station trials; farmers may visit station to identify farmer-acceptable material	Yield data; possibly farmer evaluation
2.	Researcher-managed on-farm trials, replicated design; farmers may be involved in evaluation	Yield data; possibly farmer evaluation
3.	Farmer-managed, replicated design, on-farm trials, with scientists' supervision; several entries per farmer	Yield data; farmers' perceptions
4.	Farmer-managed unreplicated design, on-farm trials; one cultivar per farmer; replication across farmers	Yield data; farmers' perceptions
5.	Trials as in 4	Farmers' perceptions only
6.	Farmer-managed trials; no formal design either within a farm or across farmers	Informal, anecdotal

(d) Wider dissemination of farmer-preferred cultivars

PVS is usually conducted with farmers situated in small geographical area. However, to be of value results must be extended to a larger area. This is easier with existing released varieties. For participatory approaches to be more cost-effective, data on farmer perceptions and demand for seed need to be considered by varietal release committees, rather than the almost total reliance presently placed on yield data from scientist managed yield trials.

5.2. Participatory Plant Breeding (PPB)

PPB, in which farmers select from segregating material, is a logical extension of the PVS. However, PPB is more resource-consuming. PPB needs to be used when the possibilities of PVS have been exhausted, or when the search process fails to identify any suitable cultivars for testing. PPB can exploit the results of PVS by using identified cultivars as parents of crosses. PPB methods are poorly documented, and there are only a few examples in the literature and none for lentils (Worede and Mekbib 1993, Sthapit *et al.* 1996).

For predominantly self-pollinated crops such as lentils, there are many PPB methods that have different degrees of farmers' participation (Table 3). In all methods, plant breeders are facilitators of the research, have an essential role in disseminating the results and managing varietal release and linking the PPB program to other breeding programs.

6. ADAPTATION OF PLANT TYPE

Plant type is the morphological appearance of a plant and is an important characteristic for the identification and characterization of cultivars (Singh and Singh 1994). The ideal plant type is that combination of structure and developmental traits of

Table 3. Methods of plant breeding in predominantly self-pollinating crop with varying degrees of farmer participation [after Witcombe *et al.* (1996)]

Sr. No.	Methods in increasing order of farmer participation	Site specificity
1.	All generations grown by plant breeders on station; farmers involved at pre-release stage or even after release	Wide adaptation targeted; early generations may all be in single location followed by multi locational testing
2.	Early generation (F_2 or F_3) in farmers' fields; all other generations and procedures with plant breeder on station (Thakur 1995)	Single location testing site for F_2 or F_3
3.	Best advanced lines at F_7 or F_8 given to farmers for testing; closest method to participatory varietal selection since farmers given nearly finished product (Galt 1989)	Easy to test best advanced lines across locations
4.	From F_3 or F_4 onwards farmers and plant breeders collaborate to select and identity the best material on farm (and also on station); farmers select; plant breeders facilitate the process; release proposal prepared by plant breeders (Sthapit *et al.* 1996)	Possible to run selection procedures on early generations in more than on location
5.	Breeder gives F_3 and F_4 material to farmers: all selection left to farmers; at F_7 to F_8 or later, breeders monitor diversity in farmers' fields and identify best material to enter in conventional trials (Salazar 1992)	Extremely easy to run selection schemes in many locations
6.	Trained expert farmers make crosses and do all selection with or without assistance from breeders; breeders can place best material in conventional trials	Specific to farmers' requirements

the genotype which are best adapted to a particular environment and suit to the cultivator's need better than other genotypes of that particular crop (Lal 2001). Traits that determine the structure of the plant are mainly stem/plant height and branch numbers and sizes. All of the traits are highly influenced by the environment and contain subcomponents (e.g. internode length) that vary as the plant grows. Hence assigning an absolute value for a specific cultivar may be of limited value. Branching patterns differ from erect compact, having a narrow branch angle, to prostrate or spreading types with several intermediate types. The lentil plant may have few or many primary branches, which arise directly from the main stem, and often many secondary branches, which arise from the primary branches. The production of branches is highly affected by plant population and at high population levels, branching is greatly suppressed. Therefore, the combination of plant height, branching and environment may result into a number of plant types like, tall, dwarf, bushy, erect, semi-erect, semi-spreading, spreading, etc. All these plant types are cultivar specific, but genotype × environment interaction plays an important role. If a cultivar is erect growing, it may behave as semi-erect if space planted.

Farmers, with large acreages in lentil cultivation, desire mechanization of cultural operations. While machines developed for cereals have been modified and used, they have not been entirely satisfactory. One reason for lack of satisfactory mechanization is poor plant type. Tall and erect types are the ideal plant type in lentil for mechanized harvesting. However, spreading/ semi-spreading plant types are very useful in rainfed areas to avoid evaporational losses from the soil, and thus, are helpful in conserving precious soil moisture.

Donald and Hamblin (1976) introduced the concept of plant ideotypes . The most significant point in the ideotype concept is the performance of a plant in isolation and in population. In many species, particularly cereals or determinate crops where the yield of the main shoot is a major contributing factor, the relationship between the individual plant yield and yield of a population, remains reasonably valid. However, this does not necessarily happen in indeterminate species such as lentil. Lentil tends to become more vegetative if the unstressed crop is irrigated at the flowering stage and ambient temperatures are not high as in north India. Also the partitioning of assimilates and particularly of nitrogen, is rather poor. All of these factors should be considered when suggesting an ideotype for lentil.

Traditionally, lentil has been grown mostly as a rainfed crop all over the world. Therefore, the centres for selection have naturally, and rightly so, attempted to select for rainfed conditions. For such a situation, a small plant population density of spreading/semi-spreading plant type is desirable to enable plants to reach maturity before the soil moisture is depleted, with a provision that the plant has the capacity to enlarge itself if more water becomes available. Consequently, the character of enlargement in growth in response to water availability at the time of the reproductive phase could prove detrimental to seed yield. Secondly, in such plant types, most of the yield is derived from secondary and tertiary branches. When such plant types are grown in a high population density, they fail to produce their reproductive branches and hence yield remains static. This means that selection for poor water regimes and for assured water availability would require different approaches. Possibly, for poor water availability, a low plant population with a capacity to respond if available water increased due to occasional rain would be a correct objective. However, selection for assured water availability would require a different approach.

Selection for adequate water availability will have to be done under conditions where soil moisture does not become limiting at a critical stage of crop growth. In most cases while lentil plants are being selected for assured moisture supply, the crop will have to be given irrigation at flowering. Those plants, which do not resume vigorous vegetative growth, will be the right plants for irrigated conditions.

There appears to be not much information available on the relationship between plant type (morphological features) and nitrogen harvest index in lentil, although such information is necessary for economic yield. However, there are features, which may have an important bearing on this aspect. First, the sequential senescence and shedding of leaves without necessarily contributing nitrogen to developing pods and seeds, is a limitation. Second, when the pods develop, they mostly derive assimilates from the leaves in the axils of which they are borne. Consequently, the leaves of non-flowering nodes do not substantially contribute their nitrogen to pods and seeds. Possibly, a slow senescence of the whole plant during the development of pods might be an indicator of uniform mobilization from different parts of the plant.

It is usually recognized that the harvest index (HI) in lentil is low. A relatively erect plant type with shorter internodes might be a suitable ideotype, particularly for irrigated agro-ecosystems under good management conditions. Breeding for erectness combined with tall growth by hybridization between conventional spreading and tall types with sturdy stem and resistance to lodging has given good results. Solanki *et al.* (1992) constructed a model plant type with the help of correlation and path coefficient analysis and the one emerging from a comparison of plant morphology of high and low yielding lines as well as the seed yield pattern of lines with high and low levels of expression of seed yield components, and all three agree to a large extent (Table 4). The architecture of this model plant was tall height with a higher number of secondary branches and pods per plant and high seed weight. Similarly, Om Vir *et al.* (2002) postulated a plant ideotype bearing higher biomass, harvest index, 100-seed weight, pods per plant, fertile nodes per plant, pods per node, seeds per pod and plant height which could enhance the seed yield of lentil. The *macrosperma* cultivar, Matilda, well adapted to the Wimmera

Table 4. Identification of model plant characteristics based on three parameters [after Solanki *et al.* (1992)]

Character	Comparison of highest and lowest yielding lines (an average of 20 lines in each case)			Pattern of seed yield (g per plant) in lines with high and low levels of expression of the quantitative traits			Correlation coefficients with yield per plant
	Highest	Lowest	Difference	Highest	Lowest	Difference	
Yield per plant (g)	2.993	1.200	1.793**	–	–	–	–
Leaf area (cm^2)	2.21	1.89	0.32	2.126	1.756	0.370	0.192
Plant height (cm)	36.40	33.00	3.40*	2.374	1.528	0.846**	0.387**
Number of primary branches	4.80	4.88	-0.08	2.169	2.239	−0.070	−0.078
Number of secondary branches	10.42	7.36	2.66*	2.420	1.596	0.824*	0.404**
Clusters per plant	34.6	25.48	9.12	2.083	1.616	0.467	0.160
Pods per plant	54.92	34.28	20.64*	2.448	1.830	0.618	0.350*
Seeds per pod	1.64	1.72	−0.08	2.049	1.759	0.290	−0.070
100-seed weight (g)	2.80	1.94	0.86**	2.438	1.661	0.777*	0.339*

*and**: Significant at 5 and 1 per cent level of probability, respectively.

region of Victoria, Australia has semi erect growth habit and shorter plant type, especially when rains occur late in the growing season (Brouwer 1995).

Huyghe (1998) reviewed genetics and genetic modifications of plant architecture in grain legumes. Crop architecture may be modified to improve adaptation of crops to different environments and to increase seed yield and its stability. The main peculiarities of grain legume architecture are: (1) the indeterminate growth habit, which may lead to a prolonged growth cycle with consequences on maturation; and (2) strong within plant competition between reproductive and vegetative growth. Flowering date is of major importance for adaptation of a crop to environmental conditions. The branching pattern may be directly affected independently of other architectural modifications. Leaf size and structure contribute to the leaf area index of the crop and may influence the light interception efficiency. The determinate growth habit modifies the duration of the growth cycle and the assimilate partitioning, while the dwarfism may improve the adaptation to a range of environments through a reduction of the risk of lodging. The pod walls may contribute to pod photosynthesis but they account for a large proportion of the pod weight at harvest. This reduces the crop harvest index.

Many lentil breeders consider what might be the ideal plant type for their target area, and often construct a crop ideotype. Such a thought process can focus attention on critical problems. For instance, in areas where greater plant height and erectness are needed for mechanized harvest, particularly in irrigated agro-ecosystems under good management, those traits would receive greater attention in the choice of parents for hybridization and subsequent selection.

However, in moisture-limited (rainfed) agro-ecosystems, breeding and selection might emphasize rapid emergence in relatively dry seedbeds; a spreading growth habit to rapidly cover the soil surface, reduce evaporation from the soil surface and compete with weeds; along with early maturity to escape hot, dry conditions that usually prevail late in the growing season. Ideotypes for irrigated agro-ecosystems under good management might be late maturing to take advantage of the long growing season made possible by the supplemental water.

It would be difficult to visualize a single plant type able to maximize seed yield over the diverse agro-ecological zones (rainfed and irrigated) in which lentil is grown. Nevertheless, for specific regions and breeding programmes, the formulation of ideotypes may serve a useful purpose. Most schemes of ideotype focus on tall plant habit and increased branch and pod number with more seeds per pod. A physiologically possible approach in lentil might be to develop compact plant types capable of greater biological yields per unit area, then focus on improving their harvest index. Greater compactness of lentil plants would allow establishment of larger plant populations and make it possible to intercept a larger portion of solar radiation, compete with weeds, use more of the available moisture, and increase seed yield per unit area.

The biological yield might be improved by developing tall, erect, compact plant types to permit increased plant populations and therefore, increase biological yield per unit area. Other possibilities might be increased branch number and longer duration of flowering and seed-filling. A more favourable partitioning of the biological yield might be possible through increased pod number, seeds per pod, or seed size.

Based on the above discussion it is possible to formulate, different plant types of lentil for diverse agro-ecosystems (Lal 2001).

6.1. Plant Type for Dryland/Rainfed Environments

Deep root system with high root volume; semi-spreading to spreading growth habit; good water retention capacity and restricted transpiration; pubescent foliage; profuse branching; reduced biomass; high harvest index; short growth duration.

6.2. Plant Type for Optimum Moisture Irrigated Conditions

Erect to semi-erect growth habit with short internodes; compact plant type with restricted branching; high biomass production capacity; relatively longer growth duration.

6.3. Plant Type for Sole Cropping

Spreading to semi-spreading growth habit for rainfed areas and erect with shorter internodes for irrigated and assured rainfall areas; high biomass production capacity.

6.4. Plant type for Inter-Cropping

Erect and compact growth habit with shorter internodes; good low light photosynthesis.

6.5. Plant type for Multiple/Relay Cropping

Quick germination; early vigour; early flowering with longer reproductive phase; early and synchronous maturity; quick senescence; high responsiveness to inputs; resistance to diseases and insect pests (Table 5).

Table 5. Suitable varieties of lentil for various inter-cropping systems

Intercropping	Suitable varieties
a. Mustard + lentil	Bihar [Ranjan, PL406, PL639, PL209, BR25] Madhya Pradesh [K75, JLS1, PL406, PL639]
b. Barley + lentil	Madhya Pradesh [K75, JLS1, PL406, PL639]
c. Linseed + lentil	Madhya Pradesh [K75, JLS1, PL406, PL639]

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