GRAIN LEGUMES

AEP

The magazine of the European Association for Grain Legume Research
Le magazine de l'Association Européenne de recherche sur les Protéagineux

ISSUE No. 57 July 2011

Biotechnology and gene mapping in lentil

Tannin-free lentils

Lentil diseases: a threat worldwide

No-till lentil

Lentil in North America, Africa, Asia and Australia

Lens sana in corpore sano

The amazing lentil

IMPRESSUM

ISSN
0245-4710

Quarterly publication
(January, April, July and October)

Published by
European Association for Grain Legume Research (AEP)

Co-published by
Legume Society (LS)
Institute of Field and Vegetable Crops (IFVCNS)

Office
AEP
CSIC, Institute for Sustainable Agriculture
Apdo. 4084, 14080 Córdoba, Spain
Phone: +34957499215 • Fax: +34957499252
http://www.grainlegumes.com

Subscriptions
AEP Office
(diego.rubiales@ias.csic.es)

Printed by
Stylos / AMB grafika, Novi Sad, Serbia

Cover photo
Healthy lentils (Marzena Krysinka-Kaczmarek)

FOR AUTHORS

Grain Legumes is aiming to interest and inform a worldwide multidisciplinary readership on very different aspects of legume research and use, including genetics, agronomy, animal production, human nutrition and health and economics.

Please write your article so that it will assist in the exchange of information between people working in different expert fields of legume research: write to the length requested; provide a review of the most important information on your topic; try to avoid (or explain) specialist words, unusual jargon and acronyms; emphasise results and conclusions; choose titles carefully and add subheadings that tell readers something. *Grain Legumes* prefers a clear, simple and comprehensive writing style that would make its articles interesting and useful for both academic and amateur audience. Your manuscripts does not have to follow the usually strict structure of the research papers.

We strongly encourage you to submit either longer (1,250 words + 2 tables, figures or photos + up to 8 references) or shorter (450 words + 1 table, figure or photo + up to 4 references) manuscripts. Editorial Board may allow any variation from case to case. Please provide also an additional abstract of between 90 and 100 words and from 4 to 6 key words.

The manuscripts should be prepared in MS Word, using Times New Roman font, 12 points size. The references should be listed alphabetically, formatted in the style used by the journals published by Springer such as *Euphytica*. The tables and figures may be incorporated in the manuscript, while it is desirable that photos are submitted separately as jpg files.

Please send your prepared manuscripts or any inquiries on publishing in *Grain Legumes* to diego.rubiales@ias.csic.es or legume.society@gmail.com

EDITORIAL

The Legume Society is delighted to present this issue of Grain Legumes Magazine devoted to lentil, one of the most neglected of the food legume crops. Our goal for this issue was to provide readers with an overview of lentil as a valuable food legume crop. The origin of the crop is examined along with the current state of genetic information and the status of breeding programs world wide. Diseases and insects that affect the crop are examined along with abiotic stresses such as the damaging effects of drought and cold. The benefits to human health are also examined.

Areas of prime use of the crop are in West Asia, North Africa and the subcontinent of India. Rapid increases in production of the crop in developed countries such as Canada, Australia and the USA have helped to meet global demand by an ever-increasing world population.

On behalf of the Legume Society I wish to thank the authors of the articles in this issue for their thoughtful and well prepared contributions.

Fred MUEHLBAUER
Managing Editor of GLM57

CONTENTS

CARTE BLANCHE

RESEARCH

Carte blanche to…

…Fred Muehlbauer[2]

The amazing lentil

"Esau sold his birthright for a pottage of lentil" and so the biblical story goes. Esau and Jacob were the twin sons of Abraham and were as different as day and night. While Jacob became a respected farmer, Esau followed his interests as an adventurer and hunter. In these early times, the first born son held the birthright to the family wealth and prestige. Despite having the unending support of his father, Esau had come to the conclusion that a birthright was of little value. One day upon returning home from one of his adventures, hungry and exhausted, Esau saw the lentil stew that Jacob had prepared. Esau asked his brother for a portion, but Jacob, ever the opportunist and uncooperative younger brother, played hard to get and demanded that Esau give him his birthright before he would hand over any of the delicious stew. Thus the passage in the bible "Upon agreeing to the trade of his birthright, Jacob gave Esau bread and lentil stew; and he ate and drank, and rose and went on his way" [Genesis 25:34]. This simplified version of the famous biblical story attests to the value placed on lentil in those early times and also that it was a prominent legume in wide spread use.

Lentils, being one of the first crops to be domesticated and cultivated by man, have been and continue to be an important food source for over 8000 years. Through much of that time they have been considered the food of the poor people and referred to as "poor man's meat." The high protein content of lentil has made them a nutritious substitute for meat. In fact, 100 grams of lentil has as much protein as 130 grams of meat in addition to beneficial dietary fiber. Lentils are most important to the diets of people in the Middle East and South Asia where they are placed on the table in some form for nearly every meal. More recently, lentil has assumed the role as a valuable health food and improvements in athletic performance.

This issue of Grain Legumes Magazine is devoted to lentil starting with its origin, domestication, genetics and breeding, production constraints, and nutritional qualities.

[2]USDA-ARS and Washington State University, Pullman, WA, USA (muehlbau@wsu.edu)

Lentil origin and domestication

by Richard FRATINI[1]*, Marcelino PÉREZ DE LA VEGA[1] and José I. CUBERO[2]

Abstract: Based on evidence from archeological sites and the presence of wild relatives, the accepted view is that the Near East is the most likely center of lentil domestication. In summing up our data on crop evolution, lentil was domesticated in the foothills of the mountains of southern Turkey and northern Syria likely by selection within populations of ssp. *orientalis*. The influence of other wild relatives cannot be excluded. Compared to wild forms, cultivated lentil have greater stem and rachis length, more leaflets per leaf, greater leaf area, and increased flower and pod numbers per peduncle. Diffusion of the lentil crop from the center of origin was in several directions and traveled with barley, wheat, chickpeas, pea and faba bean. The crop was shown to be present in Greece around 8000 BP, Central Europe 5000-7000 BP, and in Egypt around 5000 BP. Dispersion to Central Asia and the Indian Sub-continent apparently took place at a later time. Introgression from the wild species requires further study but represents a source of genes needed to improve the cultigen.
Key words: archeology, crop dispersion, evolution, gene pools, genetic linkage, interspecific hybridisation, *Lens* species, taxonomy

The genus *Lens* Miller

Although all the books on botany since the XVIth century used the name *Lens* for the species that became known as lentil. The first botanist to assign genus status was Tournefort in 1700. Miller (21) who later verified the designation and became the authority for the genus also produced the oldest available botanical description. There were many taxonomic treatments during the XIX century that were derived based on similarities with other taxa such as *Ervum, Ervilia, Vicia, Lathyrus, Orobus* and even *Cicer* (all of which belong to a young group of plants that are still in active evolution). By the end of that century, the genus *Lens* was relatively well established (historical references and synonyms are reviewed in Cubero (3).

The taxonomy of the genus is far from easy given the close relationships among its species (4). At the present time, by using morphological, including pollen and pistil, characteristics (11) as well as biochemical characters and intra and interspecific crosses, taxonomists describe six species: *L. culinaris* Medik. (*L. esculenta* Moench is a synonym still found in many publications), with two subspecies: *culinaris* and *orientalis* (Boiss.) Ponert; *L. odemensis* Ladiz. (sometimes also considered a subspecies of *culinaris*); *L. tomentosus* Ladiz. (ex *L. orientalis*) (both *odemensis* and *tomentosus* had been previously included by Ferguson (*9*), as a subspecies of *culinaris*), *L. nigricans* (M. Bieb.) Godr.; *L. ervoides* (Brign.) Grande (occasionally included under *nigricans* as a subspecies (17) and *L. lamottei* Czefranova (ex *L. nigricans*). All species are self-pollinated. Figure 1 shows the geographical distribution of *Lens* species.

Chromosomes and karyotypes

All species are diploids (2n=2x=14). According to Ladizinsky (24), *culinaris* and *orientalis* share the same karyotype with that of *L. nigricans* being slightly different. However, other authors have found different karyotypes and even differences among strains of *culinaris microsperma* and *orientalis* (14, 10). Linkage studies have revealed chromosomal rearrangements between *L. culinaris* and *L. odemensis* (17), which may explain why certain accessions of *odemensis* can be crossed with *culinaris* (16) while others need embryo rescue (12). *L. odemensis* is cross incompatible with *nigricans* and *ervoides* due to hybrid embryo abortion (17, 24).

The morphological differences between *L. nigricans* and *L. lamottei* are limited to stipule shape; however, the two species differ by four reciprocal translocations and one paracentric inversion resulting in the complete sterility of their hybrids (20).

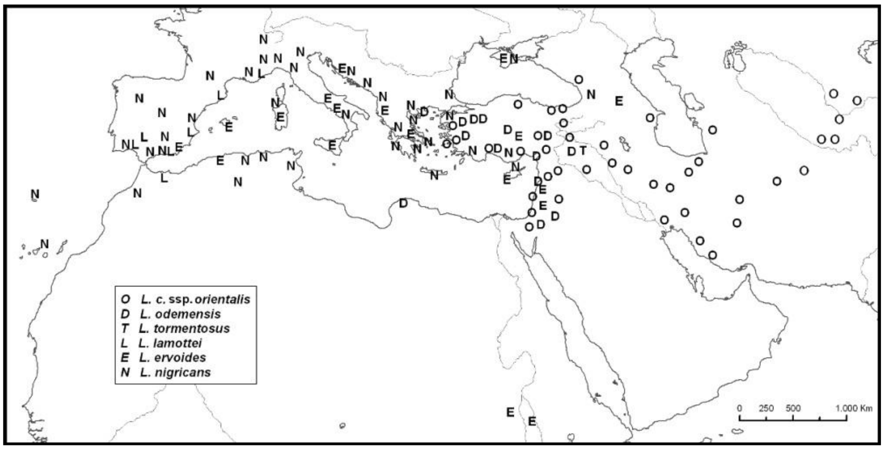


Figure 1. The geographical distribution of *Lens* species

[1]Universidad de León, Departamento de Biología Molecular, León, Spain
(richard.fratini@unileon.es)
[2]CSIC, Instituto de Agricultura Sostenible, Córdoba, Spain

Interspecic crosses

Crosses between *culinaris* × *orientalis* are generally fertile and the F_2 segregates in Mendelian fashion for growth habit, flower colour, seed colour, and pod dehiscence although the fertility of the hybrids depends on the chromosome arrangement of the wild parent (16, 20). Some studies show that meiosis is nearly normal and supports morphological data indicating that *orientalis* as a subspecies of *culinaris* (16,13). However, when the crossing scheme is widened, meiotic anomalies lead to the need for embryo culture to produce seeds even within *orientalis* (17, 25). Earlier, Barulina (1) and Zohary (27) had indicated the conspecifity of *culinaris* and *orientalis*.

Crosses between *culinaris* and *nigricans* were not viable except for one *nigricans* accession whose hybrid developed normally. That accession was subsequently classified a distinct species as *L. odemensis* (16). Ssp. *orientalis* is readily crossed with *L. odemensis* and the hybrids are vegetatively normal but are partially sterile due to meiotic irregularities resulting from three chromosome rearrangements between the parents (17). *L. tomentosus* is morphologically closer to *L. c.* ssp. *orientalis* than to any other *Lens* taxon. Nevertheless, they are isolated one from another by hybrid embryo breakdown, complete sterility and five chromosomal rearrangements (25), which supports the idea of species status for *tomentosus*, although some success in crosses between *culinaris* and *tomentosus* has been reported. *L. tomentosus* is also reproductively isolated from *L. lamottei* and *L. odemensis* by hybrid-embryo abortion (25).

L. nigricans × *L. ervoides* interspecific hybrids are vegetatively normal but completely sterile (17). Fratini and Ruiz (12) made extensive crosses between *L. c.* ssp. *culinaris* and *L. nigricans, L. ervoides* and *L. odemensis*. Hybrids between the cultigen and the other species were viable only through embryo rescue. The rates of adult plants obtained were 9% with *odemensis* and 3% with *nigricans* and *ervoides*. Previously, it had been shown that crosses between *culinaris* and *nigricans* or *ervoides* needed embryo rescue to recover interspecific hybrids (17, 18, 20). Therefore, in view of the above, it seems that *odemensis* belongs to the secondary gene pool and *nigricans* and *ervoides* can be classified in the tertiary gene pool (17).

Gene pools

The previous discussion can be confusing because no clear barriers are defined between the accepted species. The levels of fertility and sterility so far found depends on the taxa involved in a specific cross, but also, to a greater or lesser extent, on the particular populations within these taxa. It is a common situation when, as it happens in *Lens*, the taxa are close relatives. *Lens* is a genus belonging to a very active group from an evolutionary point of view. Even with the exceptions described above, hybridization experiments support the idea of the six differentiated species mentioned above.

Besides the forms of the cultigen (*L. culinaris ssp. culinaris*), those of ssp. *orientalis* obviously belong to the primary gene pool. *L. odemensis is assigned to the secondary gene pool* although success in crosses with the cultigen may require embryo rescue. This latter situation could also apply to *L. tomentosus*. *L. lamottei*, *L. nigricans* and *L. ervoides* which belong to the tertiary gene pool, but can become part of the secondary gene pool by means of embryo rescue. This seems to have been the case in transferring resistance to anthracnose from ervoides to the cultigen (24).

Cultivated lentil

Alefeld (see reference 3) recognized eight subspecies including both *orientalis* and *nigricans*: (1) *schniffspahni* (syn. *orientalis*), (2) *himalayensis* (syn. *nigricans*), (3) *punctata* (syn. *culinaris*), (4) *hypochloris,* (5) *nigra* (syn. *culinaris*), (6) *vulgaris*, (7) *nummularia,* and (8) *abyssinica*. Barulina (1) accepted these names although not as subspecies but as varieties, raising instead two of these (*microsperma* Baumg. and *macrosperma* Baumg.) to the subspecific status. Molecular evidence suggests today that they are varieties of the subspecies *L. c. culinaris* (6).

Barulina (1) described two subspecies according to the size of flowers, pods and seeds (the latter being the principal objective of human selection) and grouped characters in clusters to define regional groups or *greges* (Fig. 2). The main characters she used to define these groups were the size of leaflets, the height of plants, the length of the calyx teeth and the number of flowers per peduncle. The Barulina treatment has been largely unsurpassed although the subspecific status of both *macrosperma* and *microsperma* is not recognised today by taxonomists (see above), although admitted as large groups of modern cultivated varieties. Since the Barulina's study time, all her varieties are still cultivated except *subspontaneae* which does not appear in modern germplasm collections and has not been found.

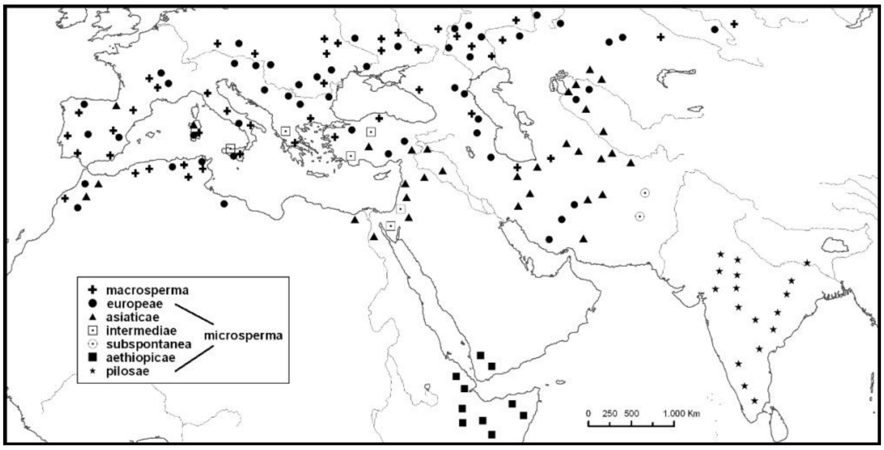


Figure 2. Regional groups or *greges* in lentil

The centre of origin

Barulina (1), based on Vavilovian criteria of the richness in endemic to define a Center of Origin, had suggested the region between Afghanistan, India and Turkistan as the possible centre of origin for cultivated lentil. She noticed that in that area wild lentils did not overlap with domesticated ones, at least to a significant level. In fact, no lentils have been found in sites dating back to the seventh millennium BP in Turkmenia. The high degree of endemism that exists in the Afghanistan–Indian–Turkmenian area is better explained, as in all other species, by an intense genetic drift, typical of highly diversified environments, coupled with artificial selection carried out by very diverse human populations, with drastic genetic fixation and losses providing secondary centres of diversity. The same situation happens in Ethiopia, where Vavilov situated his centers of origin of several crops including wheat, chickpea, faba bean and several others (26) showing a large number of endemic (in the Vavilovian sense) forms but neither wild relatives nor archaeological remains.

Archaeological data are summarised in Fig. 3. Seed size is, so far, the only character indicating domestication in archaeological remains. The oldest remains of wild lentils were found in Mureybit (Syria) dated around 10000 BP, those of the cultigen, dated around 9000 BP, in aceramic Neolithic layers in the Near East. Given the coexistence, not found elsewhere, of wild and domesticated forms as well as the archaeological data, the Near East is the most likely candidate to be the centre of origin of cultivated lentil. Besides, lentil diversity in the Centre of Origin is still very high both for cultivated primitive forms and wild relatives. By using molecular markers, Ferguson *et al.* (8) located areas of high diversity for *L. odemensis* in southern Syria, for *L. ervoides* in the Mediterranean border region between Syria and Turkey, for *L. nigricans* in western Turkey and, finally, for ssp. *orientalis* in the border between Turkey and Syria as well as in southern Syria and Jordan. According to criteria established by De Candolle (5) and accepted by students of crop evolution, these data support the archaeological evidence indicating the Near East region as the most likely center of lentil domestication. Ladizinsky (19) also suggested the Near East as the centre of origin based on the polymorphism found in wild accessions of ssp. *orientalis* and the monomorphism of *culinaris*. Indications are that some populations of *orientalis* were unconsciously subjected to selection (15) resulting in the crop we know as lentil. According to Zohary (28), based on chromosome and DNA polymorphisms, the domestication event happened once or only a few times.

Diffusion of lentil culture

Archaeological data fit a pattern of diffusion of the crop from the Near East with the spread of Neolithic agricultural (Fig. 3). Lentils, as a component of the Near East complex, travelled towards Europe along with barley, wheat, chickpea, pea, faba bean, etc., through Greece (oldest remains in Greece around 8000 BP, in Central Europe 5000–7000 BP). The crop arrived in Egypt around 5000 BP in spite of the geographical proximity to the Near East. A possible explanation could be that conditions in the Nile Delta were not favourable for preserving agricultural remains. Ethiopia was probably reached from the Arabian coast (at that time it was the *Arabia Felix*, more humid and fertile than nowadays) rather than by the Nile and was established in the Ethiopian highlands. Once established, the crop evolved in isolation producing much endemism that allowed Vavilov to designate the Ethiopian highlands as a secondary centre of origin. Indeed, grex *aethiopicae* shows very primitive characters meaning that lentils had arrived in a very primitive stage of domestication.

Intermediae forms reached Sicily, and *asiaticae* forms Sardinia, Morocco and Spain (Fig. 2), suggesting the arrival in these countries of lentil stocks either from central Europe or from the route of the isles from Levant. Recent findings show lentils in N.E. Spain around 7500 B.P. within the typical Near East crop complex (*Triticum monococcum, T. dicoccum*, *T. aestivum*, barley, pea, grasspea and faba bean). Based on seed size, these lentils fall within the range of *microsperma* (2). Archaeological remains show the arrival of the crop in Western Europe by 3000–3500 BP. As suggested by the distribution of forms belonging to *macrosperma* and *microsperma-europeae* groups (Fig. 2), central Russia and Siberia were more likely reached from the western coast of the Black Sea or from the Danube Valley rather than from Mesopotamia or Central Asia. The lentils probably reached the cradle of Indoeuropean people after the Greek ancestors split, as suggested by De Candolle (5) on linguistic grounds. Lentil in Greek is *phakos*, but it is *lens* in Latin, *lechja* in Illyrian, and *lenzsic* in Lithuanian. Ancient Greeks could take its word for lentil from the aboriginal Mediterranean populations they conquered.

Lentils did not reach India before 4000 BP and were probably carried by an Indoeuropean invasion (5) through Afghanistan; however, archaeological findings are scarce. That introduction was probably performed by very small samples of a common origin as the variability found in the Indian subcontinent in the local landraces is very limited in spite of being the largest lentil growing region in the world. The asynchrony in flowering of the local *pilosae* landraces, probably a consequence of a long reproductive isolation period, has been broken by plant breeding to broaden the genetic base (7).

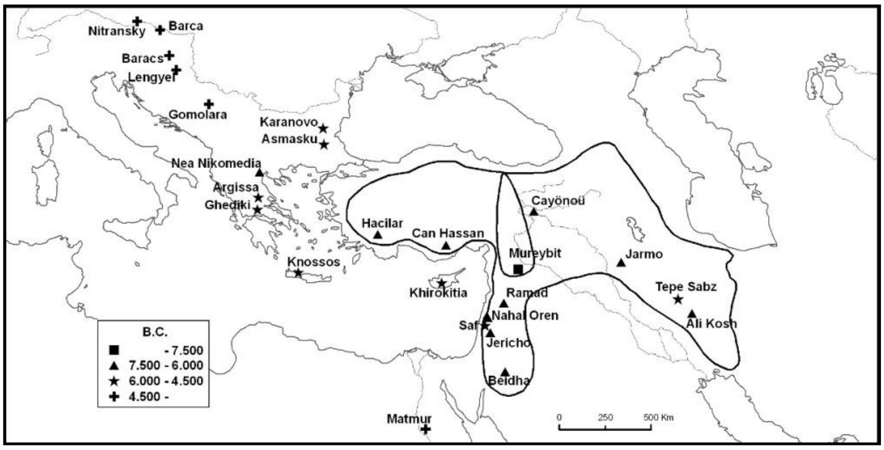


Figure 3. Diffusion of the lentil crop from the Near East

Although still geographically limited, recent analysis suggests that the interchange of genetic stocks among regions has been minimal (23). Thus, the old Barulina varieties could be very valuable in order to increase the genetic basis of the cultivated lentil for plant breeding purposes.

Evolution of cultivated forms

Compared with *L. orientalis,* cultivated lentils have greater stem and rachis length, more leaflets per leaf, greater leaf area, increased numbers of flowers per peduncle as well as increased numbers of pods and seeds. In addition, peduncles of cultivated forms are generally shorter or equal to the length of the rachis when compared to wild forms. These characters are associated with increased yields similar to that of other domesticated food legumes. The cultigen shows a higher frequency of white flowers, probably a character associated with higher culinary quality and fixed by indirect selection for lighter coloured seed coats. Some references from the Middle Ages mention the existence of cultivated lentils with primitive characters such as "blackish" and "not sweet" and others with "rounder" seeds. Although the existence of real primitive lentils cannot be ruled out, these forms could be impurities coming from mixtures with some vetches and not necessarily true primitive materials.

Figures 1 and 2, respectively, show the distribution of wild and cultivated lentils. All but three *microsperma* varieties, as well as the *macrosperma* ones overlap to a greater or lesser extent with all the known wild lentils, all of them present in most lentil growing areas. Three peculiar *microsperma* (in Barulina's sense) groups are restricted to very concrete areas; all the three show very small and dark coloured seeds, violet flowers, few flowers per peduncle, calyx teeth much shorter than the corolla, few leaflets per leaf and dwarf plants, but differ in some typical characters: *pilosae* (characterised by a strong pubescence) in the Indian subcontinent, *aethiopicae* (pods with a characteristic elongated apex) in Ethiopia and Yemen (the old Sabean kingdom), and *subspontaneae* (very dehiscent pods purple-coloured before maturity) in the Afghan regions closest to the Indian subcontinent; *subspontaneae* overlaps only with *orientalis,* and *aethiopicae* with *ervoides*; *pilosae* does not overlap with any wild lentil.

As in the case of chickpea and faba bean, there is a clear pattern in the regional distribution of cultivated lentils (Fig. 2). The trend from eastern to western lentils is increased seed size, increased number and size of leaflets as well as the length of the calyx teeth relative to corolla length. To explain this cline, it has been postulated that introgresion into western forms of lentil came from *odemensis* (more likely than from *nigricans* as *odemensis* was given its specific status because of its crossability with *culinaris*) while introgression from *orientalis* played the leading role in eastern forms. For the short calyx of *aethiopicae* forms, the genetic influence of *ervoides* has also been postulated. The comparison between the geographical patterns of wild species and cultivated forms (Fig. 1 and 2) seem to verify the introgression hypothesis that *orientalis* is the only wild form spreading eastwards, *ervoides* to the Ethiopia and both *nigricans* and *ervoides* to the West. However, the latter two species do not cross readily with *culinaris*, hybrids resulting in embryo abortion (20, 13), but sporadic crosses through a long period of time cannot be readily dismissed. Besides, in the same way that *odemensis* was separated from *nigricans* because the differential level of fertility with the cultigens, other strains of *nigricans* and *ervoides* could behave in a similar way.

Thus, although crosses between *culinaris* and *odemensis* are feasible and produced longer (some times branched) tendrils than those of *culinaris*, more experimental work, including molecular biology is necessary to show intogression. The geographical pattern could simply be an indirect (correlated) response to different human selection approaches in different parts of the world accompanied with the usual sources of variation (mutation, migration, and genetic drift) and crosses with companion weeds. In fact, molecular marker analyses indicate the genetic variability within cultivated lentils is relatively low (6, 22) suggesting that the two great groups of cultivated lentils, *microsperma* and *macrosperma*, could only be variants for quantitative traits resulting from disruptive selection.

Summing up our data on crop evolution, lentils were domesticated in the foothills of the mountains of southern Turkey and northern Syria likely by selection (15) within populations of ssp. *orientalis*. The influence of other wild relatives cannot be excluded as it occurs in the origin of most crops. In the lentil case, the similarity among wild species could have been a factor in favour of producing companion weeds and maintaining them in cultivated stocks. Ssp. *orientalis* and *L. odemensis* forms are the most likely candidates to have been the main origin of extraespecific variability for the cultigens, but more experimental proof is needed. The genetic variability studied with molecular markers seems to be low, suggesting a common origin for all cultivated forms at the present time and a narrow range for artificial selection. Differences among geographical groups could be the result of limited quantitative genetic variation resulting from a correlated response when selecting for higher yield than the consequence of a more basic genetic difference. The role of introgression from wild forms, however , requires further study. ■

References

(1) Barulina H (1930) Lentils of the USSR and other countries. Bull Appl Bot Genet Plant Breed 40:265–304
(2) Buxó R (1997) Arqueología de las plantas. Crítica, Barcelona
(3) Cubero JI (1981) Origin, domestication and evolution. In: Webb C, Hawtin GC (eds) *Lentils*. Commonwealth Agricultural Bureaux, London, UK, 15–38
(4) Cubero JI, Pérez de la Vega M, Fratini R (2009) Origin, Phylogeny, Domestication and Spread. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 13-33
(5) De Candolle AP (1882,1967) Origins of Cultivated Species. Hafner, London
(6) Durán Y, Pérez de la Vega M (2004) Assessment of genetic variation and species relationships in a collection of *Lens* using RAPD and ISSR. Span J Agric Res 4:538–544
(7) Erskine W, Chandra S, Chaudhry M, Malik IA, Sarker A, Sharma B, Tufail M, Tyagi MC (1998) A bottleneck in lentil: widening its genetic base in South Asia. Euphytica 101:207–211
(8) Ferguson ME, Ford-Lloyd BV, Robertson LD, Maxted N, Newbury HJ (1998) Mapping the geographical distribution of genetic variation in the genus *Lens* for the enhanced conservation of plant genetic diversity. Mol Ecol 7:1743–1755
(9) Ferguson ME, Maxted N, Van Slageren M, Robertson LD (2000) A re-assessment of the taxonomy of *Lens* Mill. (Leguminosae, Papilionoideae, Vicieae). Bot J Linn Soc 133:41-59
(10) Fernández M, Ruiz ML, Linares C, Fominaya A, Pérez de la Vega M (2005) The 5S rDNA genome regions of *Lens* species. Genome 48:937-942
(11) Fratini R, García P, Ruiz ML (2006) Pollen and pistil morphology, *in vitro* pollen grain germination and crossing success of *Lens* cultivars and species. Plant Breeding 125:501–505
(12) Fratini R, Ruiz ML (2006) Interspecific hybridization in the genus *Lens* applying *in vitro* embryo rescue. Euphytica 150:271–280
(13) Fratini R, Ruiz ML, Pérez de la Vega M (2004) Intra-specific and inter-sub-specific crossing in lentil (*Lens culinaris* Medik.) Can J Plant Sci 84:981–986
(14) Galasso I (2003) Distribution of highly repeated DNA sequences in species of the genus *Lens* Miller. Genome 46:1118–1124
(15) Harlan J (1992) Crops and Man. American Society of Agronomy, Madison
(16) Ladizinsky G (1979) The origin of lentil and its wild genepool. Euphytica 28:179–187
(17) Ladizinsky G (1993) Wild lentils. Crit Rev Plant Sci 12:169–184
(18) Ladizinsky G. (1997) A new species of *Lens* from south-east Turkey. Bot J Linn Soc 123:257-260
(19) Ladizinsky G (1999) Identification of lentil 's wild genetic stock. Genet Resour Crop Evol 46:115–118
(20) Ladizinsky G, Braun D, Goshen D, Muehlbauer FJ (1984) Bot Gaz 145:253–261
(21) Miller P (1740,1741) The Gardener's Dictionary, Abridged. London
(22) Sonnante G, Galasso I, Pignone D (2003) ITS sequence analysis and phylogenetic inference in the genus *Lens* Mill. Ann Bot 91:49–54
(23) Sultana T, Ghafoor A (2008) Genetic diversity in *ex-situ* conserved *Lens culinaris* for botanical descriptors, biochemical and molecular markers and identification of landraces from indigenous genetic resources of Pakistan. J Integr Plant Biol 50:484-490
(24) Vail SL (2010) Interspecific-derived and juvenile resistance to anthracnose in lentil. PhD Thesis. University of Saskatchewan
(25) Van Oss H, Aron Y, Ladizinsky G (1997) Chloroplast DNA variation and evolution in the genus *Lens* Mill. Theor Appl Genet 94:452–457
(26) Vavilov NI (1949,1950) lated bThe Origin, Variation, Immunity and Breeding of Cultivated Plants. Selected writings of N. I. Vavilov. Chronica Botanica, Waltham
(27) Zohary D (1972) The wild progenitor and place of origin of the cultivated lentil *Lens culinaris*. Econ Bot 26:326–332
(28) Zohary D (1999) Monophyletic vs. polyphyletic origin of the crops on which agriculture was founded in the Near East. Genet Resour Crop Evol 46:133–142

On some of the most ancient Eurasian words denoting lentil (*Lens culinaris*)

by Aleksandar MIKIĆ

Abstract: Since the original homelands of the Eurasian language families fall within the area of the early distribution of lentil (*Lens culinaris*), their proto-languages could contain roots related to this crop. The Proto-Indo-European **lent-*, **lent-s-* denoting lentil, survived in the modern French *lentille* or German *Linse*. The Proto-Altaic root **ʒi̯ăbsa*, denoting both lentil and pea, gave the Proto-Turkic **jasy-muk*. The Proto-Afroasiatic **ʕadas-*, denoting faba bean (*Vicia faba* L.), finally developed into the Hebrew *ʕ.dāsa* and the Arab *ʕadas-*, denoting lentil. The Proto-Caucasian **hōw ł[ā]*, denoting faba bean and lentil, retained the second meaning only in few modern Caucasian languages.

Key words: crop history, etymology, lentil, lexicology

Lentil (*Lens culinaris* Medik.) originated in the Near Eastern center of diversity, together with pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.) and many other annual cool season legumes. It was a part of the diets of both Neanderthals and the ancestors of modern humans during Paleolithic (1). Together with pea, chickpea and bitter vetch (*Vicia ervilia* (L.) Willd.), lentil is considered one of the first domesticated crops in the world, with archaeological findings from present Syria dating back more than 10,000 years ago (2). Lentil played one of the most important roles in introducing the Neolithic culture of the first farmers to the post-glacial Europe.

Institute of Field and Vegetable Crops, Forage Crops Department, Novi Sad, Serbia (aleksandar.mikic@ifvcns.ns.ac.rs, aleksandar.mikich@gmail.com)

There is a complex correlation between human genetics, ethnology and linguistics that may assist in determining the pathways of the field crop domestication. Eurasia is dominated by several great language families such as Indo-European, Uralic, Altaic, Kartvelian, Dravidian, Afroasiatic, Caucasian or Sino-Tibetan. The supposed original homelands of all these families fall within the area covered by the early distribution of lentil, allowing a possibility that in the proto-languages of these families there were the roots related to this crop. A brief etymological survey of the existing etymological databases brings forth several examples.

The Proto-Indo-European language is the ultimate progenitor of the majority of the languages developed and spoken in Europe, such as Germanic, Romance or Slavic. The ancient Indo-European society was obviously an agricultural one, as evidenced by numerous common roots related to cereals and grain legumes. One of them is **lent-*, **lent-s-*, denoting lentil and retaining its meaning in the modern words such as *lentille* in French, *Linse* in German and *leća* in Serbian and Croatian (3).

The Proto-Altaic root **ʒi̯ăbsa*, denoting both lentil and pea, gave the Proto-Turkic **jasy-muk*, as well as the modern Kazakh *jasimiq*, Manchu *sisa* and the Japanese *sasage*, with the shift of meaning in the last to cowpea (*Vigna unguiculata* (L.) Walp.) (4).

In Proto-Afroasiatic, there is a root **mang*, denoting both millet (*Panicum miliaceum* L.) and lentil, but retaining only the first meaning in its modern descendants. On the other hand, the Proto-Afroasiatic **ʕadas-*, denoting faba bean (*Vicia faba* L.), was developed first into Proto-Semitic **ʕadaš-*, denoting lentil, and then into the Hebrew *ʕ.dāsa* and the Arab *ʕadas-*, with the same meaning (4).

There is also a Proto-Caucasian root, **hōw ł[ā]*, denoting both faba bean and lentil, retaining the second meaning only in few modern Caucasian languages, such as the Lak *hulū* and the Tsakhur *hI ɨwa*.

Although the root words possibly related to lentil still have not been reconstructed in other proto-languages of Eurasia, the existing evidence is strong enough to demonstrate that lentil was a part of the diets of the ancestors of many modern Eurasian nations. ■

For Laure.

References

(1) Henry AG, Brooks AS, Piperno DR (2011) Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; Spy I and II, Belgium). Proc Natl Acad Sci USA 108:486-491

(2) Tanno K, Willcox G (2006) The origins of cultivation of *Cicer arietinum* L. and *Vicia faba* L.: Early finds from north west Syria (Tell el-Kerkh, late 10th millennium BP). Veg Hist Archaeobot 15:197-204

(3) Mikić A (2011) A note on some Proto-Indo-European roots related to grain legumes. Indoger Forsch 116:60-71

(4) Mikić A (2010) Words denoting lentil (*Lens culinaris*) in European languages. J Lentil Res 4:15-19

Lentil germplasm: A basis for improvement

by Clarice J. COYNE[1]*, Rebecca J. McGEE[1] and Robert REDDEN[2]

Abstract: While lentil offers a high quality food for human consumption, the lentil crop is constrained by low biomass, weakly upright plants with poor standing ability, and flowering sensitivity to temperature. Germplasm resources held ex situ are available to assist in overcoming these constraints. Apparent genetic bottlenecks lentil during domestication of the crop limit the genetic diversity in the cultivated gene pool for use in breeding. Ex situ collections need to expand beyond the few examples of regions to target that are presented in this article. Larger scale phenotypic characterization and high through-put genome-wide associations studies of lentil germplasm is on the cusp of breaking wide open that historic bottleneck for lentil breeding efforts.

Key words: genetic diversity, genetic resources, germplasm descriptors, genomics, molecular markers

Genetic resources for breeding research purposes are maintained at a number of centers around the world. The most prominent of which is the extensive collection held at the International Center for Agricultural Research in the Dry Areas (ICARDA) with over 10,800 accessions that includes 583 wild lentil species. This extensive collection is readily accessible and is distributed under the standard material transfer agreement (SMTA) established by the International Treaty on Plant Genetic Resources for Food and Agriculture, popularly known as the International Seed Treaty (3). The world collection was formed by extensive exploration and collection of diverse lentil landraces, varieties and wild species in the center of origin of lentil and also in the many countries that produce lentil.

To efficiently study and use this extensive world collection, a subset of 1000 accessions has been formed and genotyped for available genetic diversity (4). Similarly, the lentil germplasm collection of nearly 4000 accessions held by the USDA at Pullman, USA, has been organized based on geographic origin into a manageable set of 234 accessions (commonly referred to as "the lentil core") (4). The ICARDA and USDA subsets of their germplasm collections provide a convenient means for breeders and other plant scientists to access these collections for traits needed in their research and breeding programs.

Phenotypic characterization

The germplasm collections have been characterized using a set of International lentil germplasm descriptors that was published by IBPGR in 1985. The booklet, 'Lentil Descriptors' is available as a PDF file from Bioversity International, Rome, Italy (www.bioversityinternational.org). These standard descriptors are the primary guidelines used in recording data on the USDA lentil collection. Exceptions exist where the phenotype was not included in the international standards, e.g mineral nutrient concentration in the seed. The entire dataset is available for downloading at http://www.ars-grin.gov/cgi-in/npgs/html/desclist.pl?107. Several of the published studies have phenotyped the entire USDA collection searching for needed and rare alleles conferring resistances to fungi and viral pathogens. An International Crop Information System (ICIS) platform was used to construct a phenotypic search-query data base for lentil germplasm (ILIS), which encompasses the USDA, ICARDA and ATFCC collections. This is available at http://biofire34.pbcbasc.latrobe.edu.au:8080/atfcc_qm.

The source of selected germplasm can be identified by the respective prefixes, PI for USDA, ILL for ICARDA and ATC for ATFCC, with some duplication between collections.

It is advisable to contact the curator of the collection you are interested in to learn what phenotypic characterization is available for the collections held by the various genebanks (Table 1).

Molecular diversity of lentil

The development of fine genetic maps that include direct gene markers is expected to revolutionize the use of lentil genetic resources. Breeders have moved from wide cross/population improvement utilization of lentil germplasm to inbreeding a specific gene/allele from unadapted landrace and wild germplasm (see Tullu this issue of Grain Legumes). Microsatellite markers have been developed and deployed to characterize composite and core collections at ICARDA (e.g. 5) and numerous other national collections. A core of 119 accessions of lentil including subspecies of *culinaris* (57), *orientalis* (30), *tomentosus* (4) and *odemensis* (18) from the ICARDA collection was genotyped using 14 mircrosatellite (SSR) markers (5). This study revealed that the wild accessions were rich in alleles (151 alleles) compared to cultigens (114 alleles) (5). New molecular tools will increase the speed and precision of introgression (moving) these newly identified alleles from both adapted and wild lentil species and subspecies into advanced breeding populations. For example, a lentil pyrosequencing and SNP discovery project is currently underway at the University of Saskatchewan (8). Successful completion of this project will lead to dense linkage maps and greatly reduced gene/QTL discovery time lines. High through-put and precise genotyping of lentil germplasm resources is in progress.

[1]USDA-ARS and Washington State University, Pullman, Washington, USA (coynec@wsu.edu)
[2]Horsham, Victoria, Australia

Table 1. Examples of genebank web sites and curator contacts for initiating, expanding and/or improving a lentil germplasm collection for breeding and research.

Genebank	Accessions	Follow SMTA[4]	Web site	Curator
ICARDA[1]	10,800	Yes	http://www.icarda.org/GeneBank.htm	Kenneth Street k.street@cgiar.org +963 21 2213433
ATFCC[2]	5,250	Yes	http://biofire34.pbcbasc.latrobe.edu.au:8080/atfcc_qm	Robert Redden Bob.Redden@dpi.vic.gov.au +03 53622151
USDA ARS[3]	2,798	Yes, for lines covered by SMTA	http://www.ars-grin.gov/npgs/	Clarice Coyne clarice.coyne@ars.usda.gov + 1 509 335 3878

Genomics and germplasm

Besides progress in high throughput genotyping of the world's lentil germplasm collections, we can safely speculate that lentil will be sequenced within the next five years. The human genome can now be sequenced 2x in one run on new platforms, so 10X coverage of lentil, about the same size as the human genome, can be accomplished in one week (7). New software, longer sequencing reads and sample preparation strategies have overcome the past problem of sequencing larger repetitive genomes, e.g. soyabean, maize recently announced completions. The high through-put genotyping conducted by the CGIAR Challenge Program and other national programs will characterize the world's *ex situ* germplasm resources leading to an understanding of the population structure from a statistical genetics perspective (4). This information combined with genome sequencing, SNP variation studies (haplotype mapping) and detailed phenotyping of the lentil germplasm will lead to successful genome-wide association studies. The understanding of the allele value from any lentil in the gene pool, adapted and wild, will dramatically increase both the efficiency and efficacy of germplasm utilization in lentil breeding programs.

Lentil collection, future needs

Of course, for this to happen, the variable and valuable alleles must be in *ex situ* collections for genotyping and phenotyping to discover new useful variants. One example is recent findings of high genetic differentiation among accessions from Azerbaijan suggests that this gene pool needs to be augmented by additional samples/accessions (1). Another example, Chinese landraces are not represented in the ICARDA nor USDA core collections, however evidence from other Chinese landrace pulses (e.g. 9) strongly indicate that collected Chinese landrace lentil, from west and central China, will be very interesting germplasm to explore for traits and allelic variation (6).

Summary

While lentil offers a high quality food for human consumption (summarized elsewhere this issue), the lentil crop suffers from significant drawbacks including low biomass and flowering sensitivity to temperature that *ex situ* resources may assist in alleviating or ameliorating. Recently summarized were the genetic bottlenecks lentil suffered over the millennia, based on archeological records and flowering time and research conducted in the Middle East and the Indo-Gangetic Plain (2). *Ex situ* collections need to expand, beyond the few examples of regions to target that are presented in this article. Larger scale phenotypic characterization and high through-put genome-wide association studies of lentil germplasm is on the cusp of breaking wide open that historic genetic bottleneck for lentil breeding efforts. ■

References

(1) Babayeva S, Akparov Z, Abbasov M, Mammadov A, Zaifizadeh M, Street K (2009) Diversity analysis of Central Asia and Caucasian lentil (*Lens culinaris* Medik.) germplasm using SSR fingerprinting. Genet Resour Crop Evol 56:293-298

(2) Erskine W, Sarker A, Ashraf M (2010) Reconstructing an ancient bottleneck of the movement of the lentil (*Lens culinaris* ssp. *culinaris*) into South Asia. Genet Resour Crop Evol 58:373-381

(3) Fowler C, Moore G, Hawtin GC (2003) The International Treaty on Plant Genetic Resources for Food and Agriculture: A Primer for the Future Harvest Centres of the CGIAR. IPGRI, Rome

(4) Furman BJ, Coyne C, Redden, Sharma SK, Vishnyakova M (2009) Genetic resources: Collection, characterization, conservation and documentation. In: Erskine W, Muehlbauer FJ, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses, CABI, Wallingford, UK, 64-75.

(5) Hamwieh A, Udupa SM, Sarker A, Jung C, Baum M (2009) Development of new microsatellite markers and their application in the analysis of genetic diversity in lentils. Breed Sci 59:77–86

(6) Liu J, Guan J-P, Xu D-X, Zhang X-Y, Gu J, Zong X-X (2008) Analysis of genetic diversity and population structure in lentil (*Lens culinaris* Medik.) germplasm by SSR markers. Acta Agron Sin 34:1901-1909

(7) Metzker ML (2010) Sequencing technologies - the next generation. Nat Rev Genet 11:31–46

(8) Sharpe A, Li R, Sidebottom C, Links M, Sanderson L, Vijayan P, Vandenberg B, Bett K, Taran B, Warkentin T, Datla R, Selvaraj G, Bekkaoui F, Murrell D, Keller W (2010) 454 transcript profiling for SNP discovery in pulse crops. Abstracts, Vth International Congress on Legume Genetics and Genomics, Pacific Grove, USA, 20

(9) Zong X, Redden RJ, Liu Q, Wang S, Guan J, Liu J, Xu Y, Liu X, Gu J, Yan L (2009) Analysis of a diverse global *Pisum* sp. collection and comparison to a Chinese local *P. sativum* collection with microsatellite markers. Theor Appl Genet 118:193–204

A walk on the wild side: Exploiting wild species for improving cultivated lentil

by Abebe TULLU*, Sabine BANNIZA, Kirstin BETT and Albert VANDENBERG

Abstract: Wild species have genetic variation for important production traits including disease resistance, winter-hardiness and resistance to insects and broomrape. The use of this diversity in breeding is hampered by the difficulty in making the necessary interspecific crosses. However, with the aid of embryo rescue, crosses were made between cultivated lentil and *L. ervoides* and used to develop breeding material with resistance to anthracnose while also expanding the genetic base. Using this approach and giving high priority to maintenance and development of these extremely valuable genetic resources for lentil will help ensure that lentil can maintain high rates of genetic gain and continue to be a valuable component of the human diet and agriculture.
Key words: breeding, gene pool, genetic diversity, interspecific hybridization

Historical background

Lentil (*Lens culinaris*) is one of the ancient crops of agriculture and originated from *Lens culinaris* subsp. *orientalis* in the Near East arc and Asia Minor. The earliest gene bank collection of lentils was undertaken by Nikolai I. Vavilov who developed innovative concepts for the use of plant diversity and wild species to breed better adapted, stress resistant and high yielding crops. His colleague and second wife, Elena Ivanovna Barulina, was the first to describe the wide lentil diversity of native landraces, local selections, elite cultivars and wild relatives maintained at the Vavilov Institute of Plant Industry located at St. Petersburg, Russia. According to her descriptions (1), cultivated lentil can be grouped into subspecies *macrosperma* for large seeded types and subspecies *microsperma* for the small seeded types.

University of Saskatchewan, Crop Development Centre, Saskatoon, Canada (a.tullu@usask.ca)

The genus *Lens* comprises seven taxa in four species, namely; *L. culinaris* with subspecies [*culinaris*, *orientalis*, *tomentosus* and *odemensis*], *L. ervoides*, *L. nigricans* and *L. lamottei*. Crosses are readily obtained between *L. culinaris* ssp. *culinaris* and the other subspecies, particularly ssp. *orientalis* and ssp. *odemensis*. Based on crossability studies, *L. ervoides* and *L. nigricans* are considered to be in the secondary/tertiary gene pool. However, these latter two species can be crossed to the cultivated species, *L. culinaris ssp. culinaris* provided embryo rescue is employed (2, 9).

Improved lentil varieties are generally derived from crosses involving genetically related elite varieties, breeding lines and, to a lesser extent, unadapted germplasm accessions. In many cases, breeding and selection has progressively replaced indigenous landraces with improved and uniform varieties that meet local needs. For example, the demand for higher yields by industry and stringent quality requirements, particularly for greater uniformity of seed size, shape and color, has led to a narrowing of genetic variation and increased vulnerability (6, 7). The use of wild and exotic germplasm has taken on increased importance in efforts to find genetic sources of resistance/tolerance to biotic and abiotic stresses as well as improved yield and seed quality. The wild species represent a needed source of genetic variation for improving cultivated lentil and include the wild subspecies of *L. culinaris* as well as *L. ervoides* and *L. nigricans*. Genes from the latter two species will need to be accessed through embryo rescue procedures.

Genetic diversity: Broadening the genetic base related to diseases and agro-morphological traits

Much of the lentil literature reports identification of resistance and production of interspecific hybrids but there are no reports of the release of cultivars and their use by growers. Resistance sources have been identified for fusarium wilt, ascochyta blight, powdery mildew, rust, Sitona weevil and broomrape (10, 4) . Genetic variation has also been reported for winterhardiness, unique protein subunits and amino acids in wild species of lentil (10, 4). In North America, sources of resistance to race Ct1 of anthracnose has been reported (Figure 1a), whereas, no resistance has been identified to the more aggressive race Ct0 in the cultivated species nor in the closely related subspecies, *L. orientalis*. The frequency of resistance to race Ct0 of anthracnose was the highest in *L. ervoides* followed by *L. nigricans* and *L. lamottei*. Unlike the resistance to anthracnose, resistance to Canadian isolates of *A. lentis* was evident in most of the *Lens* species including *L. culinaris*, *L. orientalis* and *L. odemensis* (11) (Figure 1b). Nevertheless, the frequency of accessions with resistance to *A. lentis* was the highest within *L. ervoides*.

Advanced materials of interspecific crosses of *L. culinaris* and *L. orientalis* from ICARDA have appeared in international nurseries. In India, advanced materials of crosses of *L. culinaris* and *L. orientalis*, and *L. culinaris* and *L. nigricans* were evaluated for various agronomic traits and drought, respectively (6, 3). In Russia, 3 hybrid plants were recovered from a cross *L .culinaris* x *L. tomentosus* with the aid of embryo rescue and viable seeds of F_1 to F_5 were obtained. However, introgressed materials have not found their way to advanced breeding stages. As evident from various experiments, *L. ervoides* followed by *L. nigricans* accessions (11, 4) appeared to have better resistance to various diseases and higher variation for agronomic traits.

The experience in Canada, with breeding lentil for resistance to anthracnose provides an illustrative example of the value of wide crosses in the genus *Lens*. Our attempt to cross cv 'Eston' (*L. culinaris*) with PI 72815 and L01-827 (*L. ervoides*) was successful with the aid of embryo rescue (Figure 2). For various protocols, see (3). Production of hybrid seeds followed by F_2 to F_7 seeds led to the development of two recombinant inbred populations (RILs) with varying degrees of sterility. These inbred lines have been evaluated in the greenhouse and field (unpublished) and revealed transgressive segregants for various agronomic traits including an 8% increase in seed size, which could be utilized in breeding lentil.

Utilization of allelic variation in interspecific crosses

Studies of introgression of genes from exotic species and the number of cultivars from wild germplasm is steadily increasing in major cereal crops, tomato, potato, rice, sunflower, and lettuce (5). Virtually all resistance genes currently in commercial tomato cultivars originated from wild germplasm (8). There are attempts in several other crops, including lentil, to transfer favorable genes to adapted cultivars. Resistance to race Ct0 of anthracnose in lentil interspecific RILs appeared to be controlled by two recessive genes unlike a single gene (*Lct2*) previously reported in cultivated germplasm. From phenotypic segregation data (resistance and susceptibility) alone it could not be determined whether the alleles conferring resistance to race Ct1 and race Ct0 are the same. However, exotic gene(s) for resistance have been successfully transferred to the cv. Eston from *L. ervoides* thereby expanding the genetic base for breeding (5).

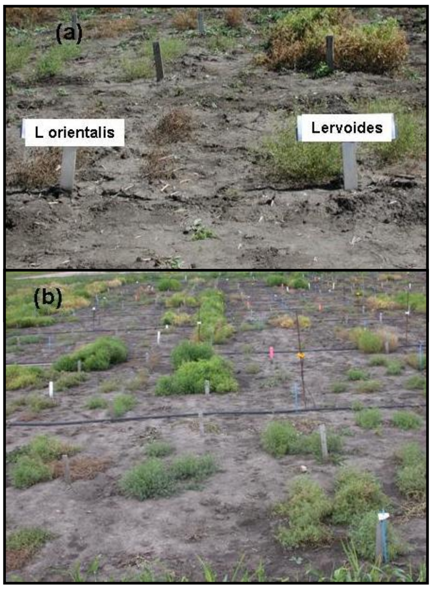


Figure 1. Outdoor screening of wild germplasm for anthracnose (a) and ascochyta blight (b) in field experiments in Saskatoon, Canada

We have targeted a breeding approach that combines evaluation of interspecific RILs (*L. culinaris* x *L. ervoides*) and backcrosses of selected RILs to adapted cultivars in order to transfer desired traits. We select individual RILs for traits of interest and then backcross to adapted cultivars. For example, backcrosses to cultivars of different market classes, such as 'CDC Greenland' (large green) and 'CDC Viceroy' (small green) are currently in advanced generations. The results of the successful transfer of anthracnose resistance from *L. ervoides* (L01 827) using interspecific hybridization followed by intensive backcrossing indicated that 13% of backcross derived breeding lines exceeded the mean yield of check cultivars in field trials (Vandenberg et al., unpublished). Other attributes include earliness, seed size, lodging, and resistance to stemphylium blight, sclerotinia white mould and ascochyta blight. Lentil cultivars with greatly improved resistance to anthracnose will become available in the next few years, providing increased genetic diversity for lentil breeding.

Genomics to better access and use genetic variation

The genetic base of a crop can be widened by exploring the pool of germplasm using allelic diversity at the nucleotide level. In Canada, we have begun to develop genomic resources for lentil starting with EST development under NAPGEN (https://www.nrc-cnrc.gc.ca/eng/programs/pbi/plant-products/napgen.html), followed by SNP identification and mapping under several projects funded by the Canadian and Saskatchewan governments as well as the Saskatchewan Pulse Growers. In collaboration with the Plant Biotechnology Institute of the National Research Council of Canada, we have identified SNPs by comparing 454-based sequences from transcripts of ten *L. culinaris* lines and two *L. ervoides* lines against the reference genotype 'CDC Redberry'. In collaboration with D.R. Cook at UC Davis, we have also identified SNPs in sequences generated from tentative orthologous genes (TOGs) already mapped in several other legumes. These SNPs are being used to screen collections of cultivated and wild *Lens* species from the CDC and USDA-ARS to assess genetic variability at nucleotide level. The TOGs are also being used to map the *L. culinaris* and *L. ervoides* genomes and compare them with each other and with various other model and crop legumes. This comparative mapping will allow for leveraging of genomic resources across the legumes for use in lentil, giving breeders tools never before accessible in a 'small' crop like lentil. Giving the highest priority to maintenance and development of these extremely valuable genetic resources for lentil will help ensure that this crop can maintain high rates of genetic gain and increase as a valuable component of the human diet and agriculture. ■

.

References

(1) Barulina H (1930) Lentils of the USSR and other countries. Bull Appl Bot Genet Plant Breed 40:265–304

(2) Cubero JI, Pérez de la Vega M, Fratini R (2009) Origin, Phylogeny, Domestication and Spread. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 13-33

(3) Davis PA, Lülsdorf MM, Ahmad M (2007) Wild relatives and biotechnological approaches. In: Yadav SS, McNeil D, Stevenson PC (eds) Lentil: An Ancient Crop for Modern Times, Springer, Dordrecht, the Netherlands, 225-240

(4) Fernandez-Aparicio M, Sillero JC, Rubiales D (2009) Resistance to broomrape in wild lentils (*Lens* spp.). Plant Breed 128:266-270

(5) Fiala JV, Tullu A, Banniza S, Séguin-Swartz G, Vandenberg A (2009). Interspecies transfer of resistance to anthracnose in lentil (*Lens culinaris* Medic.). Crop Sci 49:825-830

(6) Gupta D, Sharma SK (2006) Evaluation of wild *Lens* taxa for agro-morphological traits, fungal diseases and moisture stress in north western Indian hills. Genet Resour Crop Evol 53:1233-1241

(7) Gupta D, Sharma SK (2007) Widening the gene pool of cultivated lentils through introgression of alien chromatin from wild *Lens* subspecies. Plant Breed 126:58-61

(8) Hajjar R, Hodgkin T (2007) The use of wild relatives in crop improvement: A survey of developments over the last 20 years. Euphytica 156:1-13

(9) Ladizinsky G, Braun D, Goshen D, Muehlbauer FJ (1984) The biological species of the genus *Lens* L. Bot Gaz 145:253-261

(10) Muehlbauer FJ, Kaiser WJ, Simon CJ (1994) Potential for wild species in cool season food legume breeding. Euphytica 73:109-114

(11) Tullu A, Banniza S, Tar'an B, Warkentin T, Vandenberg A (2010) Sources of resistance to ascochyta blight in wild species of lentil (*Lens culinaris* Medik.). Genet Resour Crop Evol 57:1053-1063

Genes for traits of economic importance in lentil

by Balram SHARMA

Abstract: Small plant size and small seeds restrict attempts to boost yields in lentil (*Lens culinaris* Medik.). There are several properties of plant structure, seed size, seed coat and cotyledon colour, maturation and biotic and abiotic stresses that are valuable economically. Genetic control of many of these characters is fairly well understood, and the information has been used in developing new varieties. Seed protein content has been claimed to be positively correlated with seed size. The International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria, has an impressive programme for developing disease resistant varieties.
Key words: breeding, genetic control, lentil, traits

Lentil is not a high yielding grain legume. Small plant size and small seeds restrict attempts to boost yields. Lentil is inherently a less water demanding (drought tolerant) plant and is often a preferred crop in the water deficient areas. Several biotic stress factors such as wilt, rust, blights caused by *Ascochyta* and *Stemphylium*, and parasitic infestations of *Orobanche* (broomrape) have become major constraints to yield in specific areas. Fortunately, chemical control measures are available for most biotic stresses. Cultural practices are also helpful in providing relief under field conditions, especially when environmental factors are conducive.

Besides traits associated with biotic and abiotic stresses, there are several properties of plant structure, seed size, seed coat and cotyledon colour, and maturation that are valuable economically. Seed size, testa and cotyledon colours impact market prices for lentil. Genetic control of many of these characters is fairly well understood, and the information has been used in developing new varieties.

Indian Agricultural Research Institute, Division of Genetics, Delhi, India (drbrsh@yahoo.co.in)

Growth habit

Spreading growth habit, as in many plant species, is a dominant trait. The erect plant type is its contrasting analogue and is recessive. Although there is a gradation between spreading and completely erect growth habit among cultivated varieties, a monogenic recessive phenotype was identified by Emami and Sharma (4) and was assigned gene symbol *ert*. This gene is linked to genes for red pod (*Rdp*), brown leaf (*Bl*) and green/red stem (*Gs*). These visible traits are convenient for screening segregating populations and can be used for selection at early stages of plant development. Erect plants having the recessive *ert* gene are easy to spot in the seedling stage.

Genotypes with spreading growth habit can be grouped into several categories from highly prostrate to more upright. With the exception of the erect plants of *ert* type, the lentil plant has extremely slow growth rates in the beginning. The basal branches adhere to the soil surface for nearly a month before beginning upward growth.

The spreading genotypes are generally endowed with profuse branching (basal as well as secondary). The erect plants (*ert ert*) have relatively few branches; however, crop density can be enhanced by higher seeding rates.

Plant pubescence

Development of pubescence of the leaves, stems and pods of the plant is a unique wild type trait of *microsperma* lentils, which are probably more primitive in evolution. Almost all varieties of Indian lentil are pubescent to some degree. It appears that the presence of pubescence provides protection against water loss and insect attack. This may be the reason for wider adaptability of the small seeded lentils across the continents. The *Pub* gene for pubescence formation falls in the linkage group *Ph*–*Gl*–*Pub*–*Hi* (8). *Macrosperma* lentils are almost universally glabrous.

Plant height

Plant height was shown to be a monogenic trait in pea by Mendel and also holds true for lentil. The gene for plant height (*Ph*) is a member of a linkage group which has eight morphological and at least thirteen enzyme markers (8). Plants of erect and very tall varieties tend to lodge as they approach maturity. Therefore varieties with erect plant habit and medium height are expected to be more lodging resistant. Such varieties are also amenable to mechanical harvesting.

Flowering time and maturity

Generally speaking, Indian type *microsperma* lentils are contrastingly earlier than the large seeded *macrosperma* lentils. So far only one exception has been found in the *macrosperma* variety Precoz (from Argentina) which is as early as the earliest *microsperma* varieties. Earliness is a desirable trait ensuring completion of crop cycle in a relatively short period of time, thereby making more efficient use of resources as well as avoiding losses due to high temperatures during crop maturation. Sarker et al. (10) reported monogenic inheritance of flowering time with earliness being recessive. However a more elaborate study based on 25 crosses concluded that flowering time and maturation were under polygenic control (2). The genes for earliness in the *microsperma* and *macrosperma* lentils belong to different gene pools and transgressive segregation for earliness is obtained when the early *microsperma* varieties are crossed with early *macrosperma* genotypes. If the earliest genotypes from the two lentil groups flower in about 65–70 days, transgressive segregants from crosses between them produce flowers in 45–50 days. Gene symbol *Sn* has been proposed for the major gene controlling days to flowering in lentil.

Number of flowers per peduncle

Prolificacy is the ability of a genotype to produce flowers and ultimately pods on each peduncle. This trait is highly influenced by environment. Emami (2) and Kumar (7) concluded that high prolificacy is dominant over low flower number.

Pod dehiscence

This is a typical property of wild lentils. However, in cultivated lentil the trait can cause severe losses at harvest. Pod indehiscence, conferred by the gene *pi* (9), is recessive and is considered to have played a major role in lentil domestication.

Seedcoat colour

The lentil seedcoat has four basic colours: black, brown, grey and green. In the absence of any colour in the seedcoat, the background looks whitish and the colours of cotyledons (red, yellow or green) become visible through the translucent seedcoat. The green pigment of cotyledons is also transferred to the cotyledons in the early period of seed development. In that case, the mature seed may appear green even if its seedcoat does not have any pigment of its own. The lentil seed may also appear black because of black spotting and/or speckling on the seedcoat.

Black seedcoat is epistatic and does not allow expression of other seedcoat colours even if their genes are present in dominant state. The gene for black seedcoat was assigned gene symbol *Blt* with a kind of dosage effect, as a result of which the seeds borne on the F_1 plant are a mixture of black and non-black, and in the F_2 the homozygous *BltBlt* plants are all solid black, the heterozygous *Bltblt* plants produce mixture of black and non-black seeds (not in any genetic ratio), and the recessive homozygotes are uniformly non-black (5).

Brown seedcoat is dominant over grey and tan. The tan phenotype is possibly caused when all colour genes are recessive. A specific gene has not been assigned for green seedcoat independent of the cotyledon genes.

Seed spotting

Lentils have two types of seedcoat spotting: small and round pin spots, and larger irregularly shaped speckles, and are referred to as speckling and mottling, respectively (2). They are caused by two tightly linked genes, *Mot* and *Spt*, for mottling and speckling, respectively. In the germplasm, strains can be found with the mottling or speckling patterns in isolation, and also with a mixture of both which is conferred by the double dominant situation. In the double recessive *motmotsptspt* situation, the seedcoat lacks pigmentation.

A value tag is attached to seed colour in the market. Varieties with pigment free seedcoats are called "green" lentils in western countries, which is clearly a misnomer because the cotyledons are nearly always yellow. Genetically, lentils are green when they have recessive genes for yellow and 'brown' cotyledon colour. The markets in the western countries generally offer a premium on lentils that have yellow or orange cotyledons and pigmentless seedcoats. In the Old World, however, red/orange lentils are more valued and usually have dense black spotting on the seedcoat.

Cotyledon colour

From commercial point of view, cotyledon colour (besides seed size) is a most important characteristic. Cotyledon colour in lentil is controlled by three major genes: *Y* (yellow), *B* (brown), and *Dg* (dark green). The so-called brown is a mildly pinkish yellow colour and differs from the bright yellow colour caused by the *Y* gene. The double dominant combination of both these genes (*BBYY*) gives rise to the orange pigmentation which is commonly known as red lentils (3). Double recessive condition of these genes (*yybb*) gives rise to light green cotyledons. The third gene, *Dg*, is epistatic to both *Y* and *B* in recessive condition (*dgdg*) and results in dark green cotyledons. Apparently, the recessive *dg* gene blocks the synthesis of pigments by the two pigment producing genes, *Y* and *B* (11).

Seed size

Seed size is the most important criterion in determining the price paid to farmers in wholesale markets world over. Consumer preference and yield potential decide the choice of varieties to be cultivated. For example, small seeded *microsperma* lentils are preferred in the Indian subcontinent. Here again, larger seeded varieties with 1000-grain weight of 26–35 grams are cultivated in the central provinces of India. Small seeded varieties (1000-grain seed weight below 25 grams) are preferred in the northern parts of India. Correspondingly, the larger seeded lentils attract higher prices in central India while the smaller seeded lentils command higher prices in the north.

Seed size has been reported to be a quantitative trait with continuous variation in the segregating populations of crosses between large and small seeded parents. When *macrosperma* and *microsperma* lentils are crossed they do not show discrete Mendelian segregation for seed size. Analysis for quantitative trait loci (QTLs) showed that seed weight is under polygenic control and the alleles for low seed weight have partially dominant effects.

Seed hardness

Seed hardness is a seed dormancy trait; however, the seeds gradually soften over time in storage. This is a wild trait and more prevalent in related wild relatives. Reports on the nature of its inheritance are conflicting; however, it has been repeatedly shown to be a monogenic trait. Seed hardness has been designated with gene symbol *Hsc* and is linked to the *Pi* gene for pod dehiscence.

Seed protein content

Lentil is possibly the richest source of proteins among edible pulses that are cooked and directly consumed without prior processing for quality alterations. The usual protein content in dry lentils is around 26%, although the range reported in germplasm is from 20.4 to 29.8%, and is considered a polygenic trait. In most crops, especially cereals, protein content is invariably negatively correlated with seed size. However, lentil is possibly an exception. According to available reports, protein content has been claimed to be positively (although mildly) correlated with seed size.

Abiotic stresses

Lentil is a viable crop in many drought-prone areas. In the northern latitudes of West Asia, Europe and North America (including Canada), low temperatures and frost injury are equally serious problems. Sources of cold resistance have been identified among cultivars as well as wild germplasm. The single gene for radiation-frost tolerance (*Frt*) has been tagged with a molecular marker (6).

Disease resistance

Lentil can be damaged by a number of diseases. Major among them are rust, wilt, blights caused by *Ascochyta* and *Stemphylium*, anthracnose, and viruses. Rust resistance in lentil is known to be controlled by two dominant genes (*Urf1* and *Urf2*). A third gene has been reported recently (1). Wilt is another serious disease of lentil which is associated with moisture stress. Frequently wilt resistance is reported to be controlled by a single gene, *Fw*. At the same time, one report claimed that wilt resistance is controlled by as many as five dominant genes. The International Center for Agricultural Research in the Dry Areas (ICARDA) located in Aleppo, Syria, has developed an impressive programme for developing wilt resistant varieties, and has created a very effective screening nursery to identify resistant lines.

Resistance to ascochyta blight is controlled by one dominant (*Ral1*) and another recessive gene (*ral2*). The recessive gene has been tagged in flanking positions with two molecular markers. The other blight disease, caused by *Stemphylium*, is more prevalent in the humid areas of eastern India and Bangladesh. Sources of resistance have been identified.

The pea seed-borne mosaic virus (PSbMV) is the major viral disease of lentil. Several PSbMV resistant donors have been identified which were used to show that viral immunity is a monogenic recessive trait. The gene for PSbMV resistance is designated as *sbv*. ■

References

(1) Basandrai D, Basandrai AK, Sarker A, Mishra SK, Thakur HL, Thakur SK (2006-2007) Genetics of rust resistance in lentil (*Lens culinaris* ssp. *culinaris*). J Lentil Res 3:28–31.

(2) Emami MK (1996) Genetic mapping in lentil (*Lens culinaris* Medik.). PhD Thesis. Indian Agricultural Research Institute

(3) Emami MK, Sharma B (1996) Digenic control of cotyledon colour in lentil. Indian J Genet 56:357–361

(4) Emami MK, Sharma B (1999) Linkage between three morphological markers in lentil. Plant Breed 118:579–581

(5) Emami MK, Sharma B (2000) Inheritance of black testa color in lentil. Euphytica 115:43–47

(6) Eujayl I, Erskine W, Baum M, Pehu E (1999) Inheritance and linkage analysis of frost injury in lentil. Crop Sci 39:639–642

(7) Kumar Y (2002) Inheritance and linkage of genes for morphological traits in lentil (*Lens culinaris* Medik.). PhD Thesis. Charan Singh University

(8) Kumar Y, Mishra SK, Tyagi MC, Singh SP, Sharma B (2005) Linkage between genes for leaf colour, plant pubescence, number of leaflets and plant height in lentil (*Lens culinaris* Medik.) Euphytica 145:41–48

(9) Ladizinsky G (1979) The genetics of several morphological traits in the lentil. J Hered 70:135–137

(10) Sarker A, Erskine W, Sharma B, Tyagi MC (1999) Inheritance and linkage relationship of days to flower and morphological loci in lentil (*Lens culinaris* Medikus subsp. *culinaris*) J Hered 90:270–275

(11) Sharma B, Emami MK (2002) Discovery of a new gene causing dark green cotyledons and pathway of pigment synthesis in lentil (*Lens culinaris* Medik). Euphytica 124:349–353

Genetics of economic traits in lentil: Seed traits and adaptation to climatic variations

by Richard FRATINI and Marcelino PÉREZ DE LA VEGA

Abstract: Several seed traits are important in world trade considering that prices for small-seeded lentil are often much less than larger-seeded varieties. Seed coat coloration also plays an important role in presumed value for the crop. In production, traits such as reduced seed shattering, tall and upright plant habit, flowering, and adaptation to biotic and abiotic stresses are important for sustainable production and acceptable returns to farmers. These traits are mostly under genetic control while the environment can also play and important role in trait expression. Breeding programs must focus on these traits to ensure adaptation to the environment for which they are intended and also in providing products acceptable to producers and consumers.

Key words: drought tolerance, flowering, photoperiod sensitivity, pod and seed traits, polygenic variation, QTL analysis, winter-hardiness

Universidad de León, Área de Genética, Departamento de Biología Molecular, Spain. (richard.fratini@unileon.es; m.perez.delavega@unileon.es)

The global economic position of lentil among grain legumes has increased in importance in international trade and currently ranks sixth in terms of production after dry bean, pea, chickpea, faba bean and cowpea. In the period from 2003 to 2006 lentil constituted 6% of the total dry pulse world production, having increased more than a fourfold (413%)from 917,000 t in 1961-1963, with an average yield of 560 kg/ha' to a world harvest in 2004-2006 of 3,787,000 t with a mean yield of 950 kg/ha (10). The spread of lentil from its centre of origin in the 'Fertile Crescent' of the Near East after its early domestication about 10,000 years ago (7), has been accompanied by selection for traits that enhance adaptation to a wide range of agro-ecological environments. The crop is now being cultivated on all continents except Antarctica. With an initial selection against pod dehiscence, the main objective of human selection has remained seed size together with flowering response to photoperiod and temperature and resistance or tolerance to abiotic and biotic stresses.

Pod and seed characteristics

Reduced shattering is a trait of great economic value as pod dehiscence can cause significant losses before or during harvest. Pod dehiscence was found to be completely dominant over indehiscence and was assigned the gene symbol *Pi* (25, 26, 36), nonetheless, response to selection for pod indehiscence indicates the presence of quantitative variation (9), which was confirmed by quantitative trait loci (QTL) analysis that indicate one major recessive QTL and two minor* dominant QTLs accounting for 81% of the observed variation (15).

*The concepts "major" and "minor" in relation to QTLs are used here as QTLs explaining a major and significant part of the character variation, or a small proportion of it, respectively. NO with the orthodox genetic meaning of qualitative (major) or quantitative (minor) genes.

Seed size is an important economic trait with special attributes in lentil consumption and trade considering that wholesale prices of small- (*microsperma*) and large-seeded (*macrosperma*) varieties differ by a large margin depending on consumer preferences and farmers' choice. Cultivated lentils are divided on basis of seed size differences into *microsperma* (< 4.5 mm) and *macrosperma* (>4.5 mm and sometimes over 7 mm). Seed size has a continuous distribution in F_2 progenies following crossing of large and small seeded types (25) and at least two major additive QTLs and one minor dominant QTL have been described for seed size (15). With regard to seed mass, QTL analysis has shown polygenic control with partial dominance for low seed weight alleles (1), which has also been confirmed in a second study which describes two recessive and one additive QTL associated to low seed weight (15).

Lentil is a rich source of dietary proteins among crops that are consumed without industrial processing. Studies to analyze the inheritance of seed protein concentration in lentil (5, 19, 35) have revealed the quantitative nature of this trait and a non-significant correlation with grain yield and seed size (19, 35).

Flowering and plant architecture

Flowering time is particularly important for adaptation and yield; it determines the length of the vegetative phase and conditions crop exposure during reproductive growth to climatic settings. Selection of a response to specific regional balances between photoperiod and temperature for the onset of flowering has played a vital role in the adaptation of lentil to different regions and conditions around the globe (11). The inheritance of flowering time was described as monogenic, with earliness being recessive (28). However, transgressive segregation for early flowering was also observed. That segregation was considered a consequence of interaction between the recessive *sn* and a polygenic system of minor earliness genes.

Continuous polygenic variation has been described in another analysis regarding flowering response based on crosses between early maturing *microsperma* varieties from India and an early maturing *macrosperma* variety from Latin America. Likewise, transgressive segregation was observed in these crosses suggesting the quantitative nature of the trait (34). As crosses between *microsperma* varieties did not produce transgressive flowering segregants, the study concluded that *microsperma* and *macrosperma* lentils have different sets of genes controlling flowering time, while the Indian *microsperma* genotypes all share the same gene pool to flowering response. Finally, three QTLs that accounted for more than 90% of the observed variation in flowering response were detected, one was a major recessive gene while the remaining two were minor and dominant (15). As the *Sn* locus was shown to be linked to *Scp* (gene *S*eed *c*oat *p*attern gene) and the latter major recessive QTL was located in the linkage group (LG) containing *Gs* (*G*reen *s*tem), it seems likely that flowering response is under a complex genetic control with qualitative and quantitative genes.

Plant structure holds many implications regarding yield and ease of harvesting. Incomplete dominance of a bushy/erect growth habit was reported and the gene symbol *Gh* proposed (25), later, the recessive *ert* gene was discovered and mapped in the LG containing *Gs* (8). The erect phenotype *ert* is recessive to the most prevalent growth habit in cultivated lentil in which plants remain procumbent for about a month and thereafter branches grow in a semi-erect or semi-spreading fashion, while the wild *Lens* species retain prostrate stems much longer. QTL analysis has revealed that the number of branches at the first node is mainly controlled by a dominant quantitative locus together with two minor loci of opposing effects which together explain 92% of the observed variation. Two additive QTL explained one third of the variance for the height of the first node. Finally, one recessive and one dominant QTL jointly explained half of the variation encountered for the total number of branches (15).

Plant height is strongly associated to yield. In lentil, the gene *Ph* for plant height was first reported (31) and found to be dominant over dwarfness. *Ph* is located in a LG comprising eight morphological (24) and more than a dozen isozyme markers (31). In addition, plant height was also found to be quantitatively inherited (18): another study described one additive QTL and two recessive QTLs, but the three QTLs explained only the 38% of the observed variation in plant height (15).

Flower number per peduncle in lentil may retain significance in relation to productivity potential. Genetic analysis is complicated because of an inconsistent expression of the trait which is highly influenced by environmental conditions and declines as plants get older. Nonetheless, monogenic inheritance with the two-flower phenotype dominant over the three flowered was initially described (16) followed by contrasting results from different studies that concluded that a higher flower number per peduncle was dominant (30).

Abiotic stresses

Tolerance to frost injury is an essential requirement when lentils are sown during the winter and cultivated at cooler climates. Monogenic inheritance of radiation-frost tolerance was reported and assigned gene symbol *Frt* (13), the gene has also been tagged with a random amplified polymorphic DNA (RAPD) marker at a distance of 9.1 cM. On the other hand, it has been concluded that winter hardiness in lentil is a polygenic trait and several QTL together accounted for 42% of the variation observed in recombinant inbred lines (RILs) (21, 22). At least four QTLs were detected under controlled frost conditions and field conditions in two RIL populations; furthermore, two QTLs related to frost response were also related to yield under winter sown conditions (3).

Lentil was traditionally grown in semi-arid regions under rainfed conditions, thus it combines a high degree of drought resistance and a low water requirement; in fact, excessive water supply is damaging to the crop. The genetics of drought tolerance is still to be explored. Likewise, genetic variation has been found in lentil for response to salinity, nutrient deficiency and toxicity, but no genetic studies have uncovered details on these agronomic traits.

Biotic stresses

Most genetic studies regarding rust (*Uromyces fabae*) resistance in lentil reported that resistance is under a monogenic control, resistance being dominant over susceptibility. However, reports of incomplete resistance, as well as duplicate dominant genes controlling resistance have frequently emerged; only one unconfirmed report has suggested rust resistance to be a recessive trait (see 30 for review). Furthermore, research at the Division of Genetics of the Indian Agricultural Research Institute of New Delhi has observed that the dominant gene for resistance of a *macrosperma* variety from Latin America differs from that of an Indian *microsperma* variety. Therefore, it seems that at least two separate genes controlling rust resistance have evolved in spatially and temporally isolated lentil groups. Gene symbols *Urf1*, *Urf2* and the unconfirmed *urf3* have been proposed (30).

Allelism tests concluded that *Fusarium* resistance in lentil is conferred by five dominant genes (23). However, subsequently only one dominant gene (*Fw*) for wilt resistance was reported. It was tagged with a RAPD marker at 10.8 cM (12); a microsatellite marker and a amplified fragment length polymorphism (AFLP) marker were further linked to the *Fw* locus at distances of 8.0 and 3.5 cM, respectively (20). Moreover, a three year screening of lentil germplasm at ICARDA yielded 34 strains confirmed for resistance to fusarium wilt. Evaluations from F_5 to F_8 successfully identified 753 resistant lines. Among the small seeded lines, 72% were wilt-resistant compared to 41% of the large-seeded lines, suggesting that genes for small seed size might be loosely associated with genes for wilt-resistance (29).

The genetic control of ascochyta blight resistance was described to be monogenic recessive (32). However, two complementary dominant genes were further described in a cross between *L. ervoides* and *L. odemensis* (2), while only one dominant gene was found in crosses between *L. culinaris* accessions (2). The existence of two complementary dominant genes within cultivated lentils was thereafter established (27). Two flanking RAPD markers at distances of 8.0 and 3.5 cM from the designated resistance locus *Ral1* (*Abr1*) have been mapped (14); likewise, two additional RAPD markers have been located in flanking positions of the recessive gene for resistance *ral1* at distances of 6.4 and 10.5 cM (6).

Resistance to anthracnose caused by *Colletotrichum truncatum* has been reported to be under the control of one recessive gene (*lct-1*) in one cultivar, while two dominant genes designated *LCt-2* and *LCt-3* were respectively responsible for resistance in two additional cultivars (4). The LCt-2 resistance locus has been tagged with two flanking RAPD markers at 6.4 and 10.5 cM (33).

Pea seed-borne mosaic virus (PSbMV) is a major disease in lentil transmitted through seed as well as aphids. Monogenic recessive inheritance of viral immunity has been confirmed in four crosses and the gene symbol *sbv* was proposed to denote PsbMV resistance in lentil (17).

Future perspectives

Further inheritance studies of resistance/tolerance to biotic and abiotic stresses are required for a better understanding of the respective genetic systems controlling these responses. This knowledge will be useful to design adequate breeding programs based on regional requirements. There is a need to include more morphological and molecular markers and to develop a comprehensive consensus genetic linkage map in lentil, allowing for molecular tagging of resistance genes against biotic and abiotic stresses in order to exploit them in breeding with increased selection efficiency. ■

References

(1) Abbo S, Ladizinsky G, Weeden NF (1992) Genetic analysis and linkage studies of seed weight in lentil. Euphytica 58:259- 266

(2) Ahmad M, Russell AC, McNeil DL (1997) Identification and genetic characterization of different resistance sources to ascochyta blight within the genus *Lens*. Euphytica 97:311-315

(3) Barrios A, Kahraman A, Aparicio T, Rodríguez M, Mosquera P, García P, McPhee K, Pérez de la Vega M, Caminero C (2007) Preliminary identification of QTLs for winter hardiness, frost tolerance and other agronomic characters in lentil (*Lens culinaris* Medik.) for Castilla y León (Spain) region. 6th European Conference on Grain Legumes, Lisbon, Portugal

(4) Buchwaldt L, Anderson KL, Morrall RAA, Gossen BD, Bernier CC (2004) Identification of lentil germ plasm resistant to *Colletotrichum truncatum* and characterization of two pathogen races. Phytopathol 94:236-243

(5) Chauhan MP, Singh IS (1995) Legume Research 18:5-8

(6) Chowdhury MA, Andrahennadi P, Slinkard AE, Vandenberg A (2001) RAPD and SCAR markers for resistance to *Ascochyta* blight in lentil. Euphytica 118:331-337

(7) Cubero JI, Pérez de la Vega M, Fratini R (2009) Origin, Phylogeny, Domestication and Spread. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 13-33

(8) Emami MK, Sharma B (1999) Linkage between three morphological markers in lentil. Plant Breed 118:579–581

(9) Erskine, W. (1985). Selection for pod retention and pod indehiscence in lentils. Euphytica 34:105-112

(10) Erskine W (2009) Global production, supply and demand. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 4-12

(11) Erskine W, Ellis RH, Summerfield RI, Roberts EH, Hussain A (1990) Characterization of responses to temperature and photoperiod for time to flowering in a world lentil collection. Theor Appl Genet 80:193-199

(12) Eujayl I, Bayaa B, Erskine W, Baum M, Pehu E (1998) Fusarium vascular wilt in lentil: Inheritance and identification of DNA markers for resistance. Plant Breed 117:497-499

(13) Eujayl I, Erskine W, Baum M, Pehu E (1999) Inheritance and linkage analysis of frost injury in lentil. Crop Sci 39:639–642

(14) Ford R, Pang ECK, Taylor PWJ (1999) Genetics of resistance to ascochyta blight (*Ascochyta lentis*) of lentil and identification of closely linked molecular markers. Theor Appl Genet 98:93-98

(15) Fratini R, Durán Y, García P, Pérez de la Vega M (2007) Identification of quantitative trait loci (QTL) for plant structure, growth habit and yield in lentil. Span J Agric Res 5:348-356

(16) Gill AS, Malhotra RS (1980) Inheritance of flower color and flower number per inflorescence in lentil. Lens Newsl 7:15-19

(17) Haddad NI, Muehlbauer FJ, Hampton RO (1978) Inheritance of resistance to pea seed-borne mosaic virus in lentils. Crop Sci 18:613-615

(18) Haddad NI, Bogyo TP, Muehlbauer FJ (1982) Genetic variance of six agronomic characters in three lentil (*Lens culinaris* Medic) crosses. Euphytica 31:113-120

(19) Hamdi A, Erskine W, Gates P (1991) Relationships among economic characters in lentil. Euphytica 57:109-116

(20) Hamwieh A, Udupa SM, Choumane W, Sarker A, Dreyer F, Jung C, Baum M (2005) A genetic linkage map of *Lens* sp. based on microsatellite and AFLP markers and the localization of fusarium vascular wilt resistance. Theor Appl Genet 110:669-677

(21) Kahraman A, Kusmenoglu I, Aydin N, Aydogan A, Erskine W, Muehlbauer FJ (2004a) Genetics of winter hardiness in 10 lentil recombinant inbred line populations. Crop Sci 44:5-12

(22) Kahraman A, Kusmenoglu I, Aydin N, Aydogan A, Erskine W, Muehlbauer FJ(2004b) QTL mapping of winter hardiness genes in lentil. Crop Sci 44:13-22

(23) Kamboj RK, Pandey MP, Chaube HS (1990) Inheritance of resistance to Fusarium wilt in Indian lentil germplasm. Euphytica 105:113-117

(24) Kumar Y, Mishra S, Tyagi M, Singh S, Sharma B (2005) Linkage between genes for leaf colour, plant pubescence, number of leaflets and plant height in lentil (*Lens culinaris* Medik.). Euphytica 145:41-48

(25) Ladizinsky G (1979) The genetics of several morphological traits in the lentil. J Hered 70:135–137

(26) Ladizinsky G (1985) The genetics of hard seed coat in the genus *Lens*. Euphytica 34:539-543

(27) Nguyen TT, Taylor PWJ, Brouwer JB, Pang ECK, Ford R (2001) A novel source of resistance in lentil *(Lens culinaris* ssp. *culinaris*) to ascochyta blight caused by *Ascochyta lentis*. Australas Plant Pathol 30:211-215

(28) Sarker A, Erskine W, Sharma B, Tyagi MC (1999) Inheritance and linkage relationship of days to flower and morphological loci in lentil (*Lens culinaris* Medikus subsp. *culinaris*) J Hered 90:270–275

(29) Sarker A, Bayaa B, El-Hassan H, Erskine W (2004) New sources of resistance for Fusarium wilt in lentil (*Lens culinaris* Medikus subsp. *culinaris*). J Lentil Res 1:30-33

(30) Sharma, B. (2009) Genetics of economic traits. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 76-101

(31) Tahir M, Muehlbauer FJ, Spaeth SC (1994) Association of isozyme markers with quantitative trait loci in random single seed descent derived lines of lentil (*Lens culinaris* Medik.). Euphytica 75:111-119

(32) Tay J, Slinkard AE (1989) Transgressive segregation for Ascochyta resistance in lentil. Can J Plant Sci 69:547

(33) Tullu A, Buchwaldt L, Warkentin T, Taran B, Vandenberg A (2003) Genetics of resistance to anthracnose and identification of AFLP and RAPD markers linked to the resistance gene in PI 320937 germplasm of lentil (*Lens culinaris* Medikus). Theor Appl Genet 106:428-434

(34) Tyagi MC, Sharma B (1989) Lens Newsl 16:3-6

(35) Tyagi MC, Sharma B (1995) In: Sharma B, Kulshreshtha VP, Gupta N, Mishra SK (eds) Genetic Research and Education: Current Trends and the Next Fifty Years. Indian Society of Genetics and Breeding, New Delhi, India, 1031-1034.

(36) Vaillancort RE, Slinkard AE (1992) Inheritance of new genetic markers in lentil (*Lens* Miller). Euphytica 64:227-236

Biotechnology and gene mapping in lentil

by Rebecca FORD[1]*, Barkat MUSTAFA[1], Prabhakaran SAMBASIVAM[1], Michael BAUM[2] and P.N. RAJESH

Abstract: Genomic tools and genetic mapping are assisting the understanding of the lentil genome and have made possible the use of marker assisted selection for breeding purposes. Although some important traits are conferred by single genes most are determined by quantitative trait loci (QTL) and influenced by environmental factors. Genes for several traits have been genetically mapped and shown to be linked to molecular markers. These include resistance to fusarium wilt, ascochyta blight, anthracnose, and stemphylium blight. Winter hardiness and tolerance to frost have also been mapped. It is now feasible to use the linked markers in a marker assisted selection breeding program. Proteomics and metabolomics are emerging technologies that can be used to better characterize the functional mechanisms behind breeding targets.
Key words: abiotic stress resistance, disease resistance, functional genes, genetic mapping, metabolomics, molecular markers, proteomics, quantitative trait loci, recombinant inbred lines

Introduction

Significant advances in the availability of genomics tools towards understanding the function and selection of specific components of the lentil genome have recently been made. Several advanced breeding programs worldwide have implemented and are currently using molecular assisted breeding technology. However, this has to date been limited to the selection of rather few traits, mostly likely due to lack of resources for broad validation and implementation. Nevertheless, high throughput marker generation and genotyping that is functionally associated, together with novel tools such as next generation sequencing and available genome maps, are illuminating the complex and intertwined nature of responses to biotic and abiotic stimuli in the lentil genome.

[1]The University of Melbourne, Sustainable Society Institute / Melbourne School of Land and Environment, Melbourne, Australia (rebeccaf@unimelb.edu.au)
[2]ICARDA, Aleppo, Syria
[3]USDA-ARS and Department of Crop and Soil Sciences, Washington State University, Pullman, USA

Genomics and functional gene identification

Global gene expression profiling at the mRNA level has been used to identify functionally-associated genes. Characterization of the RNA population under a particular environmental and/or developmental condition enables understanding of the dynamic functioning of genes as well as their mutual role in specific regulatory networks. This approach may be used to dissect regulatory mechanisms and transcriptional networks involved in defence responses to pathogen and physiological responses to abiotic stress such as drought, cold and salinity.

Differential gene expression methods include cDNA-amplified fragment length polymorphism (cDNA-AFLP) (1), suppression subtractive hybridization (SSH) (6), serial analysis of gene expression (SAGE) (30), differential display (18. 31), massively parallel signature sequencing (MPSS™) and microarray technology (25). Of these, microarrays have become the method of choice for large scale systemic analysis of differential gene expression profiling. This method is semi-quantitative, sensitive to low abundance transcripts that are represented on a given array and has been successfully used to study plant responses to various biotic and abiotic factors in *Arabidopsis thaliana* (3, 22, 26), *Medicago truncatula* (11, 17), soybean (*Glycine max*) (19, 28) and chickpea (*Cicer arietinum*) (5, 20).

Most recently, this method was used to elucidate the functional response to attack from Ascochyta blight, caused by *Ascochyta lentis* Vassilievsky, an important fungal disease worldwide (8).

Differentially expressed genes were identified among resistant (Ill7537) and susceptible (ILL6002) genotypes, which may serve as accurate selection tools in the future development of varieties with increased and sustainable resistance. For this, a cDNA microarray was used to observe substantial difference in functional category and timing of gene expression among the two genotypes, often referred to as the Pathogen/Microbe-Associated Molecular Pattern (P/MAMP). In particular, large differences were observed in early up-regulation of Resistance Gene Analogues (RGA; Figure 1), as well as several classes of mycotoxic producing genes such as PR4 and PR10. In ILL7537 (resistant), RGAs were switched on very early and quickly down regulated before being up-regulated again. Conversely, the same genes were up-regulated 24 hours later in ILL6002 (susceptible) and at much higher levels. Thus the question arises as to whether these genes act as 'surveillence molecules' or recognition/receptors to quickly initiate subsequent defence signalling cascades in the resistant genotype and it's a case of a little too much, too late in the susceptible genotype? Perhaps the failure to quickly recognise the invading pathogen prior to colonisation leads to the high susceptibility response.

Similarly, in the early stage of invasion, several other classes of defence responses are seen to be initiated much faster in the resistant ILL7537 genotype. In fact, the classic symptoms associated with an hypersensitive response (HR), such as browning of tissue and necrosis around the point of invasion, is not seen at all in ILL6002, and less frequently in ILL5588 (cv. Northfield; moderately resistant), when compared to ILL7537. Early evidence of this differential response is seen by tracking expression of superoxide dismutase, a enzyme used in the "mopping up" process of reactive oxygen species (ROS) following an oxidative burst, whereby the gene is expressed much sooner and at higher levels in ILL7537 than in ILL6002 (Figure 2).

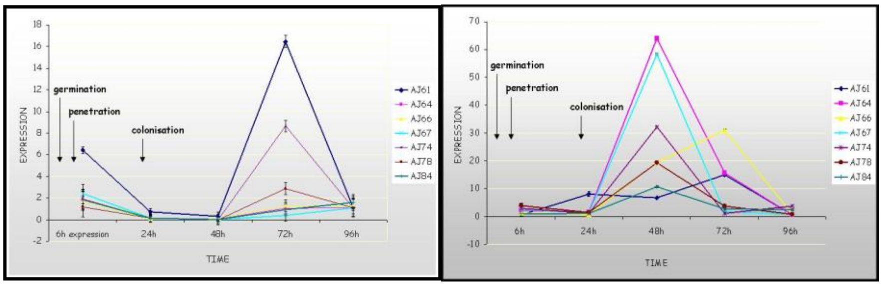


Figure 1. The differential timing of expression of RGA sequences among seedlings inoculated and un-inoculated with *Ascochyta lentis* (left) ILL7537 and (right) ILL6002 genotypes

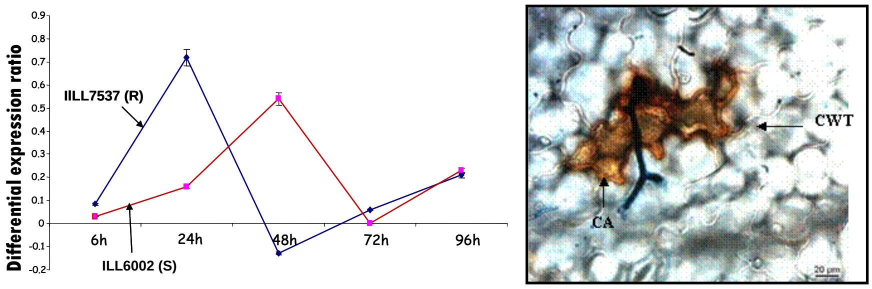


Figure 2. Evidence of (left) a differential early HR between ILL7537 and ILL6002 to Ascochyta lentis inoculation and (right) HR symptoms seen in ILL7537 including browning, necrosis, cell wall thickening (CWT) and cytoplasmic aggregation (CA).

A major current limitation of microarray technology for lentil is the lack of pre-requisite lentil-specific functional genome data (cDNA/EST sequences) to place as probes upon the arrays. However, several research teams (AgriFood, Canada and VicDPI, Australia) are preparing large lentil EST data sets, as well as developing single nucleotide polymorphism (SNP) markers that may be used for genotype-phenotype association and validation study. Once these tools are available, high-throughput functional genomic assessment using arrays will be next leap in lentil biotechnology towards faster, smarter and more sustainable trait selection. However, prior to the accurate use in selection programs of molecular markers, that have been functionally validated, their genomic positioning is required.

Mapping the lentil genome

Although some agronomically important traits are governed by single genes, most are governed by quantitative trait loci (QTL), influenced by both genetic and environmental factors. Since the expression of a QTL is likely to vary among populations and environments, their genomic location and effect must be determined for a specific genetic background and environment (2). The previous "orphan" status of the lentil genome has meant that most existing framework genome maps contain many non-functional RAPD, AFLP, ISSR and SSR-type markers, which are effective for saturating the entire genome but are not directly related to desirable traits or QTL. However, the newly developed gene/locus specific EST and SNP markers are reproducible and represent definite genomic regions. Their placement on existing maps will draw together the functional and physical association for ultimate accurate trait selection.

Mapping the lentil genome

Although some agronomically important traits are governed by single genes, most are governed by quantitative trait loci (QTL), influenced by both genetic and environmental factors. Since the expression of a QTL is likely to vary among populations and environments, their genomic location and effect must be determined for a specific genetic background and environment (2). The previous "orphan" status of the lentil genome has meant that most existing framework genome maps contain many non-functional RAPD, AFLP, ISSR and SSR-type markers, which are effective for saturating the entire genome but are not directly related to desirable traits or QTL. However, the newly developed gene/locus specific EST and SNP markers are reproducible and represent definite genomic regions. Their placement on existing maps will draw together the functional and physical association for ultimate accurate trait selection.

The current status of marker-assisted breeding

Using non-functional markers (7), there were first mapped five QTL for height of the first ramification, three for plant height, five for flowering, seven for pod dehiscence, one for shoot number and one for seed diameter. Subsequently, QTL have been identified conditioning winter survival and injury, however, only one of five QTL was expressed in all environments assessed. QTL conditioning resistance to ascochyta blight (23), stemphylium blight (24), rust and white mould have also been mapped. Also, the major QTL underpinning physical seed quality traits such as size, shape and colour have been mapped (Inder et al., Melbourne University, unpublished). However, ideally, the "candidate" gene(s) actually controlling a trait of interest would be used for marker-assisted selection (MAS). Hence, genomic regions where the trait is mapped should be characterized at high resolution (since recombination rates may vary at different genomic regions) and be validated across genetic backgrounds, in order to determine their utility in MAS and to potentially uncover the functional gene(s) themselves. This has been made more of a possibility with next generation sequencing of genomic fragments, such as BACs, associated with the QTL region of interest.

Table 1 Published genetic linkage maps for lentil; mapping populations and types of markers mapped

Population mapped	Marker types mapped	Citation
Interspecific F_2	RFLP, isozymes, morphological	Havey and Muehlbauer, 1989
Inter-subspecific RIL	RFLP, RAPD, AFLP	Eujayl *et al.*, 1998
Intraspecific F_2	RAPD, ISSR,	Rubeena *et al.*, 23
Intraspecific RIL	RAPD, ISSR, AFLP	Kahraman *et al.*, 24
Inter-subspecific F_2	RAPD, ISSR, AFLP, SSR	Durán *et al.*, 24
Inter-subspecific RIL	AFLP, SSR	Hamwieh *et al.*, 25
Intraspecific RIL	SSR, ITAP	Phan *et al.*, 27
Intraspecific RIL	SSR, RAPD, SRAP	Saha *et al.*, 2010

Table 2 Molecular markers closely associated with desirable lentil breeding traits for use in marker-assisted selection

Trait mapped	Associated molecular markers	Citation
Fusarium wilt resistance (*Fw*)	OPK15	Eujayl *et al.*, 1998
Ascochyta blight resistance (*AbR*1)	RV01, RB18, SCARW19	Ford *et al.*, 1999
Ascochyta blight resistance (*ral*2)	UBC227, OPD-10	Chowdury *et al.*, 2001
Ascochyta blight resistance (mapped as a QTL)	C-TTA/M-AC (QTL1 and QTL2), M20 (QTL3)	Rubeena *et al.*, 2003
Anthracnose resistance (*Lct*2)	OPE06, UBC704	Tullu *et al.*, 2003
Frost tolerance (*Frt*)	OPS-16	Eujayl *et al.*, 1999
Winter hardiness	UBC808-12	Kahraman *et al.*, 2004
Fusarium wilt resistance (*Fw*)	SSR59-2B, p17m30710	Hamwieh *et al.*, 2005
Stemphylium resistance	SRAP ME5XR10 and ME4XR16c	Saha *et al.*, 2010

Meanwhile, there are several markers available for different traits that have the potential for use in MAS and gene pyramiding (Table 2). These include SCARW19 and SCARB18 linked to and flanking the *Ab*R1 *A. lentis* resistance loci (27). These enabled successful pyramiding of the *Ab*R1 and *ral*2 *A. lentis* resistance loci together with the *LCt*2 *Colletotrichum truncatum* (anthracnose) resistance loci (23). Most recently the sequence related amplified polymorphism (SRAP) marker, ME4XR16c, has been validated for utility in selecting resistance to stemphylium disease (24).

The future of lentil biotechnology

Without doubt, reports using biotechnology approaches such as proteomics and metabolomics will soon begin to emerge for lentil, in order to discover and better characterize the functional mechanisms behind the breeding targets. This will include a thorough investigation of pathogen effector and host recognition factors involved in disease defence. In particular, the whole genome sequence of the *Ascochyta lentis* genome has recently become available and is currently being annotated (Ford and Lichtensvieg, unpublished). This will be searched for possible effector-related sequences in comparative studies for respective gene expression and protein/metabolite molecules to determine lentil host recognition factors. Also, it is envisaged that next generation sequencing technologies will uncover families of host transcription factors (i.e. *Myb* genes) and downstream genes that are key in the specific biochemical pathways for many stress tolerance and quality traits. With the advancement in functional genomics, expression QTL (eQTL) can be identified for the traits of interest by coupling global genome expression profiling and suitable genetic materials. Since eQTL affect the expression of the genes for the trait of interest, the markers linked to this eQTL will have enormous reliability in MAS compared to the markers identified by traditional QTL analysis. Ultimately, and with sufficient funding, precise formulation of superior and high yielding genotypes will emerge through the combination of lentil 'omics' approaches that will be delivered to a multitude of environments and market preferences. ■

References

(1) Bachem C, Oomen R, Visser R (1998) Transcript imaging with cDNA-AFLP: A step-by-step protocol. Plant Mol Biol Report 16:157-173
(2) Bagge M, Xia X, Lubberstedt T (2007) Functional markers in wheat. Curr Opin Plant Biol 10:211-216
(3) Cheong YH, Chang HS, Gupta R, Wang X, Zhu T. Luan S (2002) Transcriptional profiling reveals novel interactions between wounding, pathogen, abiotic stress, and hormonal responses in *Arabidopsis*. Plant Physiol 129:661–677
(4) Chowdhury MA, Andrahennadi CP, Slinkard AE, Vandenberg A (2001) RAPD and SCAR markers for resistance to ascochyta blight in lentil. Euphytica 118:331-337
(5) Coram TE, Pang ECK (2005) Isolation and analysis of candidate Ascochyta blight defence genes in chickpea. Part II: Microarray expression analysis of putative defence-related ESTs. Physiol Mol Plant Pathol 66:201-210
(6) Diatchenko L, Lau Y-FC, Campbell AP, Chenchik A, Moqadam F, Huang B, Lukyanov S, Lukyanov K, Gurskaya N, Sverdlov ED, Siebert PD (1996) Suppression subtractive hybridization: a method for generating differentially regulated or tissue-specific cDNA probes and libraries. Proc Nat Acad Sci USA 93:6025-6030
(7) Durán Y, Fratini R, García P, Vega MP (2004) An intersubspecific genetic map of *Lens*. Theor Appl Genet 108:1265–1273
(8) Mustafa BM, Coram TE, Pang ECK, Taylor PWJ, Ford R (2009) A cDNA microarray approach to decipher Ascochyta blight resistance in lentil. Australas Plant Pathol 38:617-631
(9) Eujayl I, Baum M, Powell W, Erskine W, Pehu E (1998) A genetic linkage map of lentil (*Lens* sp.) based on RAPD and AFLP markers using recombinant inbred lines. Theor Appl Genet 97:83-89
(10) Eujayl I, Erskine W, Baum M, Pehu E (1999) Inheritance and linkage analysis of frost injury in a lentil population of recombinant inbred lines. Crop Sci 39:639-642
(11) Fedorova M, van de Mortel J, Matsumoto PA, Cho J, Town CD, VandenBosch KA, Gantt JS, Vance CP (2002) Genome-wide identification of nodule-specific transcripts in the model legume *Medicago truncatula*. Plant Physiol 130:519-537
(12) Ford R, Pang ECK, Taylor PWJ (1999) Genetics of resistance to ascochyta blight of lentil and the identification of closely linked markers. Theor Appl Genet 98:93–98
(13) Gupta D, Taylor PWJ, Inder P, Oliver R, Ford R (submitted/unpublished). Integration of EST-SSR markers of *Medicago truncatula* to intraspecific linkage map of lentil and identification of QTL conferring resistance to blight at seedling and pod stage.
(14) Hamwieh A, Udupa SM, Choumane W, Sarker A, Dreyer F, Jung C, Baum M (2005) A genetic linkage map of lentil based on microsatellite and AFLP markers and localization of Fusarium vascular wilt resistance. Theor Appl Genet 110:669–677
(15) Havey MJ, Muehlbauer FJ (1989) Linkages between restriction fragment length, isozyme, and morphological markers in lentil. Theor Appl Genet 77:395–401
(16) Kahraman A, Kusmenoglu I, Aydin N, Aydogan A, Erskine W, Muehlbauer FJ (2004) QTL mapping of winter hardiness genes in lentil. Crop Sci 44:13–22
(17) Kuster H, Hohnjec N, Krajinski F, El Yahyaoui F, Manthey K, Gouzy J, Dondrup M, Meyer F, Kalinowski J, Brechenmacher L, van Tuinen D, Gianinazzi-Pearson V, Puhler A, Gamas P, Becker A (2004). Construction and validation of cDNA-based Mt6k-RIT macro- and microarrays to explore root endosymbioses in the model legume *Medicago truncatula*. J Biotechnol 108: 95-113
(18) Liang P, Pardee A (1992) Differential display of eukaryotic messenger RNA by means of the polymerase chain reaction. Sci 257:967 971
(19) Maguire TL, Grimmond S, Forrest A, Iturbe-Ormaetze I, Meksem K, Gresshoff P (2002) Tissue-specific gene expression in soybean (*Glycine max*) detected by cDNA microarray analysis. J Plant Physiol 159:1361-1374
(20) Mantri NL, Ford R, Coram TE, Pang ECK (2007) Transcriptional profiling of chickpea genes differentially regulated in response to high-salinity, cold and drought. BMC Genomics 8:303
(21) Phan HTT, Elwood SR, Hane JK, Ford R, Materne M, Oliver RP (2007) Extensive macrosynteny between *Medicago truncatula* and *Lens culinaris* ssp. *culinaris*. Theor Appl Genet 114:549-558
(22) Reymond P, Weber H, Damond M, Farmer EE (2000) Differential gene expression in response to mechanical wounding and insect feeding in *Arabidopsis*. Plant Cell 12:707–719
(23) Rubeena, Ford R, Taylor PWJ (2003) Construction of an intraspecific linkage map of lentil (*Lens culinaris* ssp. *culinaris*). Theor Appl Genet 107:910–916
(24) Saha GC, Sarker A, Chen W, Vandemark GJ, Muehlbauer FJ (2010) Inheritance and linkage map positions of genes conferring resistance to stemphylium blight in lentil. Crop Sci 50:1831-1839
(25) Schena M, Shalon D, Davis R, Brown P (1995) Quantitative monitoring of gene expression patterns with a complimentary DNA microarray. Sci 270:467-470
(26) Seki M, Narusaka M, Ishida J, Nanjo T, Fujita M, Oono Y, Kamiya A, Nakajima M, Enju A, Sakurai T, Satou M, Akiyama K, Taji T, Yamaguchi-Shinozaki K, Carninci P, Kawai J, Hayashizaki Y, Shinozaki K (2002) Monitoring the expression profiles of 7000 *Arabidopsis* genes under drought, cold and high-salinity stresses using a full-length cDNA microarray. Plant J 31:279–292
(27) Tar'an B, Buchwaldt L, Tullu A, Banniza S, Warkentin T, Vandenberg A (2003) Using molecular markers to pyramid genes for resistance to ascochyta blight and anthracnose in lentil (*Lens culinaris* Medik). Euphytica 134:223–230
(28) Thibaud-Nissen F, Shealy RT, Khanna A, Vodkin LO (2003) Clustering of microarray data reveals transcript patterns associated with somatic embryogenesis in soybean. Plant Physiol 132:118-136
(29) Tullu A, Buchwaldt L, Warkentin T, Taran B, Vandenberg A (2003) Genetics of resistance to anthracnose and identification of AFLP and RAPD markers linked to the resistance gene in PI 320937 germplasm of lentil (*Lens culinaris* Medikus). Theor Appl Genet 106:428–434
(30) Velculescu VE, Ahang L, Vogelstein B, Kinzler KW (1995) Serial analysis of gene expression. Sci 270:484-487
(31) Walsh J, Chada K, Dalal S, Cheng R, Ralph D, McClelland M (1992) Arbitrarily primed PCR fingerprinting of RNA. Nucleic Acids Res 20:4965 -4970

Lentils – the little seeds with the big impact on human health

by Bert VANDENBERG

Abstract: People like eating lentil as evidenced by production increases from about 1 million tons in 1960 to over 4 million tons today. Besides excellent food value, lentil combined with rice provides a quickly prepared meal that is well balance nutritionally. The balance continues with micro nutrient concentrations where the combination of rice and lentil overcome deficiencies of either food alone. Lentil also contains nutritionally significant amounts of selenium, a nutrient not needed by plants but required by humans. On a global scale, lentil consumption is rising at a rate more than twice that of human population growth. Among the cool season pulses, it is by far the fastest growing crop while many of the others are actually in decline. Newly developed products such as the Genki energy bar is an example of potential wider use of the wholesome lentil.

Key words: human health, micronutrients, minerals, nutritional components, vitamins

Lentil was domesticated in the Fertile Crescent like pea, faba bean and chickpea. It has always been considered a minor pulse crop. In the 1960s global production was estimated at about 1 million tonnes at a time that world human population was about 3.3 billion. Today there are 6.7 billion people and we product about 4 million tonnes of lentils. Conclusion? People like to eat lentils – consumption is rising faster than human population growth and this is definitely not the case for many of the other legume crops.

Why are people eating more lentils? One of the important factors may simply be the fact that lentils cook very quickly – this saves time and fuel. Both of these factors are very influential in the behavior patterns of humans these days. Dehulled lentils cook even faster than milled rice. But could it also be that people so have to do with recognition that lentils are linked to better health.

Together rice and lentils make a quickly prepared meal that is well balanced nutritionally. Cereals and legumes eaten together create a mixture that has better protein balance. As an example the high lysine of legume seed proteins balances the lysine deficiency of cereal seed proteins. Many studies in nutrition and biochemistry have explored complementarity of protein components in great detail. We also know that on all continents, these facts were incorporated into dietary customs – corn with beans in the Americas, sorghum with cowpea in Africa, various types of wheat with faba beans, peas, lentils and chickpeas in Europe and the Middle East, rice with many tropical legumes like pigeon pea, black gram and green gram in Asia. Complementary proteins are high quality proteins that are essential in the human body for making our own proteins. The protein in the human body is obviously important for anything related to muscles. The human body is also reported to have more than 50,000 different enzymes which are made primarily of proteins - so eating good quality balance protein is important.

Figure 1. A Genki energy bar based on lentil

University of Saskatchewan, Crop Development Centre, Saskatoon, Canada (bert.vandenberg@usask.ca)

But the balancing act continues at the level of micronutrients – for example, milled rice is relatively low in iron, zinc and beta carotene which are important fundamental micronutrients in human nutrition. Iron is required for the proper function of enzymes involved in oxygen transport, regulation of cell growth, and differentiation of cells. Zinc has antioxidant properties and is necessary for DNA replication, protein synthesis, oxidative stress reduction, and protection against brain tumors. Lentils contain significant quantities of iron and zinc – recent research indicates that 50 g of lentils (a bowl of soup) grown in the central areas of North America contain a minimum of 20-50% of the daily requirement for iron and a minimum of 20-30% of the daily requirement for zinc. Lentils are also relatively low in phytates, a condition which improves the availability of iron and zinc in human nutrition.

An interesting recent discovery is that lentils may also contain nutritionally significant levels of selenium. Plants don't need it, but humans do. Adequate dietary selenium is important for enzyme activity, antioxidants, and protective physiological pathways that are associated with cancer suppression, HIV treatment, suppression of free radical induced diseases, and protection from toxic heavy metal toxicity. Research in Italy on the muscle strength of older people showed that those who consumed sufficient amounts of selenium had much stronger muscles. Over the past decade public health concerns about inadequate intake of selenium, have increased, especially in Europe, where agricultural soils are deficient in this essential micronutrient. In soils where selenium is in plentiful supply because they were formed on old sea beds, like the central part of North America, the same bowl of lentil soup can supply 60-70% of the daily requirement for selenium recommended in Europe.

Carotenoid pigments, including beta-carotene, are also present in lentil seeds. Beta-carotene helps prevent night blindness and other eye problems, skin disorders, enhance immunity, and also protects against toxins and cancer formations, colds, flu, and infections. It is an antioxidant and protector of the cells. Right now scientists are researching the specific types of carotenes and the quantities that are available in lentil to see if they can be increased by plant breeding.

A study of dietary habits of more than 78,000 women in the US, recently published in the *American Journal of Clinical Nutrition*, found that higher spending on food is associated with healthier diets, but the authors claim it is possible to improve diets without increased spending. *"The purchase of plant-based foods may offer the best investment for dietary health"* was one of the conclusions. Foods like lentil are an excellent fit in this type of diet, which leads to lower rates of cardiovascular disease, lower rates of angina, and lower rates of type-2 diabetes and hypertension.

One of the most intriguing qualities of lentils is that the balance of about ¼ protein and ¾ carbohydrate and fiber is ideal for regulating blood sugar – a low glycemic index. This can translate into more effective control of appetite so that people eat less between regular meals. But even more interesting is the effect that this combination of nutrients has on athletic performance, especially in endurance sports like Nordic skiing, long distance running and also for the world's most popular sport, *football!!*

Researchers in Canada have investigated the effects of eating lentils before a football game in comparison to potato and pasta. All athletes were asked to run on a programmed treadmill for 75 minutes using a simulated soccer game – combinations of running, walking and sprinting. In the last 15 minutes, the program was stopped and they were asked to sprint as much as they could. This simulated a real football match where most of the important goals are scored in the last 15 minutes and this is the reason that teams wait until then to use substitute players. Well it turned out that lentil eaters had excellent sprinting and recovery ability compared to other diets based on the carbohydrate-protein balance combination that exists in lentil. A natural energy food! This concept is now being marketed by at least one small company that has developed a lentil based energy bar for endurance athletes – see www.genkibar.com for details (Fig. 1). "Team Lentil" recently used these energy bars to great success at the football tournament held at the joint meeting of the International Food Legume Research Conference – European Conference on Grain Legumes at Antalya. Even more impressive is that for the past two World Cups, this author has successfully predicted the outcomes of all matches between the 8 finalists based on per capita lentil consumption!!

On a global scale, lentil consumption is rising at at a rate more than twice that of human population growth. Among the cool season pulses, it is by far the fastest growing crop – many of the others are actually in decline. We expect that by 2030, world lentil consumption will double. This projection may even be low if the benefits associated with eating lentils and the convenience of preparing them in whole food dishes is effectively communicated to a wider audience. ■

Tannin free lentils: A promising development for specialty use and increased value

by Fred MUEHLBAUER[1]* and Ashutosh SARKER[2]

Abstract: Tannin free lentils have been developed and are now available for production over a wide area in North America. The trait is controlled by a single recessive gene that eliminates tannin precursors in the seeds thereby making it possible to prevent the development of darkened seeds. Lentil varieties that are tannin free represent a new type that may appeal to specialty markets. Varieties with the zero-tannin trait have been released in Canada ('CDC Gold') and the U.S. ('Shasta' and 'Cedar'). The red cotyledon Cedar variety could possibly be used in place of commonly decorticated and split red lentils. Acceptance on a wide scale is still to be determined.

Key words: lentil, tannins, testa color, specialty type

Seed size, shape and color are the basis of consumer preferences and overall lentil marketing strategies. Differences in taste and texture between red and yellow cotyledon types and between whole or decorticated lentils determine consumer preferences, marketing strategies and prices. Nearly all lentil varieties in use in the world at the present time have seed coats that will darken upon long term storage and also when cooked. In nearly all cases, tannin precursors in the seed coats of whole lentils will cause the cooking solution and the lentils themselves to become brown or dark brown upon being cooked. This situation is often avoided by the process of removing the seed coats (decortication) and splitting of the lentil seeds. Consequently, many users prefer lentils that have been decorticated thus removing the source of discoloration of not only the lentil seeds but the cooking liquid as well. Elimination of the tannin precursors in the seed coats would prevent darkening of the whole seeds and the cooking solution during preparation. An interesting recessive gene for zero tannin was found in accession P.I. 345635 of the U.S. Department of Agriculture world collection of lentil germplasm (1). Seeds of that accession were observed not to darken when kept in storage for extended periods of time or when cooked. The recessive gene designated as *tan* was shown to eliminate the content of tannin precursors responsible for darkening during the cooking process or darkening when kept in long term storage.

Commonly used lentil varieties have polyphenolic compounds (tannin precursors) that slowly oxidize when exposed to air and progressively turn brown. Cooking also has the effect of turning the seed coats brown and also to darken the cooking solution. In the case of P.I. 345635, these precursors are not present and consequently they do not darken during storage or cooking. The *tan* gene appears to be associated with a thin and somewhat opaque seed coat that causes difficulties at planting time through poor plant establishment due to increased pathogen attack and susceptibility to cold temperatures during germination. Effective breeding for thicker seed coats among zero-tannin selections and the judicious use of fungicides to prevent pre-emergence damping off should successfully overcome these problems.

The great promise of zero-tannin lentil lies in the unique nature of the trait and the visually desirable appearance of the seeds. With the lack of seed coat pigmentation, cotyledon color is visible through the slightly opaque seed coats. In addition, it has been suggested that varieties with the zero-tannin trait may not require decortication to improve cooking time and appearance before and after cooking. The direct use of zero-tannin varieties by consumers without the need for decortication would reduce processing costs as well as a certain percentage of processing loss.

[1]USDA-ARS, Washington State University, Pullman, USA (muehlbau@wsu.edu)
[2]ICARDA, Aleppo, Syria

Progress has been made in breeding zero-tannin types in Canada and the U.S. with several varieties already available to producers. The first zero-tannin variety, 'CDC Gold', was released in Canada; while two varieties, 'Shasta' and 'Cedar', have been released in the U.S. Shasta has yellow cotyledons and Cedar has red cotyledons. Comparisons of seeds of Shasta and Cedar with a conventional red cotyledon variety 'Redberry' are shown below (Fig. 1). These varieties have comparable yields to conventional varieties provided seed treatment fungicides are applied to prevent seed rotting and ensure an adequate plant population.

Zero-tannin lentils are expected to be appealing to certain markets and uses. In the case of the red types, they could be used without decortication in the food preparations in South Asia and other places. They could be used effectively to avoid the processing losses inherent with the decortication process and possibly be more nutritious due to the presence of the relatively seed coat. However, the main advantage would be reduced costs to consumers. Another possible use of zero-tannin lentil would be in dry soup mixes. The zero-tannin lentil would impart a brighter appearance to the dry mix and when prepared would not turn the preparation dark brown typical of conventional lentils. ■

References

(1) Matus A, Slinkard AE, Vandenberg A (1993) The potential of zero tannin lentil. In: Janick J, Simon JE (eds) New Crops. Wiley, New York, USA, 279-282

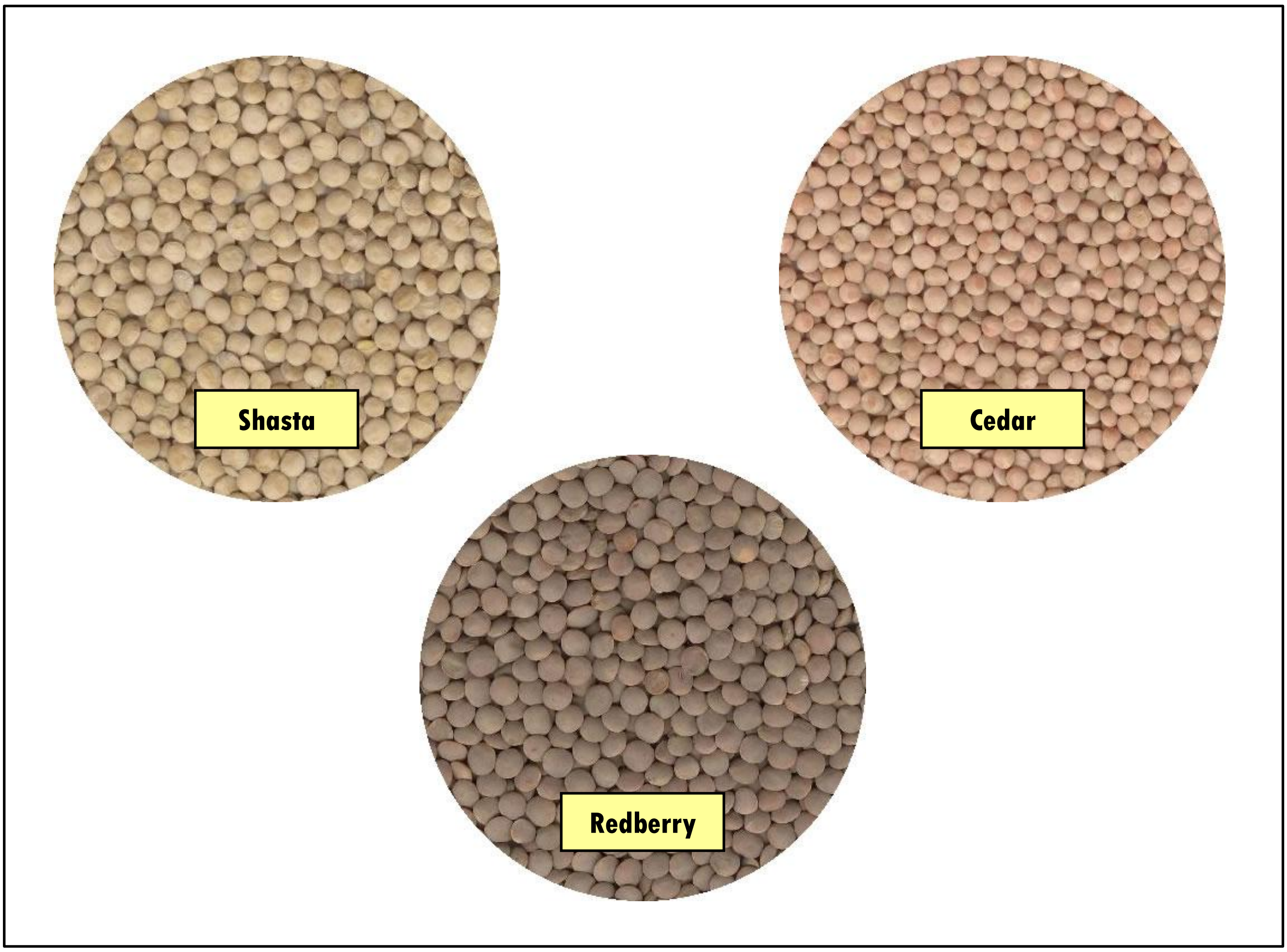


Figure 1. Comparisons of seeds of Shasta and Cedar with a conventional red cotyledon variety 'Redberry'

Lentil (*Lens culinaris*) as a biofortified crop with essential micronutrients: A food-based solution to micronutrient malnutrition

by Dil THAVARAJAH[1]* and Pushparajah THAVARAJAH[2]

Abstract: The nutritional benefits of pulses have long been recognized. However, intensive work recently carried out on lentil within global mineral biofortification efforts has highlighted its superior nutritional profiles: lentils are a rich source of highly bioavailable minerals and other micronutrients and are naturally low in phytates. Lentils could be an ideal crop for micronutrient biofortification in countries other than North America. They are a rich source of protein as well as essential minerals, beta-carotene, dietary fiber, and folate. Our future research on lentil will focus on further increasing mineral bioavailability; this may be of increasing importance with rising food prices and smaller portion sizes for the billions of impoverished people worldwide who have minimal access to nutritious foods.

Key words: biofortification, minerals, nutrition, vitamins

Micronutrient malnutrition affects more than two billion people worldwide. Particularly vulnerable are women and preschool children in south Asia, Africa, and Latin America. Solutions to micronutrient malnutrition have included food fortification, dietary supplementation, and agronomic-fortification of staple crops, but such programs have had limited success to date. Sustainable solutions to micronutrient malnutrition call for approaches linking food systems with the dietary needs of people. Micronutrient rich pulse crops, such as lentil, field pea, and chickpea, may provide an answer to global micronutrient malnutrition.

Lentil is a traditional pulse crop mostly grown in low-rainfall, dryland cropping systems in rotation with wheat and rice. Lentil was first identified in the Near East countries of western Asia between the Mediterranean and Iran, and has been part of the human diet since 8500 BC. Currently, annual world lentil production is approximately 4 million tonnes (MT), more than 85% of which occurs in five specific regions: India, Nepal, and Bangladesh (32%); western Canada (29%); Turkey and northern Syria (18%); Australia (4%); and, as an emerging crop, in the upper Midwest of USA, including North Dakota, South Dakota, and eastern Montana (3%) (8). North American lentils, encompassing several diverse market classes, are exported to more than 100 countries in Europe, the Middle East, Africa and Asia (5).

Lentil consumption over the past 40 years has increased more than other food crops. This is likely due to the convenience of short cooking time and the consequent saving in the costs of cooking fuel. Moreover, lentil requires less processing when compared to soyabeans and cereals. Lentils are rich in protein (20-30%), complex carbohydrates, and dietary fiber, and are an excellent source of a large range of micronutrients. Our research group has been working with lentil as a model crop for biofortification. Biofortification is a new approach that relies on conventional plant breeding to increase the micronutrient concentration of staple food crops (4). This approach holds great promise for improving the nutritional, health, and socioeconomic status of people around the world. One of our key research goals at the North Dakota State University - Pulse Quality and Nutrition Program is to understand the genetic potential for biofortification of lentil, field pea, and chickpea for key bioavailable micronutrients to combat global micronutrient malnutrition. In this article, we provide an overview of selenium (Se), iron (Fe), zinc (Zn), and other micronutrient concentrations in lentil; review the role of antinutrients on mineral bioavailability; share preliminary results of our clinical trial work; and describe key agronomic and climatic factors that may limit global biofortification efforts.

[1]North Dakota State University, School of Food Systems, Fargo, USA
(dilrukshi.thavarajah@ndsu.edu)
[2]North Dakota State University, Department of Plant Sciences, Fargo, USA

Selenium

Selenium is an essential micronutrient, the nutritional benefits of which were first reported in 1957. Since then, Se roles in enzymes, cofactors, antioxidants, and protective pathways have been discovered. The recommended daily allowance (RDA) of 55 μg of Se day^{-1} is generally met by North Americans. However, an estimated 30-100 million people are Se deficient, mainly due to low concentrations of Se in commonly eaten foods (3). Low intake of dietary Se is likened to arsenic poisoning in Bangladesh, juvenile cardiomyopathy (heart problems) in China, poor skeletal muscle strength in adults, infections, chronic heart failure, and prostate and bladder cancer (5). Intakes of 400 μg of Se per day reduce prostate cancer risk (2) and hundreds of animal studies indicate Se inhibits the formation or growth of tumors, and thus reduces cancer risk through several cellular and metabolic mechanisms (3).

Lentils grown in North America are a rich source of bioavailable Se. The total Se concentration in lentils grown in Canada ranges between 425 and 673 μg kg^{-1}, with 100 g of dry lentils providing 77-122% of the RDA (5). Our recent research with North Dakota-grown lentils shows they are rich in Se, with concentrations ranging between 500 and 1500 μg kg^{-1} (unpublished data). Most Se in lentil seeds is concentrated in the embryo axis (3600 μg kg^{-1}), compared to the cotyledon (2800 μg kg^{-1}) and seed coat (2600 μg kg^{-1}). The chemical speciation of Se in lentils governs both bioavailability and projected health benefits. Almost all the Se (86-95%) in lentil is present in bioavailable organic forms, as selenomethionine with a smaller amount (5-14%) as selenate (5). Moreover, several other organic Se forms, including selenocysteine, selenooligopeptides such as γ-glutamylselenocysteine, and other anti-cancer Se compounds, may be present in lentil seeds (unpublished data). Enrichment of lentil with Se forms found to provide unique health benefits in the prevention of certain forms of cancers might offer unique marketing opportunities for northern USA grown lentils.

The Se concentration of lentil varies with soil Se content. A survey of Se concentrations in lentil genotypes grown in eight major regions of the world indicated considerable variation; countries producing lentils with very low Se concentrations include Nepal and Australia (180 and 148 μg kg^{-1}, respectively) and Syria, Morocco, and Turkey (22, 28, and 47 μg kg^{-1}, respectively). Soil application of selenium might be necessary for developing countries to maximize the Se nutritional quality of their lentil crops. The addition of Se to Finnish fertilizer (16 ppm as sodium selenate) used since 1984 for major food crops has resulted in an increase in Finnish people's daily Se intake from 39 to 110 μg of Se per day (9). Similar approaches may effectively increase the Se status of people from countries with low soil and seed Se concentrations.

Iron and zinc

Iron is an essential element for all life forms and for normal human physiology. It is an integral part of many proteins and enzymes and is essential for oxygen transport, regulation of cell growth, and differentiation. Zinc exhibits antioxidant properties and is necessary for protein synthesis, DNA replications, proper sense of taste and smell, and oxidative stress reduction; it also protects against brain tumors. Estimates indicate that over 60% of the world's 6 billion people are Fe deficient, and over 30% are Zn deficient. Health issues related to Fe and Zn deficiencies are prevalent in both developed and developing countries. A major contributing factor to Fe deficiency is the consumption of staple foods that are low in bioavailable Fe.

Research in Canada has highlighted the micronutrient value of pulse crops (8). The total Fe concentration ranged from 73 to 90 mg of Fe kg^{-1}. For example, 100 g of lentils can provide a minimum of 91-113% of the RDA of Fe for males and 41-50% for females. Cell culture study results indicate that more of the Fe in lentils is bioavailable than in common bean, wheat, or finger millet. Zn concentrations in lentils range from 44-54 mg of Zn kg^{-1}, with a 100 g serving providing 40-49% of the RDA of Zn for males and 55-68% for females. Therefore, lentils are an excellent natural food source of these essential minerals.

Similar to Se, Fe and Zn concentrations in lentils vary with soil mineral content. The highest Fe concentrations are found in lentils grown in Syria (63 mg/kg), Turkey (60 mg /kg), USA (53 mg/kg), and Nepal (50 mg/kg), and the lowest in Australia (46 mg/kg) and Morocco (42 mg/kg); for Zn, lentils grown in Syria (36 mg/kg), Turkey (32 mg/kg), and USA (28 mg/kg) have the highest concentrations and Australia (18 mg/kg) and Morocco (27 mg/kg) the lowest (unpublished data). The release of high Fe and Zn lentil varieties by ICARDA with Harvest Plus in 2005 might have led to the higher levels in Syrian crops (1). Results from North America and Syria indicate increases in the content of these micronutrients in lentil can be achieved in other regions through genetic biofortification. Broad-sense heritability estimates for these elements are high, indicating it is possible to breed lentil cultivars with enhanced ability to accumulate Fe and Zn in seed despite environmental influences.

Potassium, magnesium, calcium, manganese and copper

More than half the people in the world have diets that are deficient in one or more essential mineral elements. Populations largely dependent on cereal diets are often deficient in minerals such as potassium (K), magnesium (Mg), calcium (Ca), manganese (Mn), and copper (Cu). We studied the potential of lentil as a dietary source of these minerals and demonstrated that lentils are a good source of K (9063-9825 mg/kg), Mg (911-1087 mg/kg), Mn (10.8-16.4 mg/kg), and Cu (6.9-9.3 mg/kg). Consumption of 50 g of lentil could provide 10 to 58% of the dietary reference intakes for these four essential nutrients. Genotype effects for Ca, Mg, K, Mn, and Cu indicate good potential to enhance the content of these micronutrients in lentil seeds. Genetic factors conferring lentil element uptake appear to be largely element specific; hence, the significant genetic variability could be exploited by focusing on individual elements. Concentrations of all these micronutrients could be further increased by appropriate genetic selection and development through plant breeding. The lentils we evaluated were generally not a good source of Ca; however, some genotypes (CDC Rouleau; 432 mg/kg and CDC Redberry; 377 mg/kg) contained notably higher concentrations of Ca in their seeds than others, and could be targeted in efforts to select for this particular micronutrient. Significant genotype × location interactions observed for other micronutrients may be due to variable soil conditions (moisture, aeration, fertilizer application, and soil pH), weather conditions (rainfall and temperature), or other crop management practices.

Beta-carotene

Carotenoids are a group of naturally occurring lipophilic pigments found in fruits and vegetables. Common provitamin A carotenoids found in plant-based foods are beta-carotene, alpha-carotene, and beta-cryptoxanthin. The vitamin A family, including retinol, retinal, and retinoic acid, plays an important role in vision, bone growth, reproduction, cell division, and cell differentiation in humans. Approximately 3 million children around the world develop xerophthalmia (damage to the cornea of the eye) and more than half a million of children lose their sight every year as a result of vitamin A deficiency. Pulses are naturally rich in carotenoids. Our preliminary analyses indicate that pulses grown in North America have a significant amount of beta-carotene, ranging from 2 to 12 $\mu g\ g^{-1}$ for lentils and from 1 to 6 $\mu g\ g^{-1}$ for field peas. Therefore, consumption of 100 g of lentils could potentially provide daily beta-carotene requirements.

Phytic acid

Phytic acid (PA) is an antinutrient present mainly in the seeds of legumes and cereals. It has the potential to bind mineral micronutrients in food and reduce their bioavailability. Phytate-mineral complexes are not absorbed across the intestinal mucosa, resulting in low bioavailability of Fe and Zn. Fiber, tannins, oxalic acid, goitrogens, and heavy metals are also considered antinutrients. Low phytic acid crops have been developed to reduce PA concentrations in staple foods including rice, soybean, wheat, maize, and common bean. The total phytic P levels of these phytic mutants fall within ranges of 1.22-2.23 mg/g for rice, 1.77-4.86 mg/g for soybean, 1.24-2.51 mg/g for wheat, 3.3-3.7 mg/g for maize, and 0.52-1.38 mg/g for common bean. However, lentils are naturally low in PA (PA=2.5-4.4 mg/g, phytic P=0.7-1.2 mg/g), with concentrations lower than those reported for low phytic acid mutants. Processing, such as decortication (removing the hull), and regular cooking further reduces the total PA concentration by >50% (6). Therefore, minerals in lentil are not only highly bioavailable (e.g., Se, Fe), but inclusion of lentils in regular diets could also significantly reduce the impact of antinutrients on micronutrient absorption.

Lentil production environments significantly affect PA and other micronutrient concentrations. Among the environmental factors, temperature has a substantial effect on PA synthesis in lentils. Lentil PA concentration increases when lentil plants are exposed to rising temperatures during seed filling (7). Accordingly, lentils grown under cooler or temperate climates, such as in Saskatchewan, Canada, and North Dakota, USA, remain a good source of Fe and Zn but with low concentrations of PA. Thus, lentil production region might influence total PA levels and hence the bioavailability of mineral micronutrients.

Clinical trial evidence

Lentil is an important staple crop in many developing countries. Sri Lanka is a developing country with 19.7 million population and dehulled split red lentil is the main pulse consumed. Sri Lanka currently imports 100,000 MT of lentils from Turkey, India (until 2007), Canada, Australia, and other minor lentil exporting countries. We conducted a clinical study to assess changes in blood Se concentrations in two groups of healthy children before and after consumption of lentils. This study was conducted in 2009-2010 at the Lady Ridgeway Hospital for Children in Colombo, Sri Lanka, with 60 children aged 5-15 years. One group of children received 50 g of cooked lentil meals prepared from local market lentils (30 μg of Se kg^{-1}) while the second group was served Canadian-grown red lentils (727 μg of Se kg^{-1}) for 1-30 days. The group fed with the Canadian red lentils had significantly higher blood Se concentrations (82 ppb) compared to the group of children fed with local lentils (64 ppb) 2 hours after the lentil meal. Lentil type (Canadian vs. local market), treatment (before lentil meal, 2 hours after lentil meal, 30 days after lentil diet), and treatment × lentil type interactions were significant. Thus, incorporation of Se-rich lentils in the diets of Sri Lankan children has the potential to improve their Se nutrient status. Overall, lentil may be a target crop for Se biofortification and should be investigated further as a food-based solution to combat global micronutrient malnutrition (8).

Conclusion

The nutritional benefits of pulses have long been recognized. However, intensive work recently carried out on lentil within global mineral biofortification efforts has highlighted its superior nutritional profiles: lentils are a rich source of highly bioavailable minerals and other micronutrients and are naturally low in phytates. Lentils could be an ideal crop for micronutrient biofortification in countries other than North America. They are a rich source of protein as well as essential minerals, beta-carotene, dietary fiber, and folate. Our future research on lentil will focus on further increasing mineral bioavailability; this may be of increasing importance with rising food prices and smaller portion sizes for the billions of impoverished people worldwide who have minimal access to nutritious foods. Would 10 to 25 g of cooked lentil provide daily requirements of Fe, Zn, Se, beta-carotenes, and other micronutrients? This reality may be within reach!!! ■

Acknowledgements

Funding for work presented was received from the Saskatchewan Pulse Growers Association, SK, Canada; the Northern Pulse Growers Association, ND, USA; and North Dakota State University, ND, USA. We also greatly appreciate research comments and critical scientific inputs received from Dr. Jerry Combs Jr., ARS/USDA Grand Forks Human Nutrition Centre, ND, USA and international collaborators.

References

(1) Baum M, Hamwieh A, Furman B, Sarker A, Erskine W (2008) Biodiversity, genetic enhancement and molecular approaches in lentil. In: Sharma AK, Sharma A (eds) Plant Genome, Biodiversity and Evolution, 1, E, Phanerogams – Angiosperm. Science Publishers, 135-156
(2) Clark LC, Combs GF Jr, Turnbull BW, Slate EH, Chalker DK, Chow J, Davis LS, Glover RA, Graham GF, Gross EG, Krongrad A, Lesher JL Jr, Park HK, Sanders BB Jr, Smith CL, Taylor JR (1996) Effects of selenium supplementation for cancer prevention in patients with carcinoma of the skin. A randomized controlled trial. Nutritional Prevention of Cancer Study Group. J Am Med Assoc 276:1957-1963
(3) Combs GF Jr (2001) Selenium in global food systems. British Journal of Nutrition 85:517-547
(4) HarvestPlus (2010) http://www.harvestplus.org/
(5) Thavarajah D, Ruszkowski J, Vandenberg A (2008) High potential for selenium biofortification of lentils (*Lens culinaris* L.). J Agric Food Chem 56:10747-10753.
(6) Thavarajah D, Thavarajah P, Sarker A, Vandenberg A (2009) Lentils (*Lens culinaris* Medikus subsp. culinaris): A whole food for increased iron and zinc intake. J Agric Food Chem 57:5413-5419
(7) Thavarajah D, Thavarajah P, See C-T, Vandenberg A (2010) Phytic acid and Fe and Zn concentration in lentil (*Lens culinaris* L.) seeds is influenced by temperature during seed filling period. Food Chemistry 122, 254-259.
(8) Thavarajah D, Thavarajah P, Wejesuriya A, Rutzke M, Glahn RP, Combs GF Jr, Vandenberg A (2011) The potential of lentil (*Lens culinaris* L.) as a whole food for increased selenium, iron, and zinc intake: Preliminary results from a three year study. Euphytica 180 :123-128
(9) Wang W-C, Näntö V, Mäkelä A-L, Mäkelä P (1995). Effect of nationwide selenium supplementation in Finland on selenium status in children with juvenile rheumatoid arthritis. A ten-year follow-up study. Anal 120:955-958

Winter lentil for cold highland areas

by Abdulkadir AYDOĞAN

Abstract: Winter lentil offers advantages of crop establishment during dryer and more favorable soil conditions in the fall rather in soils that are cold and wet typical of spring sowing conditions. With the availability of winter hardy germplasm, varieties were developed with sufficient hardiness to survive most winters in cold highland areas. There is a continued need for additional research on agronomic aspects of winter lentil production and also a critical need for weed control. Controlling weeds in winter lentil is a major obstacle to its more widespread use in production systems. Continuous emergence of problem weeds throughout the winter season is seen as a serious problem. The substantial yield advantages of winter lentil warrant continued research and development of the technology.
Key words: cropping systems, no till, phenology, reduced tillage, winter hardiness

Lentil (*Lens culinaris* Medik. ssp. *culinaris*) is one of the world's oldest cultivated plants. It was domesticated in the 'Fertile Crescent' of the Near East over 7000 years ago. It is used as a grain in the human diet to supplement protein requirements, especially for those who cannot afford animal protein. Food legumes have been referred to as the 'poor man's meat' implying a meat substitute and associated with poverty. They are considered a meat substitute based on protein concentrations of 24-29%.

Lentil is cultivated commonly as a spring crop in the high altitude areas (>850 m elevation) of West Asia and North Africa (WANA). The average yield of the spring–sown crop is lower than winter–sown crop. However, shifting of lentil sowing time from spring to winter requires cold tolerant cultivars for successful over-wintering of the crop.

Highland farming systems are characterized by cereal mono-cropping and cereal-fallowing. This farming system is practiced in all highland areas. The tendency to increase cereal mono-cropping, a non-sustainable system, calls for research to introduce a legume into this system, and lentil is a potential option. Lentil, therefore, has great potential for replacing traditional fallow and improving sustainability of the farming system.

Production environment of lentil

Lentil is suitable for cultivation in warm temperate, subtropical and high altitude tropical regions of the world. It grows well on slightly acidic (5.5-6.5 pH) to moderately alkaline (7.5-9.0 pH) soils. However, it shows best production performance at neutral pH. Lentil is grown on a variety of soils ranging from sandy loam to clay-loam. However, loam soils are best suited for lentil cultivation. Soils should be well drained and properly leveled so that temporary water stagnation is avoided.

Lentil is adapted to a wide range of environments and varied ecological conditions including regions and climatic conditions where the wild progenitor is not adapted. Lentil requires cool temperatures for optimum growth and warm temperatures for maturation. Seed germination is optimum between 15 and 25^{O}C and seedlings may emerge in five to six days. As temperatures decrease, the rate of emergence becomes slow and complete emergence may take as long as 25 to 30 days at 5^{O}C. A temperature range 18-30^{O}C is optimum for lentil production. Lentil requires totally 1500-1800^{o}C heat throughout vegetative growth (7).

Central Research Institute for Field Crops, Ankara, Turkey (akadir602000@yahoo.com)

Temperature, and the distribution and quantity of rainfall are the main determinants of where and when lentil is grown around the world. In West Asia, North Africa (WANA) and Australia lentil is sown in winter in areas that receive annual rainfall of 300–450 mm (4). In these regions, low temperatures and radiation restrict vegetative growth during winter, but growth is rapid in spring when temperatures rise. Ripening occurs prior to, or during early summer, when temperatures and evaporation are high and rainfall low. Lentils are grown on stored moisture and/or snow melt supplemented by rainfall during spring and summer when temperatures are warm and day lengths are long.

Cropping system of lentil in cold highland areas

Lentil is rotated with winter cereals in highland areas of Turkey. In a typical field, a cereal (wheat or barley) is planted in October and harvested in August. After harvest, wheat stubble is left on the soil surface throughout the autumn and winter months. In spring, stubble burning before cultivation and broadcasting of seeds for planting are common practices. In other areas, wheat stubble is ploughed down in the autumn and the lentil crop is planted in spring. Experiments conducted in Central Anatolia on the effect of fallow and winter lentil on wheat yield and profitability of rotation system showed that winter lentil was more profitable instead of leaving land fallow before wheat. Also, winter lentil after fallow in highland areas leaves the highest amount of soil moisture for wheat (2).

The current status of lentil production for cold highland areas

Turkey is the most active country regarding research on lentil winter-hardiness and breeding of winter hardy varieties. Two types of lentil are produced in Turkey. Yellow cotyledon types with large seeds are grown as a spring planted crop in highland areas (>850 m); whereas, the orange (red) cotyledon type with small seeds is produced in lowland areas (<850 m) (Figure 1). Presently, lentil in the highland areas of Turkey is planted in late spring. The average yield of the spring–sown crop is about 0.85 t ha^{-1}. in Turkey (Figure 2) . Lentil is grown exclusively in the drier areas. Drought and high temperature are main constraints for the spring-sown lentil crop. Late planting coincides with the beginning of the dry period, and the crop depends completely on residual soil moisture. Growing period and critical phenological stages of spring-sown lentil coincide with extended dry periods. Limited soil moisture and dry atmospheric conditions, especially during the reproductive period, reduce yields from 25% to 30% (21) (Figure 1 and 2), as well as biological yield and nitrogen fixation (8).

Adaptation of lentil to highland areas

The highlands of WANA are characterized by cold winters with precipitation, springs with rapidly rising temperatures and hot, dry summers. The major limiting factors to crop growth and development are cold temperatures in winter and both low moisture availability and high temperature stress in late spring.

In West Asia, lentil is spring-sown at elevations above 850 m because of the severe winter cold. When lentil crop is planted late in spring, vegetative growth and yields are reduced because of drought stress. Where winter temperatures are less severe and the crop is fall sown, adequate moisture is usually available for excellent crop development and seed production. Fall sown lentil crops develop rapidly in spring and generally show early maturity when compared to spring sown lentil. In Turkey, a study showed that when winter hardy lentil cultivars were fall sown, yields were 50 to 100 % greater than spring sown lentils (6) (Figure 2).

In order to produce lentil in highlands, there is a need to develop winter hardy lentil cultivars. To shift from spring planting to winter planting, cultivars should have appropriate phenology in addition to winter hardiness to develop yields greater than spring sown lentil varieties. Phenology is the key factor for a good adaptation over a wide geographical area. Timing of major phenologic events such as germination, flowering and maturity are critical factors in the development of winter varieties of lentil.

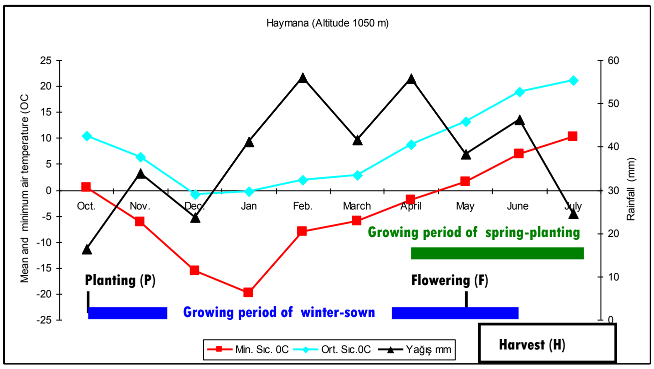


Figure 1. Climatic conditions during the growing season of winter and spring-sown lentils at Haymana, Turkey (altitude 1050 m)

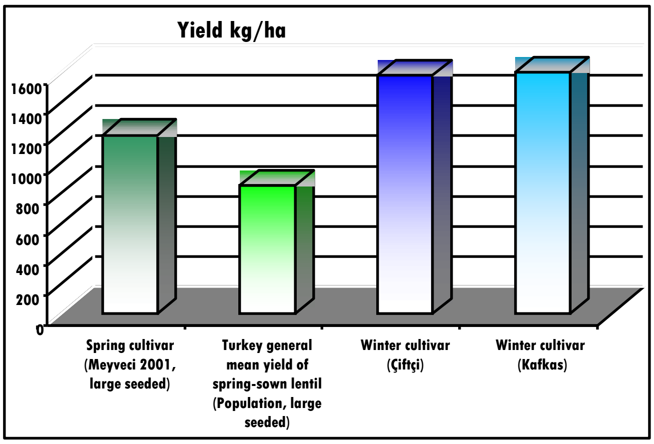


Figure 2. Mean Yields of spring and winter sown cultivars, respectively, in the highlands of Anatolia, Turkey

Genetic variation for winter hardiness

The adaptations of grain legumes to environment depend largely on different genotypic responses to the separate effects of day and night temperature. In the highlands, frost damage can occur at any time during vegetative and flowering periods. Cold damage on lentil depends on growth stage of plant, genotype, duration and severity of cold (Figure 3).

Lentil is relatively more cold tolerant than either chickpea or faba bean. Severity of cold temperatures and desiccating winds are the most important environmental stress factors affecting winter lentil cultivation in high altitudes of Turkey, southern Europe, Iran, Afghanistan and Nepal. A world collection of 3592 lentil accessions was screened for cold tolerance near Ankara, Turkey over a severe winter during which temperatures dropped to as low as -26.8 ^{0}C with 47 days of snow cover (1). In Turkey, studies on development of winter hardy lentils were based on screening the existing germplasm. Kışlık Pul 11, Kışlık Yeşil 21, Kışlık Kırmızı 51, Kafkas, Özbek, Çiftçi, Kayı 91 winter cultivars were selected from local landraces. They have survived exposure to -25 ^{O}C air temperature without snow cover and -29 ^{O}C with snow cover at Sivas, Turkey and released as winter hardy cultivars for highland regions.

Influence of morphological and agronomic traits on winter hardiness and heritability

Negative correlations were found between winter hardiness and number of days to flowering, days to maturity, seed yield, a 100-seed weight, seedling height and large leaf area while positive correlations have been found between winter hardiness and biological yield. Cultural factors such as stubble remaining in no-till systems, seeding date, sowing depth and mixed sowing systems influence winter hardiness of winter-sown lentil (5). Winter hardiness is controlled quantitatively (3).

Summary and conclusions

In Turkey and USA, winter hardy genotypes for highland areas have been selected, evaluated and released as varieties for production. These releases of winter varieties of lentil have shown significant yield increases over the traditional spring sown varieties. Quality traits such as seed size and color remain to be improved aand there is need for additional work on agronomic factors, particularly weed control. Controlling weeds in winter lentil is a major obstacle to more widespread use of winter lentil. The problem of controlling weeds is especially difficult because many species germinate and emerge at various times or continuously during the winter season. Even though herbicides may be effective in controlling many of these weeds, continuous emergence of these winter annual weeds throughout the winter season is a serious problem. The advantages of winter sown lentil in terms of water use and yield are considerable and warrant continued improvement of the technology. ■

References

(1) Erskine W, Meyveci K, Izgin N (1981) Screening of world lentil collection for cold tolerance. Lens Newsl 8:5-9

(2) Eyüpoğlu H, Meyveci K, Karagüllü E, Işık M, Orhan A (1995) The current status and future plants for agronomic research on winter or early spring-sown lentils in the target environments of the Anatolian Highlands. Proceedings, Workshop *Towards Improved Winter-Sown Lentil Production for the West Asian and North African Highlands*, Antalya, Turkey, 72

(3) Kahraman A, Küsmenoğlu İ, Aydin N, Aydoğan A, Erksine W, Muehlbauer FJ (2004) Genetics of winter hardiness in 10 lentil inbred line populations. Crop Sci 44:5-12

(4) Materne M, Siddique KHM (2009) Agroecology and crop adaptation. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 47-63

(5) Muray GA, Eser D, Gutsa LV, Eteve G (1988) Winterhardiness in pea, lentil, faba bean and chickpea. In: Summerfield RJ (ed) World Crops: Cool Season Food Legumes. Kluwer, Dordrect, the Netherlands, 831-843

(6) Şakar D, Durutan N, Meyveci K (1988) Factors which limit the productivity of cool season food legume in Turkey. In: Summerfield RJ (ed) World Crops: Cool Season Food Legumes. Kluwer, Dordrect, the Netherlands, 137-146

(7) Şehirali S (1988) Yemeklik Tane Baklagiller. Ziraat Fakültesi, Ankara Üniversitesi

(8) Wery J (1978) Relations entre la nutrition azote' et la production chez legumineuses. In: Guy P (ed) Les colloques de I'INRA 37: Nutrition azotée des légumineuses. INRA, Paris, France

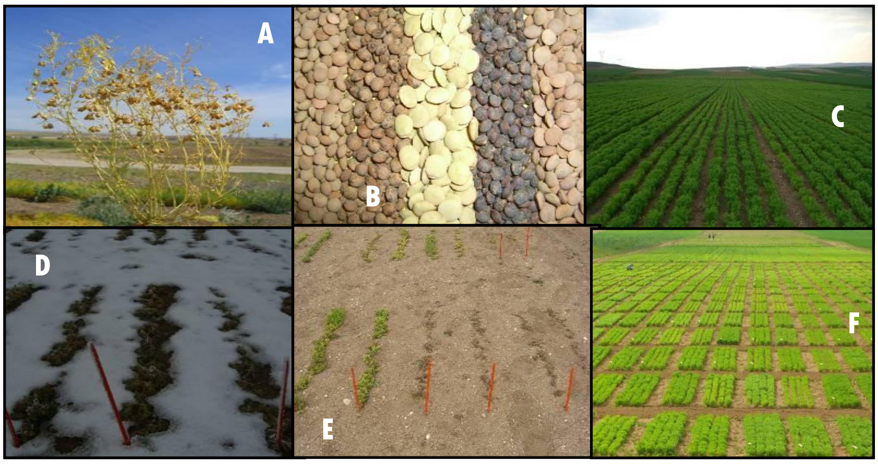


Figure 3. Breeding winter hardy lentil for the highlands of Turkey. (A) lentil plant; (B) seed of several winter lentil varieties; (C) production field of winter lentil, Haymana (Altitude 1050 m), Turkey; (D) large seeded lentil plants under the snow; (E) resistant and susceptible lines to cold; and (F) Winter lentil trials, Haymana, Turkey

Lentil diseases: A threat to lentil production worldwide

by Weidong CHEN

Abstract: Numerous diseases are important in lentil producing regions of the world with their relative importance dependent on environmental conditions. Rust and stemphylium blight are important in regions of Nepal and Bangladesh whereas anthracnose is an important lentil disease in the provinces of western Canada. Ascochyta blight, botrytis grey mold and fusarium wilt are important in some production regions. Management of these diseases is mainly through resistant varieties and agronomic practices to minimize disease development and their effects on production. In addition to these diseases, certain viruses and soil borne pathogens including nematodes can seriously damage lentil crops. Breeding for resistance to these diseases will continue to be the main approach to alleviating their effects on lentil production.

Key words: biotic stress, breeding for resistance, disease control, lentil

Lentil plants encounter numerous diseases that are caused by fungi, viruses, nematodes, and sometimes by bacteria (1, 2, 4). Diseases occur, spread and become epidemic under environmental conditions conducive to particular diseases. Due to wide variation of climatic conditions where lentils are cultivated, major and economically important diseases of lentil differ by production regions. For example, rust and stemphylium blight are important diseases of lentil in Bangladesh and Nepal, whereas anthracnose is an important disease of lentil in western Canada (3, 4). Diseases not only affect plant growth and reduce yield, but also infect seeds reducing grain quality and grading which affect market price, and transmitting diseases if the grain seeds are used for planting (4). Some diseases are important in almost all lentil production areas, others are important in limited number of countries and production regions; still others are important only at specific conditions like in greenhouses. Some of the better-known, well-studied diseases include anthracnose, ascochyta blight, botrytis gray mold, fusarium wilt, and rust.

USDA-ARS, Washington State University, Pullman, USA (w-chen@wsu.edu)

This article is to introduce some of the important lentil diseases to legume scientists and to encourage more research efforts directed toward knowledge gaps in better-studied diseases and to less-known diseases.

Ascochyta blight is a foliar disease that affects all above ground parts of lentil plants. Ascochyta blight of lentil is caused by the fungus *Ascochyta lentis*, which is specific for lentil. The pathogen survives between crop seasons on infected debris and on seeds, serving as primary inoculum. Initial symptoms include necrotic tan spots on leaves and stems with dark margins. The necrotic lesions enlarge and produce light-colored and speckled, flask-shaped fruiting bodies called pycnidia (1, 2, 8). The formation of pycnidia on lesions readily distinguishes the disease from other similar lentil diseases like anthracnose, stemphylium blight and rust. Infected leaflets drop prematurely. Infections on stems may girdle the stems and cause wilting and dying of the stems or branches above the infection. Pycnidia formed on disease lesions contain abundant conidia that are dispersed by splashing rains, spreading the disease. The disease is favored by cool and moist conditions. Significant information is available about genetics of lentil resistance to Ascochyta blight. However, despite the fact that the pathogen is known to have two mating types for sexual reproduction and PCR markers are available to distinguish the two mating types, the genetic variation and pathogenic variation in terms of races or pathotypes have not been systematically investigated.

Botrytis gray mold of lentil affects all above ground parts including leaves, stems, flowers, pods and seeds (6). The disease is found worldwide in all lentil production regions. Botrytis gray mold of lentil is caused by *Botrytis cinerea* and occasionally also caused by *Botrytis fabae* (6). The two pathogen species cause the same symptoms and are very similar in morphology, but *Botrytis fabae* has larger conidia and has narrower host range than *B. cinerea* does (4). *Botrytis cinerea* infects more than 200 plant species including many ornamentals, vegetables, field crops and weeds. Frequently affected field crops include legumes (alfalfa, bean, chickpea, and lentil) and oil crops (safflower and sunflower). *Botrytis fabae* mainly infects Faba bean, vetch, and lentil. Because of the ubiquitous nature and wide host range of the species, the inoculum is almost always present in lentil cropping systems (6). Management of the disease is mainly through utilizing resistant cultivars, and agronomic practices like increased row spacing, reduced seeding rate, delayed sowing and reduced nitrogen fertilizer to minimize the disease. Such practices reduce or delay canopy closure, consequently delaying onset of the disease (Fig. 1).

Figure 1. A dense lentil crop may be highly susceptible to diseases

Rust is a widespread and economically important disease of lentil in several countries (Bangladesh, Ethiopia, India, Morocco, Nepal, Pakistan and Turkey) (4, 7). Rust of lentil is caused by the fungus *Uromyces viciae-fabae,* which is autoecious (completing its life cycle on lentil plant without an alternating host). *Uromyces viciae-fabae* produces three types of spores (aeciospores, urediniospores and teliospores). Teliospores are resistant to adverse conditions and serve as survival structure between crop seasons, and serve as primary inoculum. Urediniospores may also serve as primary inoculum in cool climate conditions. Aeciospores and uredioniospores are secondary inoculum and are spread by wind. All above ground parts of lentil plants are susceptible to rust. Lentil rust usually starts at low area in the field. Infected plants have dark-brown appearance due to dark brown color of uredial pustules. Resistant cultivars are available and are the best means for managing the disease. Other control measures include planting clean seeds and applying fungicides when economically feasible. In addition to infecting lentil, *Uromyces viciae-fabae* also infects faba bean and vetch. Host specialization of *Uromyces viciae-fabae* has been observed (7). The differences in host range or host specialization along with differences in spore dimensions suggest existence of host specialized forms within *Uromyces viciae-fabae.*

Fusarium wilt of lentil is a wide spread disease in every continent where lentil is grown. Fusarium wilt of lentil is caused by the soilborne fungal pathogen *Fusarium oxysporum* f. sp. *lentil*, which infects only lentil. Main symptoms in adult plants consist of drooping of top leaflets, dull green color of forage and wilting of the whole plant (2, 5, 8). Unlike in its cousin *Fusarium oxysporum* f. sp. *ciceris* that causes Fusarium wilt of chickpea, very little is known about cultivar specification (races) and genetic variation of *Fusarium oxysporum* f. sp. *lentil.* The pathogen prefers high temperatures (20- 30 C) and relatively dry conditions. Management practices include selecting resistant cultivars if possible, or selecting early mature cultivars so that the lentil plants may escape high temperature period late in the growing season.

Anthracnose of lentil is an example of diseases that are very important only in restricted areas. Anthracnose is an economically important disease of lentil in western Canada, despite the fact the disease occurs in many other countries (3). Anthracnose refers to disease lesions that are sunken and necrotic, and with a defined black margin. The lesions can be found on leaves, stems and pods. Anthracnose of lentil is caused by the fungus *Colletotrichum trunatum* (4). The pathogen produces black, minute pinhead sized microsclerotia (organized mycelium aggregates) that can survive in soil for up to three years. It also produces single-celled conidia in acervuli with dark brown setae risen above conidia masses. The presence of acervuli with setae and microsclerotia helps differentiate anthracnose from Ascochyta blight and Stemphylium blight. The pathogen has a restricted host range, and has two morphologically similar races (Ct0 and Ct1) which can be differentiated using pathogenicity tests on differential lentil genotypes (3).

In temperate regions, lentil breeding programs relay on greenhouse cultivation to gain an extra growing season in a year. Some diseases, although may not be important in commercial fields in the production region, are important in greenhouses. The disease powdery mildew is an example. The inoculum of powdery mildew is airborne and ubiquitous. The disease is common and may be severe at times due to conducive environmental conditions in the greenhouse (4). The disease may devastate precious breeding materials such as F1 plants. The pathogen is *Erysiphe trifolii* in North America, and the disease affect all above ground part of lentil plants including leaves, stems and pods. It produces sexual fruiting bodies called chasmothecia that have long flexuous appendages with dichotomously branched tips (4). The ascospores produced in chasmothecia survive between crop seasons. Its host range is wide including some wild, uncultivated legumes. Sulfur chemicals are effective in managing powdery mildew in greenhouses.

There are several other economically important diseases like Stemphylium blight caused by *Stemphylium botryosum*, Sclerotinia stem rot caused by *Sclerotinia sclerotiorum* (4). Some virus diseases and many soil-borne diseases including nematode diseases could cause significant economical losses in certain years or at certain locations. Some lentil diseases are known merely by names and their effect on lentil production and yields are poorly understood (4, 5). Some more diseases are even not documented yet. With lentil production expanding to areas where lentil is not previously cultivated and with climate change, less important diseases of lentil may become important and new diseases may emerge. Research efforts need to be directed to those less-known diseases for us to gain more complete understanding of the impact of diseases on lentil production. ■

References

(1) Bayaa B, Erskine W (1998) Diseases of lentil. Allen DJ, Lenné JM (eds) The Pathology of Food and Pasture Legumes. CAB International, Wallingford, UK, 423-471

(2) Beniwal SPS (1993) Field Guide to Lentil Diseases and Insect Pests. International Center for Agricultural Research in the Dry Areas, Aleppo

(3) Buchwaldt L, Anderson KL, Morrall RAA, Gossen BD, Bernier CC (2004) Identification of lentil germ plasm resistant to *Colletotrichum truncatum* and characterization of two pathogen races. Phytopathol 94:236-243

(4) Chen W (2010) Compendium of Chickpea and Lentil Diseases and Pests. APS Press, St. Paul

(5) Chen W, Basandrai AK, Basandrai D, Banniza S, Bayaa B, Buchwaldt L, Davidson J, Larsen R, Rubiales D, Taylor PWJ (2009). Diseases and their management. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 262-281

(6) Davidson JA (2004) . In: Elad Y, Williamson B, Tudzynski P, Delen N (eds). Botrytis: Biology, Pathology and Control, Kluwer, Dordrecht, the Netherlands, 295-318..

(7) Emeran AA, Sillero JC, Niks RE, Rubiales D (2005) Infection structures of host-specialized isolates of *Uromyces viciae-fabae* and of other species of *Uromyces* infecting leguminous crops. Plant Dis 89:17-22.

(8) Taylor P, Lindbeck K, Chen W, Ford R (2007) Lentil Diseases. In: Yadav SS, McNeil D, Stevenson PC (eds) Lentil: An Ancient Crop for Modern Times. Springer, Dordrecht, the Netherlands, 291-314

Broomrape management in lentils

by Diego RUBIALES* and Monica FERNÁNDEZ-APARICIO

Abstract: Lentil is highly susceptible to the root parasitic weed crenate broomrape (*Orobanche crenata*) prevalent in the Mediterranean Basin and the Middle East. Broomrapes propagate via seeds that are very small and numerous and may easily be transferred from one field to another by cultivation and other means. Seeds may remain dormant in the soil for decades but will readily germinate in response to a chemical signal from the host root. Rotations and trap crops are a promising control measure but are still to be adequately determined. Good control of broomrape can be achieved with applications of low rates of glyphosate. Studies of other herbicides for control are underway. Host plant resistance has been difficult to assess, but has had some success in faba bean

Key words: chemical control, herbicides, host plant resistance, parasitic weeds

Figure 1. Crenate broomrape

Lentil is highly susceptible to the root parasitic weed crenate broomrape (*Orobanche crenata*) prevalent in the Mediterranean Basin and the Middle East (Fig. 1). *O. crenata* is an important pest in grain and forage legumes, as well as in other crops such as carrot or celery. Lentil could also suffer although less importantly by infection of Egyptian broomrape (*Phelipanche aegyptiaca* syn. *O. aegyptiaca*, Fig. 2) that is limited to eastern parts of the Mediterranean and the Middle East (4, 7). Fortunately, lentil is not reported to suffer from other broomrape species such as *O. foetida* and *O. minor* that can infect some other legume crops.

Broomrapes propagate via seeds that are very small and may easily be transferred from one field to another by cultivation, and also by crop contaminated seeds, water, wind, animals, and especially by vehicles and farming machines. The number of seeds produced by a healthy broomrape plant can exceed 200,000. Seeds germinate only in response to a chemical signal from the host root and may remain dormant in the soil for decades. The only way to cope with the broomrapes is through an integrated approach, employing a variety of measures in a concerted manner, starting with containment and sanitation, direct and indirect measures to prevent the damage caused by the parasites, and finally eradicating the parasite seedbank in soil. Crop rotation is of little value due to the persistence of the seeds for extended periods and the broad host range. There is promise in a number of strategies such as rotations with trap or catch crops, intercropping or biological control, but the technologies are not ready yet to provide acceptable control (4, 6, 7, 8).

Chemical control of broomrape is complicated as herbicides have been effective only as a prophylactic treatment, since in most cases the actual infestation level in the field is usually unknown. It has been shown that good broomrape control can be achieved in faba bean by glyphosate at low rates. However, insufficient selectivity to this herbicide is found in lentil. Lentil tolerates pre-emergence treatments of imidazolinone herbicides imazapyr (25 g a.i./ha) and imazethapyr (75 g a.i./ha) and postemergence treatments of imazaquin (7.5 ml a.i./ha) and imazapic (3 g a.i./ha) (5, 10). A problem of these imidazolinone herbicides is that they are not registered in every country. Also, traditional imidazolinones are being replaced in some countries by imazamox that is less residual in the soil, so doses and timing of application need re-adjustment. A promising option is the development of cultivars resistant to herbicides by genetic engineering or simply by induced mutation. This second option has been successful in lentil and a number of cultivars are being introduced to the market under the trademark "CLEARFIELD® lentils" that are not genetically modified and that tolerate higher doses of imidazolinone herbicides.

[1]CSIC, Institute for Sustainable Agriculture, Córdoba, Spain (diego.rubiales@ias.csic.es)

Figure 2. A lentil stand infested by broomrape

Resistance against parasitic weeds is difficult to access, scarce, of complex nature and of low heritability, making breeding for resistance a difficult task. In spite of these difficulties, significant success has been achieved in some legume crops, such as faba bean, pea or vetch against *O. crenata* (6, 7, 9). Escape from *O. crenata* infection due to lower root density is known in lentil (11) as well as true genetic resistance (1, 2) based on lower induction of seed germination, hampered establishment and development of established tubercles or necrosis of tubercles. These traits can be exploited in lentil breeding. Combination of different resistance mechanisms into a single cultivar should provide a more durable outcome. This can be facilitated by the adoption of marker-assisted selection techniques, together with the use of *in vitro* screening methods that allow dissecting parasitic weed resistance into highly heritable components (3). ■

References

(1) Fernández-Aparicio M, Sillero JC, Pérez-de-Luque A, Rubiales D. (2008a) Identification of sources of resistance to crenate broomrape (*Orobanche crenata*) in Spanish lentil (*Lens culinaris*) germplasm. Weed Res 48:85-94

(2) Fernández-Aparicio M, Sillero JC, Rubiales D (2008b). Resistance to broomrape in wild lentils (*Lens* spp.). Plant Breed 128:266-270

(3) Fondevilla S, Fernández-Aparicio M, Satovic Z, Emeran AA, Torres AM, Moreno MT, Rubiales D (2010) Identification of quantitative trait loci for specific mechanisms of resistance to *Orobanche crenata* Forsk. in pea (*Pisum sativum* L.). Mol Breed 25:259-272

(4) Joel DM, Hershenhorn Y, Eizenberg H, Aly R, Ejeta G, Rich PJ, Ransom JK, Sauerborn J, Rubiales D (2007) Janick J (ed.) Horticultural Reviews 33: Biology and Management of Weedy Root Parasites. John Wiley & Sons, Hoboken, USA, 267-350

(5) Jurado-Expósito M, Garcia-Torres L, Castejón-Muñoz M (1997) Broad bean and lentil seed treatments with imidazolinones for the control of broomrape (*Orobanche crenata*). J Agric Sci 129:307-314

(6) Pérez-de-Luque A, Eizenberg H, Grenz JH, Sillero JC, Ávila C, Sauerborn J, Rubiales D (2010) Broomrape management in faba bean. Field Crop Res 115:319-328

(7) Rubiales D, Pérez-de-Luque A, Sillero JC, Román BM, Kharrat M, Khalil S, Joel DM, Riches C (2006) Screening techniques and sources of resistance against parasitic weeds in grain legumes. Euphytica 147:187-199

(8) Rubiales D, Fernández-Aparicio M, Wegmann K, Joel D (2009) Revisiting strategies for reducing the seedbank of Orobanche and Phelipanche spp. Weed Res 49:23-33

(9) Rubiales D, Fernández-Aparicio M, Pérez-de-Luque A, Castillejo MA, Prats E, Sillero JC, Rispail N, Fondevilla S (2009b) Breeding approaches for crenate broomrape (*Orobanche crenata* Forsk.) management in pea (*Pisum sativum* L.). Pest Manag Sci 65:553-559

(10) Rubiales D, Fernández-Aparicio M, Haddad A (2009c). Parasitic plants. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 343-349

(11) Sauerborn J, Masri H, Saxena MC, Erskine W (1987) A rapid test to screen lentil under laboratory conditions for susceptibility to *Orobanche*. Lens Newsl 14:15-16

No-till lentil: An option for profitable harvest in dry areas

by Shiv KUMAR[1]*, Ravi Gopal SINGH[1], C. PIGGIN[1], A. HADDAD[1], S. AHMED[1] and Raj KUMAR[2]

Abstract: No-till lentil holds promise for minimizing soil and crop residue disturbance, controlling soil evaporation, minimizing erosion losses, sequestering carbon and reducing energy needs. These effects reduce overall cost of production while improving yields and returns to farmers. No-till planters have been developed that cause minimal disturbance to the soil and previous crop residues while placing the seeds in an optimum position for germination and emergence. Timely planting of lentil under no-till systems in rainfed lowland ecologies help the crop to escape negative effects of terminal water stress and rising temperatures. No-till technology has been demonstrated at farm levels, resulting in adoption by farmers in some regions. The main advantages are cost savings, flexibility in planting times and reduced water requirements. Problems with adoption relate to weeds, crop establishment and availability of no-till seeders. Varieties suitable to no-till are also needed. With awareness and knowledge of a package of practices, these issues can be overcome for widespread adoption of this cost saving and environmentally friendly technology.

Key words: direct seeding, lentil, moisture utilization, reduced tillage

[1]ICARDA, Aleppo, Syria (SK.Agrawal@cgiar.org)
[2]CIMMYT, Regional Maize Research and Seed Production Center, Begusarai, India

Lentil (*Lens culinaris* ssp. *culinaris*) is an important food legume crop with various uses as food and fodder due to its protein rich grains and straw. Globally, it is cultivated on 3.85 million ha area with 3.59 million tonnes production. The major geographical regions of lentil production are South Asia and China (44.3%), Northern Great Plains in North America (41%), West Asia and North Africa (6.7%), Sub-Saharan Africa (3.5%) and Australia (2.5%). South Asia grows lentil on 1.8 million ha area with 1.1 million tonnes production exclusively as a post-rainy season crop on residual moisture whereas West Asia and North Africa (WANA) with Turkey, Syria, Iran and Morocco as main producers grow winter and spring planted lentil on 0.39 m ha with 0.19 million tonnes production. In the Sub-Saharan Africa, Ethiopia and Eritrea are the major lentil producers with 0.10 million tonnes production. In recent years, area under lentil has expanded in the Northern Great Plains of North America (Canada and USA) which produces 1.15 million tonnes of lentil and has emerged as the foremost production base. In these regions, lentil is grown as rainfed crop under various tillage systems including conventional as well as zero tillage. Production cost play an important role in area allocation under a particular crop. For further expansion of area under lentil, its economic competitiveness needs to be improved by reducing production cost through adoption of various resource conservation technologies. No till or zero tillage (ZT) is an important component of conservation agriculture to produce crops at low cost with profound effect on natural resources such as water and soil. This system is very effective in minimizing soil and crop residue disturbance, controlling soil evaporation, minimizing erosion losses, sequestering carbon in soil and reducing energy needs.

No till (direct seeding without tillage or zero tillage) of lentil into standing stubble left after cereal (wheat or barley) harvest is becoming an option in the developed countries where soil erosion is a problem (1, 12, 14). In the no-till system of planting, seeds are placed manually or mechanically with a special seeder by opening a narrow slit in soil without much soil disturbance. The key objective is to tap residual soil moisture and leftover fertility of previous crop by the succeeding lentil crop. No till system is recommended in the USA for autumn sown lentil as a means of conserving soil moisture and to provide some surface protection to reduce winter injury to the developing lentil plants (2). No-till lentil has found favor in recent years in Great Plains of the USA, Canada and Australia where farmers grows lentil on large areas as a rainfed crop and derive benefits from diversification and export opportunities. In South Asia, the seeds of lentil are traditionally broadcasted in the standing rice crop nearing maturity or after the monsoon in fallow land without any tillage to exploit residual moisture for germination and stand establishment. This age-old practice of surface planting popularly known as paira or utera cultivation in India, Bangladesh and Nepal, is a true form of no-till lentils. The no-till method of planting, however, requires one time investment to procure suitable zero-till machine.

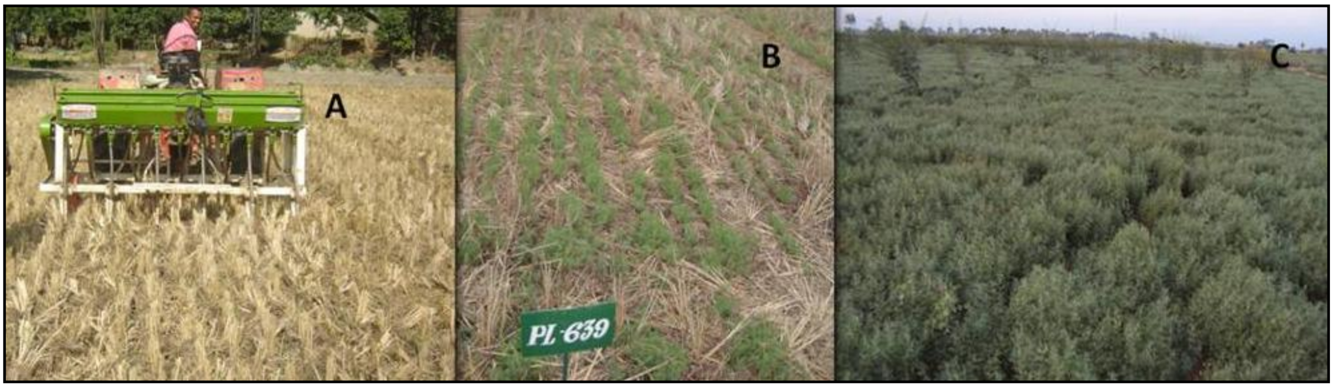
Zero till drill seeder

Planting of no-till lentil requires a special planter called zero till seeder which is similar to conventional seeder except for the furrow openers. The zero-till seeder holds a narrow inverted 'T' type furrow opener for seed and fertilizer placement in unprepared soil with anchored crop residues. However, double disk openers or star wheels are used to facilitate seeding in fields with loose crop residues. The zero till machine also varies with seed metering system. In zero till drill/seeder with fluted roller seed metering system, seeds flow continuously while seeding without maintaining plant spacing whereas zero-till planters can maintain row to row and plant to plant spacing (3). A zero till drill/planter comes with a depth control wheel or other depth control mechanisms which is very important to place seeds at uniform depth for ensuring better stand establishment. No-till system saves about 20-35 US$/ha in Indian conditions in addition to other benefits such as reduced seed rate, better use of applied fertilizers, and timely sowing (normally 5-20 days early seeding due to eliminating tillage). Timely planting of lentil under no-till system in rainfed lowland ecologies help escape negative effects of terminal water stress and rising temperature.

Benefits of no-till lentils

Lentil is an important component of no-till system because it provides an inexpensive source of soil N for subsequent crops, thrives well on less soil water, and breaks the life cycle of crop pests, which can be a problem in continuous cereal cropping systems. Research on various aspects of no-till suggests that growing crops under no-till not only increased yield but also increased other rotational benefits. It increases organic matter content of soil and microbial biomass as compared to conventional tillage (4).There are reports of higher uptake of N and P by lentil with one ploughing as compared with zero tillage on sandy loam soils of Agra in India (15). Loss of organic matter after tillage is particularly severe in the Tropics (6). The zero tillage with better crop residue management can immensely help sequestering carbon in degraded lands. An increase of 1 ton of soil carbon pool of degraded land soils may increase crop yield by 20 to 40 kg/ha for wheat, 10 to 20 kg/ha for maize and 0.5 to 1 kg/ha for cowpeas (9).

No-till method lowers mineralization and nitrification rates, and increases immobilization of N (16). This leads to a decrease in available N, which stimulates nitrogen fixation of legumes planted in no-till soil. Nitrogen fixation is reported to increase by 10% in lentil after four years in zero tillage in a semi-arid environment (16). Tillage practices can also affect nitrous oxide (N_2O) emissions, a powerful greenhouse gas produced by soils, fossil fuel burning and fertilizers. For example, increasing numbers of growers have adopted no-till practices to reduce erosion and improve soil tilth. In some areas in North America, no-till slows the decomposition of crop residues, and for this reason, no-till systems have been promoted as carbon sinks. But in certain soils, the higher water content in no-till systems may cause higher N_2O emissions than conventional tilled soil, partially offsetting the beneficial greenhouse gas mitigation of no-till. No-till still appears to be creating a net sink and not a source of greenhouse gases, on balance (16). In the system experiments, the no-tilled plots had an average of 35 mm additional soil water at sowing which can be converted into fixed N at the rate of 0.5-0.8 kg/mm (8).



Picture 1: No-till lentils; Planting in rice residues (A), cultivar PL 639 (B) and Farmer's field in eastern IGP (C)

Reducing tillage and retaining crop residues greatly help in reducing wind and water erosion. Studies conducted at the University of Idaho during 2004-06 concluded that lentil can be economically cultivated in no-till system (7). There could be advantage to no-till in some years if available soil moisture is limited. Other studies have shown that the benefit of legumes including lentil in no-till systems occurs because of the extra soil moisture conserved from leaving standing stubble over the winter, increasing snow trapping and moisture conservation and the improved microclimate during the growing season (13). Because of the low residue produced by lentil, it does not necessarily prevent erosion when used in no-till systems, at least not in comparison with soil residues from no-till wheat. Thus, it is important to maximize conservation of lentil residue when grown in highly erodible soils.

Conservation agriculture affects the plant growth environment and associated patho-systems. Evaluation of 10 lentil genotypes under zero and conventional tillage systems at ICARDA showed no significant difference on disease intensity of fusarium wilt between tillage systems (11). However, genotypic differences were noticed for wilt incidence under both the systems without interaction effect. Wilt incidence among lentil genotypes ranged from 1 to 46%, with eight genotypes showing less than 10% mortality under no-till system (Fig. 1). Similarly, a study conducted in Canada during 1996 to 1999 also revealed that the tillage management is unlikely to have an effect on severity of ascochyta blight except in rotation with short re-cropping intervals (5).

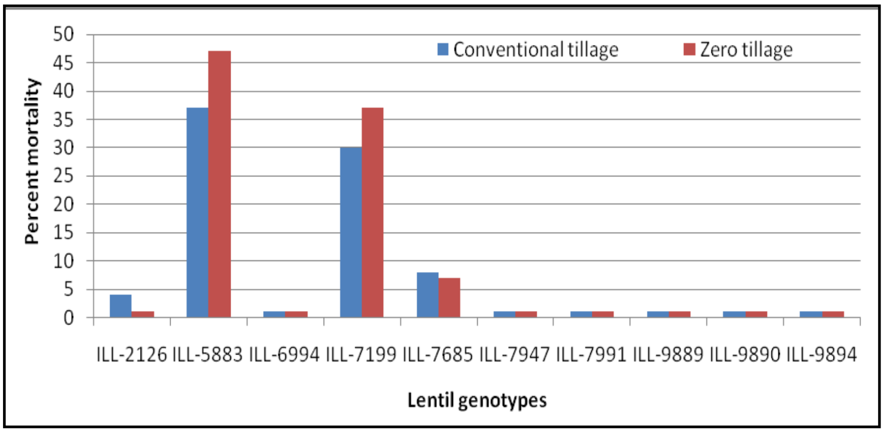


Fig. 1. Effect of tillage on percent wilt mortality of lentil genotypes

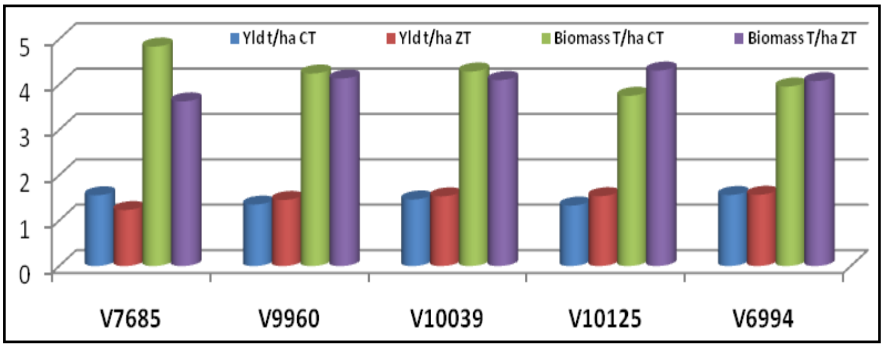


Fig. 2. Grain and biomass yield (t/ha) of top 5 varieties of lentil at Arnaz 2009-10

Lentil yields under no-till system

Experiments with 10 varieties of lentil at Arnaz (Syria) during 2010 (300 mm precipitation) revealed that the grain yield of lentil varied between 990 and 1560 kg/ha with a mean of 1330 kg/ha under conservation (one sweep cultivation was applied a week before seeding) tillage whereas it ranged between 1110 and 1570 kg/ha with an average of 1380 kg/ha under no-till system. The grain yield of most of the varieties was equal or higher under no-till system (Fig. 2). Two varieties, ILL10039 and ILL10125 gave 1540 kg/ha grain yield under no tillage. In a three-year trial conducted with a number of lentil varieties under conventional and no-till conditions at the University of Idaho revealed that the average yields of no-till lentils were 95, 102 and 128% of conventional tillage during 2004, 2005 and 2006, respectively (7). However, the performance of varieties was not consistent in response to tillage and the influence of tillage was driven by weather conditions. When moisture was limiting there was greater advantage of no-till. However, no-till was always effective with the use of crop residue as mulch (10).

In a contrasting environment of eastern Indo-Gangetic plains (IGP) with high rainfall, farmers grow local landraces of lentil at relatively high seed rate (100-150 kg/ha) to offset seed mortality due to soil-borne pathogens. Results of farmers' participatory trials conducted in the eastern IGP revealed that no-till lentil with reduced seed rate (30 kg/ha) sown 5-6 cm deep helps in reducing wilt incidence besides improving grain yield (1.53 t/ha) over conventional tillage (1.22 t/ha) and surface seeding (0.91 t/ha) (Fig. 3). In adaptive trials conducted at four locations in eastern IGP on evaluation of cultivars and economizing seed rate for surface seeding of lentils, it was observed that reducing seeds rate up to 25 kg/ha did not affected yields significantly (Fig. 4). Newly released cultivar HUL 57 and Arun yielded 40 per cent higher than farmers' grown variety PL639 (3).

Perspective

The no-till lentil technology has been demonstrated at farm levels, resulting in its adoption by farmers in some regions. The main driving forces behind the adoption at farm level were cost saving, flexibility in planting time and less water requirement. However, some technical problems with large-scale adoption of no-till system are associated with weed menace and crop establishment besides availability of zero-till seeders and development of improved varieties suitable for no-till system. Some of the traits such as early growth vigor, fast ground cover and high biomass with herbicide tolerance are desirable in no-till lentils as these traits would help lentil plants to compete with weeds as weed management emerges as a key issue for success of no-till lentils. The minimal soil disturbance under no-till ensures that most weed seeds are left on the soil surface and emerge as a major production constraint. Generally, the weed flora observed in lentil is complex including grassy, broadleaf and sometimes sedges. Weeds like *Vicia sativa, Chenopodium album* are prolific seed producers, and can drastically reduce the yields. We have limited pre- and post-emergence herbicide molecules to control the complex weeds in lentils. However, herbicides like pendimethalin, trifluralin, alachlore and fluchloralin have been recommended as pre-emergence and quizalafop, imazethapyr and aclonifen as post-emergence herbicides. However, when a field is infested with germinating or established weeds at planting time, it is always better to use glyphosate to control weeds and eliminate weed complex at early crop stage. Multi-location experiments carried out under the All India Coordinated Research Project on MULLaRP crops showed that pre-emergence application of pendimethalin @ 1 kg/ha and post-emergence application of Imazethapyr @ 37.5 g/ha at 30 days after sowing were found effective in managing weeds in lentil fields with positive effect on grain yield. In Canada, commercial production of new varieties with imidazolinone resistance (Clearfield® Lentil) has helped to control weeds through post-emergence application of selective herbicides. Similarly, lack of knowledge in machinery operation leads to poor seed distribution and improper stand establishment. However, with awareness and knowledge of package of practices, these issues can be tackled for widespread adoption of this cost-saving technology. ■

References

(1) Battikhi, A.M. and Suleiman, A.A. (1999). Effect of tillage system on soil strength and bulk density of vertisols. J Agron Crop Sci 182:285–290

(2) Chen C, Miller P, Muehlbauer F, Neill K, Wichman D, McPhee K (2006) Winter pea and lentil response to seeding date and micro and macro-environments. Agron J 98:1655-1663.

(3) CSISA (2010) Annual Report. Central, Bihar hub

(4) Ferreira M C, Andrade DD, Chueire LMD, Takemura SM, Hungria M (2000) Tillage method and crop rotation effects on the population sizes and diversity of bradyrhizobia nodulating soybean. Soil Biol Biochem 32:627-637

(5) Gossen BD, Derksen DA (2003) Impact of tillage and crop rotation on ascochyta blight (*Ascochyta lentis*) of lentil. Can J Plant Sci 83:411-415

(6) Graham PH, Vance CP (2000) Nitrogen fixation in perspective: An overview of research and extension needs. Field Crop Res 65:93-106

(7) Guy SO, Lauver M (2006) http://a-c-s.confex.com/crops/responses/2006am/1023.pdf

(8) Herridge DF (2005) Abstracts, 4th International Food Legumes Research Conference, New Delhi, India

(9) Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Sci 304:1623-1627

(10) Lal R, Reicosky D, Hanson J (2007) Evolution of the plow over 10000 years and the rationale for no-till farming. Soil Tillage Res 93:1-12

(11) Maalouf F, Ahmed S, Kabakebji M, Khalil S, Abang M, Kabbabeh M, Street K (2010) Book of Abstracts, 5th International Food Legumes Research Conference & 7th European Conference on Grain Legumes, Antalya, Turkey, 240

(12) Matus A, Derksen DA, Walley FL, Loeppky HA, van Kessel C (1997) The influence of tillage and crop rotation on nitrogen fixation in lentil and pea. Can J Plant Sci 77:197-200

(13) Miller PR, McConkey BG, Clayton GW, Brandt SA, Staricka JA, Johnston AM, Lafond GP, Schatz BG, Baltensperger DD, Neill KE (2002) Pulse crop adaptation in the Northern Great Plains. Agron J 94:261-272

(14) Pala M, Harris HC, Ryan J, Makboul R, Dozom S (2000) Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Exp Agric 36:223-242

(15) Tomar SPS, Singh RP (1991) Effect of tillage, seed rates and irrigation on the growth, yield and quality of lentil. Indian J Agron 36:143-147

(16) Van Kessel C, Hartley C (2000) Agricultural management of grain legumes; has it led to an increase in nitrogen fixation? Field Crop Res 65:165-181

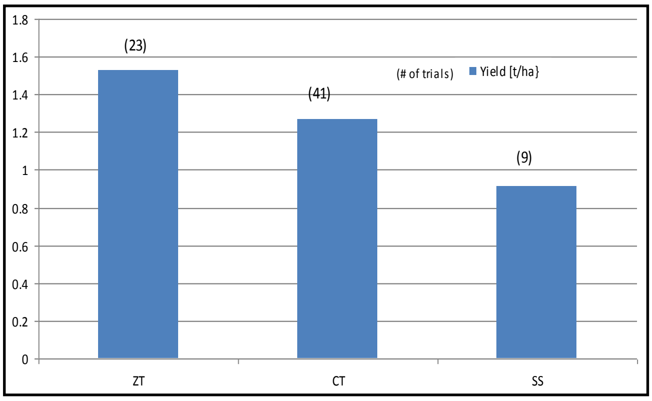


Fig. 3: Effect of tillage methods on lentil yield in farmers' participatory trials conducted in India during 2009-10

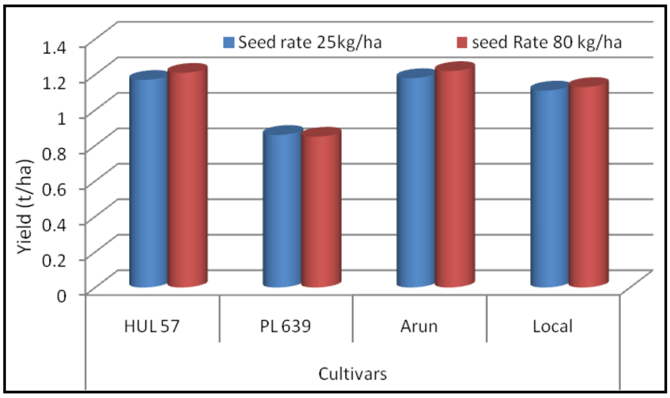


Fig 4: Effect of seed rate on grain yield under surface seeded lentil cultivars in India during 2009-10

Lentil production in North America and the major market classes

by Kevin E. McPHEE[1]* and Fred J. MUEHLBAUER[2]*

Abstract: Large areas of North America are well suited to lentil production. In the US, production areas include the so-called Palouse region of eastern Washington and northern Idaho and the northern plains states of Montana and North Dakota where approximately 200,000 hectares are produced annually (Fig. 1). In Canada, the major production areas are located mostly in Saskatchewan where production has averaged about 1 million hectares annually (Fig.1). The major share of lentil produced in North America is exported while only a small portion is used domestically. Agronomic issues have influenced research and breeding programs. Major breeding objectives have focused on increasing biomass and yields and improving seed quality traits. In the US, virus diseases, sclerotinia white mold, stemphylium blight and root rots are major factors in production; while in Canada, anthracnose and stemphylium blights can seriously limit yields and seed quality. Industry organizations in the US and Canada provide needed funds for the research programs through grower "check-off" programs.
Key words: diseases, lentil, plant breeding, varieties

Large areas of North America are well suited to lentil production and include the so-called "Palouse" region of eastern Washington and northern Idaho with its rolling hills and favorable climate, the vast Canadian prairie provinces of Saskatchewan, Manitoba and Alberta, and the Northern Plains States of North Dakota and Montana. These areas usually have sufficient rainfall during the winter months or during the early part of the growing season that promotes good lentil production as well as a prolonged dry period near the end of the growing season that is ideal for maturation and harvesting. Production of high quality crops is generally expected but extremes of weather sometimes cause significant problems.

[1]North Dakota State University, Fargo, USA (kevin.mcphee@ndsu.edu)
[2]USDA-ARS and Washington State University, Pullman, USA (muehlbau@wsu.edu)

Lentil production in North America started in the Palouse region of eastern Washington State and northern Idaho during the 1920s (2) and rapidly expanded due to demands in world markets. Canada began producing lentil in 1969 and within the past few years became the world's largest producer and exporter (Figs. 1 & 2). Production has steadily increased in Canada and despite a decline in 2006 and 2007, has continued the upward trend in 2009 and that now stands at nearly 1 million metric tonnes annually. Based on the land area available in Canada, there is every reason to believe that production can continue to increase in response to continued strong demand.

Nearly the entire lentil crop in Canada is grown in Saskatchewan, a province with large areas of flat and easily tilled land that is well suited to the crop. While there have been strong gains in production in Canada, the northern plains states of Montana and North Dakota, lying directly south of Saskatchewan, has very recently become the leading area of production in the U.S. (Figs. 1 & 2). The production increases in the U.S. from 2008-2009 have nearly all come from increases in these northern plains states where current production is over 150,000 metric tonnes annually. There is considerable area in this region and it is reasonable to expect further increases in production as market demand remains strong.

In the Palouse region, some expansion of production could take place, but there are competing crops such as spring wheat, barley and canola that can be considered by growers. In the Palouse it is likely that production will remain at about 60,000 to 70,000 hectares annually depending on market demand. In Canada, there is potential for significant expansion as monetary returns from lentil crops have been very competitive when compared to wheat. Production in the northern plains states has increased because farmers are able to substitute a legume crop in place of summer fallow while benefiting from the inclusion of a legume in the rotation.

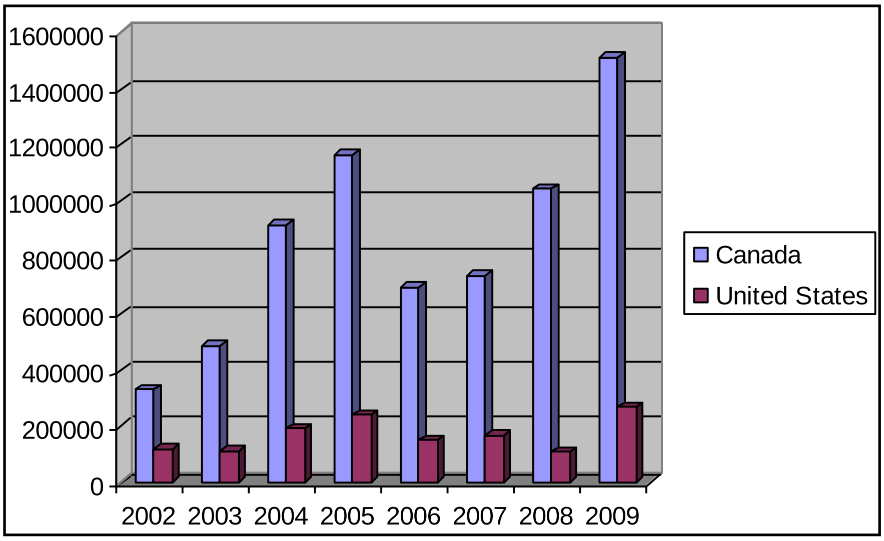


Figure 1. Lentil area harvested (hectares) in North America, 2002-2009 (1)

Lentils produced in North America are primarily exported to lentil consuming countries with a small percentage used domestically. Ethnic communities in the large cities of the U.S. and Canada are major users of lentil and are an important local market.

Agronomic issues have influenced lentil breeding and production in the U.S. These issues include the critical need to control soil erosion on the rolling hills of the Palouse. Varieties with increased biomass and residues have been a goal of the breeding to provide a means of protecting soil surfaces from the erosive effects of rain. However, there is limited scope for controlling erosion through higher biomass and residue producing lentils. Alternatively, growers have been experimenting with the use of direct seeding systems for planting lentil into standing wheat or barley stubble without tillage. A major obstacle to the use of this practice in the spring is the cool and relatively wet soil conditions that delay emergence. A major consequence of retaining residues and stubble on the soil surface for erosion control is that the soils remain wet and cold for a longer period of time. This situation also delays crop development and reduces yields.

Lentil marketing is generally based on visual quality criteria that distinguish each market class. The primary criteria include size and shape of the seeds and color of the seed coats and cotyledons. The major market classes grown in North America have yellow cotyledons; however, there is increasing interest in red lentils for decortication and splitting.

Large-seeded green lentils with seed weights ranging from 5.0 to over 7.0 grams per 100 seeds include widely grown varieties such as 'Brewer' and 'Laird'. More recently developed varieties such as 'CDC Glamis', 'CDC Grandora', 'CDC Sovereign', 'CDC Sedley', 'CDC Greenland', 'CDC Plato', 'Riveland' 'Pennell' and 'Merrit' have improved yields and quality traits. The medium sized 'Richlea', developed in Canada, is now grown throughout North America. Richlea is popular because of its excellent quality traits and exceptionally high yields.

Small-seeded green lentils such as 'Eston', 'Pardina', 'Viceroy', 'CDC Milestone' and 'CDC Invincible CL' have average seed weights between 3.0 and 4.2 grams per 100 seeds. These smaller seeded types are marketed in Europe, Central America and South America. Spanish brown lentils typified by Pardina are widely produced in the U.S. and primarily marketed to Spain. Pardina has seed coats that have a greenish-brown background, some dark speckling and mottling, and yellow cotyledons.

Red lentils have the largest volume traded on the world market. They are consumed as either decorticated and split lentils or decorticated whole seed in Egypt, West Asia, Sri Lanka, Pakistan, India and Bangladesh. These countries have become important red lentil importers. Varieties of red lentil have variously pigmented seed coats that are commonly removed by decortication. Important criteria from the splitting process are the percentage yield and the color of the cotyledons. Red lentils grown in North America include 'Crimson', 'CDC Blaze', 'CDC Redberry', 'CDC Red Rider', 'CDC Redcoat', 'CDC Rouleau', 'CDC Rosetown', 'CDC Robin', 'CDC Impact CL', 'CDC Imperial CL' and 'Redchief'.

French green lentils are primarily marketed in Europe and consumed as whole seed in salads. This market class is characterized as having green seed coats that are heavily mottled. Typical varieties include, 'Du Puy', 'Peridot CL' and 'LeMay'.

Active lentil breeding projects are underway at the U.S. Department of Agriculture located at Washington State University in Pullman, Washington, USA; the Crop Development Center, The University of Saskatchewan, Saskatoon, Saskatchewan, Canada; and more recently at North Dakota State University, Fargo, North Dakota, USA. The three breeding projects have similar objectives of improving yields and crop quality in several market classes. Disease resistance is a serious consideration. In Canada and the northern plains states of North Dakota and Montana, foliar diseases such as Ascochyta blight, Anthracnose and Stemphyllium blight are serious problems; while in the Palouse region, viruses cause considerable damage depending on the degree of aphid infestation. There is resistance/tolerance to Ascochyta and Stemphyllium blights and viruses; however, there is minimal tolerance to Anthracnose. However, resistance found in the wild species relative, *L. ervoides* (See "On the wild side", this issue), represents a potential solution to this devastating disease.

Success in the breeding programs is essential for the industry in North America to remain competitive in world markets. The industry has supported the respective research programs through proceeds from producer imposed "check-off" programs. In addition, strong grower support has been instrumental in maintaining the base research programs of the states, provinces and federal governments throughout the lentil growing regions of North America. ■

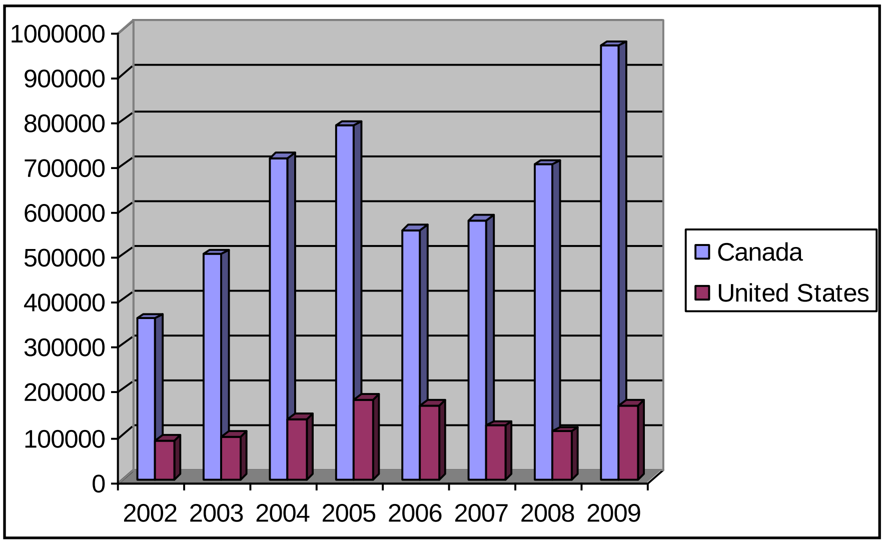


Figure 2. Lentil production (metric tonnes) in North America, 2002-2009. (1)

References

(1) FAOSTAT (2011) FAOSTAT. http://faostat.fao.org/

(2) Youngman VE (1968) Lentils - a pulse of the Palouse. Econ Bot 22:135-139

Producer organizations in North America

Saskatchewan Pulse Growers

The mission of the Saskatchewan Pulse Growers is to provide leadership for an innovative, profitable and sustainable Saskatchewan pulse industry, through research, market development and communication in collaboration with stakeholders. The organization is funded by Saskatchewan producers through a check-off of one percent of the sale of all pulse crops. Saskatchewan Pulse Growers is directed by a Board of seven elected pulse farmers.
http://www.saskpulse.com/producer/

USA Dry Pea and Lentil Council

The USA Dry Pea & Lentil Council represents the nation's dry pea, lentil and chickpea industry. These crops are grown mainly in the northern tier of the United States. Known for their nutritious qualities such as high in protein, folate and essential nutrients, dry peas, lentils and chickpea also benefit the soil and environment. Are you a grower, processor or exporter of dry peas, lentils and chickpeas? Or are you interested in the health benefits of eating dry peas, lentils and chickpeas and want to know how to cook them and what recipes are available? Or maybe you are looking for a supplier or the latest variety research? You have come to the right place for your dry pea, lentil and chickpea needs!
http://www.pea-lentil.com/

Northern Pulse Growers Association

The Northern Pulse Growers Association is a nonprofit association representing dry pea, lentil, chickpea, lupin and faba bean growers from the states of Montana and North Dakota in the U.S. The Northern Pulse Growers Association strives to increase pulse producers profitability through education, research, domestic and international marketing and government relations.
http://www.northernpulse.com/

Lentils in production and food systems in West Asia and Africa

by Ashutosh SARKER* and Shiv KUMAR

Abstract: Lentil is a staple food legume that is traditionally grown in West Asia, East and North Africa, the Indian sub-continent and is a primary component of farming systems of those areas. Lentil plays a significant role in human and animal nutrition and in maintenance and improvement of soil health. The International Center for Agricultural Research in the Dry Areas (ICARDA) has a world mandate for lentil improvement and is working with the national programs of the region to enhance production and productivity, increase farmers' income and provide lentil to consumers for food and nutritional security. Average yields of lentil in the region are considered to be relatively low due to cultivation of predominantly local cultivars that have limited yield potential and are vulnerable to a number of stresses. Yield limiting factors include a seemingly lack of response to inputs and apparent susceptibility to various biotic and abiotic stresses. Harvest mechanization is an important research goal in order to reduce production costs. Also, more effective weed management is needed. Lentil will remain as an integral component of farming and food systems in West Asia, and North and East Africa but returns to farmers need to be enhanced.

Key words: crop mechanization, farming systems, international centers, production constraints, weed control

International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria (A.Sarker@cgiar.org)

Lentil is a staple food legume crop, traditionally grown in West Asia, East and North Africa, the Indian sub-continent and in the recent past in North America and Oceania. It is an important crop in food, feed and farming systems of West Asia and North and East Africa. Lentil, among other food legumes, plays a significant role in human and animal nutrition and in soil health improvement. Its cultivation enriches soil nutrient status by adding nitrogen, carbon and organic matter which promotes sustainable cereal-based crop production systems in the regions. Lentil is a key food legume crop for intensification of crop production systems in West Asia and North Africa, where lentil is predominantly grown in rotation with barley and wheat. Countries like Turkey, Syria, Iran, Morocco and Ethiopia are the major players in global lentil production. Both red and green lentils are produced in the region with variable proportion. For example, Turkey and Syria grows about 80-85% red lentil and 15-20% green lentil; Iran and Morocco produces about 95% large-seeded green lentil; and Ethiopia is devoted to produce red lentils only. This production preference of red and green lentil by farmers relates to food preparation and consumption habit by the people in those countries. Among them, Turkey, Syria and Ethiopia exports lentil in international markets, but others import lentil to meet their domestic demands.

The International Center for Agricultural Research in the Dry Areas (ICARDA) with its world mandate for lentil improvement is working with the national agricultural research systems of the regions to enhance production and productivity, to increase farmers' income and to provide adequate lentil to consumers for food and nutritional security.

Lentil in food systems in the region

Lentil is used for preparation of various traditional foods in West Asia, North Africa and East Africa since time immemorial. It is the most desired legume because of its high protein (Up to 35.5%) content and fast cooking characteristics. It is used as starter, main dish, side dish or in salads. In West Asia and North Africa, "*Mujaddarah*", made of whole lentil and immature wheat seed, is a popular dish. *Koshary* is a commonly served dish in Egypt, made of mixture of rice and red lentil. In North Africa, lentil is prepared with vegetables and the recipe is known as *lentil Tagine*. Of course, red lentil soup is popular all over the regions, but most particularly in Turkey, Lebanon, Jordan, Palestine and Syria. *Wot* is a traditional dish in Ethiopia. Also, lentil may be deep-fried and eaten as snack, or combined with cereal flour in the preparation of such foods as bread and cake. Large-seeded green lentil is used in salad. Lentil is a key source of protein, especially for the poor, who often cannot afford animal products. Like other food legume crops lentil provides nutritional security to low- income consumers as its seed contains high amounts of digestible protein, macro- and micronutrients (Ca, P, K, Fe, Zn), vitamins (niacin, Vitamin A, Ascorbic Acid, Inositol), fiber and carbohydrates for balanced nutrition. Lentil straw is a valued animal feed throughout West Asia, North and East Africa regions, and sometimes monetary returns to farmers equal that from seed.

Agro-ecology and production environments

The national and international efforts for the last three decades identified the factors of lentil adaptation based on morphological characters, temperature and photoperiod, distribution and amount of rainfall, prevailing abiotic stresses, etc. Understanding of genotype and environment interaction, the local constraints to production and consumer requirements for seed as food and straw as feed, has been a guide to the national and international breeding programs to develop new genetic materials for West Asia, North and East Africa region. The major target agro-ecological regions of production of lentil are:

East Africa - Ethiopia, Sudan, Eritrea, where seed yield, early maturity, resistance root diseases and rust are important;

Mediterranean low to medium elevation <850 asl) - Morocco, Tunisia, Algeria, Jordan, Syria, Turkey, Iran, Lebanon, Iraq, where biomass (seed + straw), drought and heat tolerance, combined resistance to wilt and root rots, rust and ascochyta blight diseases, weed control attributes are key to lentil production;

Highlands (>850 asl) - Anatolian highland of Turkey, Atlas Mountain regions of Morocco and Algeria, where winter-hardiness, biomass, and resistance to ascochyta blight are the major focus.

The lentil breeding programs generally uses parents of diverse origin with known traits with the aim to combine gene(s) that contribute to yield and resistance to major biotic and abiotic stresses, and other morphological traits. Wide crosses among cultigens and with wilds are also done at ICARDA by manipulating planting dates and providing 18 hours extended light period to the parents to attain synchrony in flowering. More than 250 crosses are commissioned at ICARDA every year and the products in the form of yield trials, stress nurseries, segregating populations are distributed to national programs to select promising genotypes for varietal releases. Elite genetic stocks are also conserved in national gene banks for future use.

Major constraints to production

Average lentil yields in West Asia, North and East Africa except Turkey are still low because of cultivation of predominantly local cultivars which have the limited yield potential and are also vulnerable to an array of stresses. The yield limiting factors are lack of seedling vigour, slow leaf area development, high rate of flower drop, low pod setting, poor dry matter, low harvest index, lack of lodging resistance, low or no response to inputs, and subject to various biotic and abiotic stresses. The major abiotic limiting factors to lentil production in these regions are intermittent and terminal drought, high temperatures during pod filling stage, and, at high elevations, cold temperatures in winter, besides mineral imbalances like boron, iron, salinity and sodicity. Among biotic stresses, rust, vascular wilt and ascochyta blight diseases, sitona weevil, broomrape are the major agents for yield loss. Additional constraints to production include agronomic problems of pod dehiscence and lodging, and inadequate crop management, particularly weed management practices by growers. Adequate variability for many of the important traits exists within the crop gene pool allowing manipulation through plant breeding. However, several other important traits, such as biomass yield, pod shedding, nitrogen fixation, aphids and Sitona weevil and the parasitic broomrape (*Orobanche* sp.) are not currently addressable by breeding because of insufficient genetic variation, where appropriate management strategies are applied.

.

Research products and delivery

ICARDA and its partners in the regions searched for desirable genetic variability among >11,000 genetic resources conversed at ICARDA gene bank. Sources of resistance to the above stresses, parents with desirable morphological agronomic traits have been identified and used in breeding programs This has resulted in improved varieties with multiple desirable traits. Simultaneously, appropriate matching production technologies have been developed and transferred to farmers to achieve actual potential yields. Through joint research, a total of 59 lentil varieties have been released by national programs of West Asia, North and East Africa with yield advantages ranging from 12-98%, and many are in pipeline. Some of these varieties have combined resistance to multiple stresses, higher yield potential, high iron and zinc contents, lodging resistance, etc. For example, the red variety 'Alemaya' is popular in Ethiopia (Fig. 1), has high level of resistance to rust and root diseases, excellent phenological adaptation in new cropping niches, attractive seed traits, high iron and zinc. 'Bakria', an early maturing green lentil with resistance to rust have been adopted by farmers in low-rainfall areas of Morocco. 'Idlib-2' (Fig. 2) and 'Idlib-3' (Fig. 3) with higher yield, wilt resistance and erect growth habit are spreading rapidly among farmers in Syria. Of them, Idlib-3 is suitable to low rainfall areas (<280 mm). They also have high Fe and Zinc contents. Likewise 'Firat-87', locally known as 'Commando' and Syran-96 are popular in South-East Anatolia in Turkey, a major hub of red lentil in the region. The winter-hardy variety 'Kafkas' is spreading among farmers in Central Anatolia. Appropriate production packages with seeding time, seed rate, weed management, and other intercultural operations have been disseminated to farmers. Farmers have been trained in improved production technologies and the merits of new varieties.

Harvest mechanization…
…A key issue

Lentil cultivation in West Asia and North Africa has been threatened by rising costs of agricultural labour with hand harvesting accounting for approximately 47% of the total cost of production. Therefore to reduce costs, it is essential that lentil harvest be mechanized. To address this constraint, ICARDA has developed economic machine harvest systems for lentil cultivation involving cultivars with improved standing ability, a flattened seedbed and the use of cutter bars/combine (Fig. 4). The Center has developed and promoted a lentil production package that includes mechanization and the use of improved cultivars with good standing ability. Such cultivars include, Idlib-2, Idlib-3 and 'Idlib-4' in Syria, 'Hala' and 'Rachayya' in Lebanon, 'IPA-98' in Iraq, 'Saliana' and 'Kef' in Tunisia, and 'Firat-87' and 'Sayran-96' in Turkey. On average, mechanical harvesting combined with improved varieties having good standing ability reduces harvest costs by 17-20%.

Effective weed management…
to ensure a better yield

Lentil is poor competitor with weeds and this is attributed to short plant stature and slow early growth. Yield reductions due to weed infestations of up to 84% have been recorded in West Asia. Generally, weeds emerge before or at the time of crop emergence. Among five weed control techniques (preventive, cultural, mechanical, chemical and biological), the farmers in West Asia and North Africa are mostly using preventive, cultural and chemical controls. Farmers use lentil seed free of weed seed, they destroy weeds before flowering and they use clean field equipment to prevent or reduce weed infestations. Farmers also use delay planting until after the first rain to allow weeds to germinate and removed by cultivation, crop rotation, seeding depth and higher seeding rates to reduce effects of weed infestations. Mechanical weed control is rare at farmers' level. In Turkey, both pre-emergence and post-emergence herbicide use is gaining popularity. In general, most farmers still use hand weeding, which increases cost of production. Broomrape is a major menace of lentil production in West Asia and North Africa. To control broomrape, two post emergence application of Imazapic (3 g a.i./ha) is being effectively used by farmers in Syria and Turkey. The first application when lentil seedling is at 5-7 eafed stage followed by second application 2-3 weeks later. Effective weed management is necessary for good lentil crops.

Conclusion

West Asia, North and East Africa are potential regions for lentil cultivation and the crop has a unique place in food and feed systems. Although good progress has been made to develop new cultivars and improved production technologies, its true reflection has not been observed to a desirable level in farmers' fields. Among many varieties available with national programs only a few have been picked up by end users. There is an urgent need to disseminate the improved technologies at hand to farmers through strong extension systems. Farmers also need to be educated through effective training. More research emphasis is needed for drought and heat tolerance in the context of climate change, changing consumers' demands, application of new science, value addition components. **Lentil was..is..and will remain** an integral component of farming and food systems in West Asia, and North and East Africa, but it must be made remunerative to farmers. ■

Figure 1. Alemaya-revolutionized lentil cultivation in Ethiopia: A popular variety

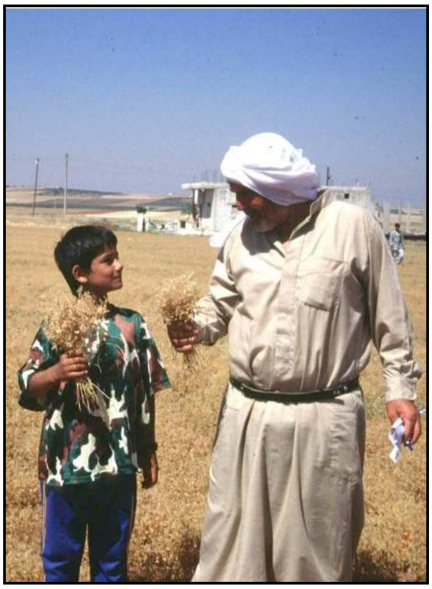


Figure 2. Transfer of production knowledge from a grandfather: Idlib-2 a popular variety in Syria

Figure 3. Idlib-3 is erect and suitable to machine harvest

Figure 4. Local-lodging type; Traditional harvest; Harvest mechanization is important to keep the crop in cropping systems; Idlib-2 is suitable for harvest by double-knife cutter bar

Lentil: An essential high protein food in South Asia

by Gopesh C. SAHA* and Fred J. MUEHLBAUER

Abstract: Lentil is an important source of protein for the people of South Asia where it is consumed almost daily irrespective of caste and wealth. It is consumed as dal, a stew typically seasoned with turmeric, ginger, onion and other spices. In Bangladesh, lentil is mostly cultivated in the Gangetic flood plains in the western part of the country; while in India, lentil is mainly grown in the northeastern states. In Nepal, 95% of the lentil crop is grown in Terai, inner Terai and valley areas where dry, humid and sub-tropical climatic conditions prevail. In Pakistan, lentil is mostly grown in Punjab, Sindh, Baluchistan and North-West Frontier Provinces, with the Punjab having 2/3rds of the total area. In South Asia, lentil has been grown for generations during the winter post rainy season, under rain-fed zero tillage conditions. Crop improvement efforts in this region are focused on increasing productivity through improved disease resistance as well as developing optimum fertilizer and weed management practices. The improvement programs in these countries have developed and released numerous improved varieties that are having a dramatic impact on production.
Key words: biotic stresses, cropping systems, lentil, plant breeding

Lentil is a major source of protein for the people of South Asia where it is consumed almost daily irrespective of caste and wealth in the form of dal, a stew typically seasoned with turmeric, ginger, onion and other spices. Lentil originated in the Near East and was one of the first cultivated crops. Lentil, along with wheat, barley, and other pulses formed the basis of agriculture during the Neolithic period. The presence of carbonized lentil remains indicates that lentil was domesticated in the Indian sub-continent around 2500-2000 BC and integrated into ancestral foods of the Harappan civilization (7).

USDA-ARS and Washington State University, Pullman, USA (gopesh_saha@wsu.edu)

Total area of production in South Asia is estimated at 1.6 million ha which represents nearly 48% of the area planted to lentil in the world. Because much of the lentil crop in this region is grown on marginal lands, this large area produces only 37% of the world's lentil crop. Since overall consumption in this region is around 45% of the world production (8), there is a significant shortage of lentil in this region. Consequently, countries of South Asia have become large importers of lentil and the region has become the world's largest pulse market (5).

Lentil growing areas

In Bangladesh, lentil is mostly cultivated in the Gangetic flood plains in the western part of the country mainly in the greater districts of Faridpur, Jessore, Kustia, Pabna, Rajshahi and Comilla, occupying about 4% of total cropped area (1). In India, lentil is mainly grown in North and northeastern states of Uttar Pradesh, Madhya Pradesh and Bihar which produce %, % and % of Indian lentils, respectively West Bengal, Rajasthan, Assam, Haryana and Punjab also produce lentil on a limited scale (11). In Nepal, 95% of lentil is grown in Terai, inner Terai and valleys areas, where dry, humid to sub-tropical climatic conditions prevail. Lentil is grown in all districts of Nepal except two trans- Himalayan districts of Manang and Mustang. However, ten districts account for 79% of national production. The highest production of lentil was recorded in the Terai region (6). In Pakistan, lentil is mostly grown in Punjab, Sindh, Baluchistan and North-West Frontier Provinces, with the Punjab having 2/3rds of the total lentil area. The districts of Chakwal, Rawalpindi, Narrowal, Gujrat, Jhelum, and Sialkot, with good rainfall and a cool sub-humid climate, account for 51% of Pakistan's lentil production (3).

Production practices

South Asian farmers have been growing pulses for generations during winter (rabi or post rainy season, November to March) under rain-fed zero tillage conditions. Population growth rates have decreased in all the South Asian countries; however, population increases have increased demand for expanded cereal production to achieve food security. This has caused reduced land area devoted to lentil in South Asia. In the areas where irrigation facilities are available, lentil faces serious competition with wheat, boro rice (grown in November to July), oilseeds, potatoes and other profitable winter crops. Consequently, lentil cultivation has increasingly shifted to marginal low input rain-fed areas.

Among the pulses, lentil ranks 1st in Bangladesh and Nepal but 3rd and 4th in India and Pakistan, respectively, based on area and production (8). South Asia produces 1/3rd of world's lentil crop (1.06 million tonnes). India is the second largest (28.6% of the world lentil production) producer in the world after Canada with 37% (8). Among the lentil growing countries in South Asia; India has the largest area and production followed by Nepal, Bangladesh and Pakistan, respectively (8). The small seeded Turkish red micro-sperma type is preferred in South Asia; however, they are low yielding compared to the macro-sperma type, which is in the main type grown in Canada and USA. Though India is the one of the largest producers of lentil, productivity is low)around kg/ha) and ranks 23rd in the world (12). Over the past 10 years, the area of lentil production has remained more or less constant in India and Nepal but significantly decreased in Bangladesh and Pakistan, where there is limited scope for expansion. In 2008, there was a dramatic decrease in lentil growing area in Bangladesh even though productivity is the highest (average yield of 985 kg/ha) among the South Asian countries followed by Nepal, India and Pakistan, respectively (8).

Bangladesh produces only one sixth of demand in the country and consequently has become a major lentil importer accounting for an estimated 11% of total world imports. It has been reported that all the countries of South Asia have a significant production deficit of lentil based on consumption; however, India and Nepal export lentil to Bangladesh and other countries due to higher market value and to complete trade agreements (4, 6).

Cropping system

Lentil is grown in a rice based cropping system as a sole, relay or inter crop in all countries of South Asia with some variation based on soil, land topography and climate. A pulse based cropping system is also practiced with little or no irrigation in some parts of the Indian sub-continent. A study of pulse based cropping systems showed that they were less input-sensitive and environmentally more sustainable when compared to rice based cropping systems (11). The cost benefit ratio showed that lentil is well suited to marginal and poor resources areas. In Bangladesh, the popular crop rotations were: broadcast aus rice (grown in March to July) -fallow-lentil jute-fallow-lentil broadcast aman rice (grown in July to December)-lentil- fallow transplanted aman rice-lentil-jute/ upland rice (1) Some important lentil based cropping systems in India are maize-lentil, moong –lentil and rice-lentil (11). In Nepal, in general, there are two major lentil cropping systems: rice based in inner Terai and valleys (lowland) and maize based in the hills (upland /bari land) are common (6). There is tremendous scope for large areas of southern Bangladesh, and Madhya Pradesh, Bihar and West Bengal in India for the rice-lentil cropping system, currently practiced as rice–fallow cropping system (1, 11). In Sind and Baluchistan provinces of Pakistan, chickpea, lentil and grasspea are grown after rice on residual moisture; while in Punjab and Northwest frontier provinces; chickpea and lentil are grown after rice on residual moisture and fit very well into the rice-wheat cropping system as an alternative to wheat. In late planting situations, short-duration lentil varieties often give better return than wheat (9).

The practice of mixed cropping and intercropping of lentil with other crops provides insurance against complete crop failure, and is characteristics of subsistence farming. Lentil mixed with wheat, mustard, linseed and sugarcane is being followed in some parts of Bangladesh, India, Nepal and Pakistan. Mixed cropping of wheat and lentil, or mustard and lentil, are economically profitable in Bangladesh. The relay cropping system provides the plants more time for vegetative growth while reducing production costs through zero tillage. Lentil relay cropping in transplanted rice fields is a common practice at a greater Comilla, Noakhali and Barisal districts of Bangladesh, where lentil cultivation is almost impossible after rice crop due to medium low land architecture (1). In Nepal, lentil in rotation with rice or relay or immediately after rice harvest, and/or as a mixed crop with wheat, barley, mustard, linseed, grasspea and field pea are grown (6). In Pakistan, lentil is intercropped with wheat or with September-planted sugarcane. Chickpea is generally grown as a relay crop in the standing rice crop in Sind and Baluchistan of Pakistan. It has been reported that a rice-chickpea rotation gives maximum monetary return, followed by rice-lentil and rice-grasspea rotations (9).

Production constraints

Low yield potential and instability of traditional cultivars, biotic and abiotic stresses, poor farming practices, weed infestations, delayed sowing and unfavorable and unpredictable weather conditions are major lentil production constraints in South Asia. Farmers traditionally usually use low rates of seed from their own storage or seeds obtained from neighbouring farmers. Such local varieties generally have low yield potential and are unresponsive to fertilizer and irrigation. Farmers are comfortable with traditional land race germplasm and age-old production practices with minimal inputs and are somewhat reluctant to adopt higher yielding varieties and production packages provided by the national agricultural research systems (NARS). There are continuing efforts to strengthen extension programs in South Asia with the goal of reducing the yield gap between farmer's fields and research station trials.

Lentil production is predominantly in the Yield losses from stemphylium blight (*Stemphylium botryosum*), collar rot (*Sclerotium* rolfsii) and rust (*Uromyces fabae*) are very common in Bangladesh, India, Nepal and Pakistan (13, 14, 15, 18). In some epidemic years, 60% of crop failure has been reported due to these diseases. Botrytis grey mold (BGM) caused by *Botrytis cinerea* has been found common in recent years in Bangladesh, Nepal and Pakistan (13, 17, 18). Pea enation mosaic virus has been found in some introduced lines in Bangladesh (16). Wilt/root rot diseases (caused by *Sclerotinia rolfsii*, *Fusarium oxysporum*, *Pythium*, *Rhizoctonia*), insect infestations (mainly bruchids), and weeds are very common problems in Nepal (18). Lack of rain or heavy rainfall during the flowering and pod filling stages cause considerable yield loss in some years. Due to uncertainty of rainfall and unpredictable precipitation patterns, farmers are sometimes reluctant to apply chemical control measures. The duration of winter growing season after rice harvest is very short (100-110 days) in some regions in South Asia making it difficult for farmers to fit in a crop of lentil. This situation emphasizes the need for short duration high yielding varieties. Cold and frosty weather conditions are problems for lentil cultivation and adversely affect yields in Pakistan (13).

Crop improvement efforts

Lentil is the backbone of nutritional security in South Asia. All the institutes under NARS are mandated to alleviate malnutrition by increasing productivity through improved disease resistant varieties as well as development of optimum fertilizer, irrigation and weed management practices. The International Centre for Agriculture Research in Dry Areas (ICARDA) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) play vital roles in coordinating research with NARS institutions in South Asia for specific problems. Ten lentil varieties with high yield potential and with resistance to biotic and abiotic stresses have been developed by the Bangladesh Agricultural Research Institute (BARI) and the Bangladesh Institute of Nuclear Agriculture (BINA). These varieties have shown a 15-20% yield advantage (2). In India, 23 popular lentil varieties have been developed through pure line selection, mutation and recombination breeding techniques (10). There is potential to increase lentil production through improved disease management and introduction of improved varieties. The Nepalese Agriculture Ministry is attempting to increase productivity and bringing more area under lentil cultivation. Variety improvement work and development of suitable production technology for different agro-ecological zones are major goals in Nepal. National institutes in Nepal have released 8 lentil varieties over the past 25 years and they are about to release three additional varieties (6). The Nuclear Institute for Agriculture and Biology (NIAB) in Faisalabad, Pakistan initiated a lentil improvement program in 1980 and has been actively engaged in lentil improvement through local selection, intraspecific crosses and induced mutations. They successfully developed 7 lentil varieties that have contributing immensely in lentil cultivation in Pakistan (10). ■

Figure 1. Typical lentil market in Bangladesh showing variation for cotyledon colour, seed size as well as decorticated and non decorticated types

References

(1) Afzal MA, Bakr MA, Hamid A, Haque MM, Aktar S (2003) Lentil in Bangladesh. Lentil blackgram and mungbean pilot project. Bangladesh Agricultural Research Institute, Gazipur

(2) Afzal MA, Hamid A, Bakr MA, Sarker A, Erskine W, Haque M, Aktar MS (2004) Technology dissemination to boost pulse production and human nutrition in Bangladesh. 4th International Crop Science Congress Brisbane, Australia, 4-1-2

(3) Anonymous (2005) Pakistan Statistical Year Book

(4) CRN India (2004) Lentil (Masur). http://www.crnindia.com/commodity/masur.html

(5) Dalal S (2010) World's largest pulse market? South Asia! USA Dry Pea & Lentil Council

(6) Deve F, Manunkami R, Bijl B (2007) The lentils sector in Nepal. Project NEP/A1/01A

(7) Erskine W (1997) Lessons for breeders from landraces of lentil. Euphytica 93:107–112

(8) FAOSTAT (2010) FAOSTAT. http://faostat.fao.org/

(9) Haqqani AM, Zahid MA, Malik MR (2000) Legumes in Pakistan. In: Johansen C, Dixbury JM, Virmani SM, Gowda CLL, Pande S, Joshi PK (eds) Legumes in rice and Wheat Cropping Systems of the Indo-Gangetic Plain – Constraints and Opportunities. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India and Cornell University, USA, 98–128

(10) Rahman MM, Sarker A, Kumar S, Ali A, Yadav NK, Lutfor Rahman M (2009) Breeding for short season environments. In: Erskine W, Muehlbauer F, Sarker A, Sharma B (eds) The Lentil: Botany, Production and Uses. CAB International, Wallingford, UK, 121-136

(11) Reddy AA, Reddy GP (2010) Supply side constrains in production of pulses in India: A case study of lentil. Agric Econ Res Rev 23:129-136

(12) Reddy AA (2004) Consumption pattern, trade and production potential of pulses. Econ Polit Wkly 39:4854-4860

(13) Sadiq MS et al (2007) Achieving Sustainable Pulses Production in Pakistan

(14) Saha GC, Sarker A, Chen W, Vandemark GJ, Muehlbauer FJ (2010) Identification of markers associated with genes for rust resistance in *Lens culinaris* Medik. Euphytica 175:261-265

(15) Saha GC, Sarker A, Chen W, Vandemark GJ, Muehlbauer FJ (2010) Inheritance and linkage map positions of genes conferring resistance to *Stemphylium* blight in lentil. Crop Sci 50:1831-1839

(16) Saha GC (2009) PhD Thesis. Washington State University

(17) Uddin J, Sarker A, Podder R, Afzal A, Rashid H, Siddique KHM (2008) Development of new lentil varieties in Bangladesh. Proceedings, 14th Australian Agronomy Conference, Adelaide, Australia, 5654

(18) Yadav SS, Rizvi AH, Manohar M, Shrestha R, Chen C, Bejiga G, Chen W, Yadav M, Bahl PN (2007) Lentil growers. In: Yadav SS, McNeil D, Stevenson PC (eds) Lentil: An ancient crop for modern times. Springer, Dordrecht, the Netherlands, 412-442

Lentil in Australia

by Michael MATERNE[1]*, Larn McMURRAY[2], JanBert BROUWER[1], Trevor BRETAG[1], Jason BRAND[1], Brondwen MACLEAN[3] and Wayne HAWTHORNE[4]

Abstract: Lentil production in Australia has expanded from 300 hectares in 1992 to a maximum of 165,000 hectares in 2002. Acceptance and expansion of lentil production was due to an integrated approach to research that enabled farmers to optimize the use of new cultivars. Support to farmers has been in the form of production packages that include agronomic and pathology advice, and information on quality and marketing issues. New cultivars, practical agronomic and pathology research and targeted extension through highly skilled consultants will enable further expansion of lentil area in Australia led by innovative and professional farmers.
Key words: lentil pathology, lentil varieties, production packages, weed management

Lentil production in Australia has expanded from 300 hectares in 1992 to a maximum of 165,000 hectares in 2002 (Figure 1). Record levels of production are estimated in 2010 as good rainfall across all major lentil growing areas has been complemented by relatively cool spring temperatures. New cultivars, practical agronomic and pathology research, and targeted extension through highly skilled consultants will enable further expansion of lentil area in Australia led by innovative and professional farmers.

A new industry for Australia

Prior to 1993, lentil area in Australia was less than 500 hectares as sporadic attempts to grow the crop were usually unsuccessful. Until this time, Australia imported nearly 2,000 tonnes of lentils annually at a cost of over 1.1 million dollars. The opportunity to grow lentil profitably came with the selection and release of vastly superior cultivars in the early 1990s. The continuing acceptance of the crop by farmers across diverse regions was due to an integrated approach to research that enabled farmers to optimize the use of the new cultivars. Farmer support has come in the form of agronomic packages that include agronomic and pathology advice, and information on quality and marketing issues. This powerful combination of different disciplines has provided much needed confidence and stability during a period when detrimental weather conditions have affected profitability.

A renewed interest in pulses during the late 1980s, initiated more extensive lentil germplasm evaluation in Australia, based largely on advanced germplasm introduced from the International Centre for Agricultural Research in the Dry Areas (ICARDA) located in Syria. ICARDA has the world mandate for lentil improvement and has a successful breeding program in a climatic region similar to southern Australia. Several ICARDA lines were subsequently released as commercial cultivars: the red lentils'Cobber' (ILL5722) and 'Digger' (ILL5728) and the green lentil 'Matilda' (ILL5823) by VDPI in 1993, and the red lentils 'Aldinga' (ILL5750) and 'Northfield' (ILL5588) by SARDI in 1993 and 1994, respectively. These lines dramatically increased yield compared to existing cultivars in the medium rainfall areas of Australia. They also had improved resistance to ascochyta blight, less shattering, earlier flowering and increased plant height. The high yielding red lentil 'Nugget' (ILL7180) was developed by the national lentil breeding program in 2000 and became the most widely grown lentil in Australia.

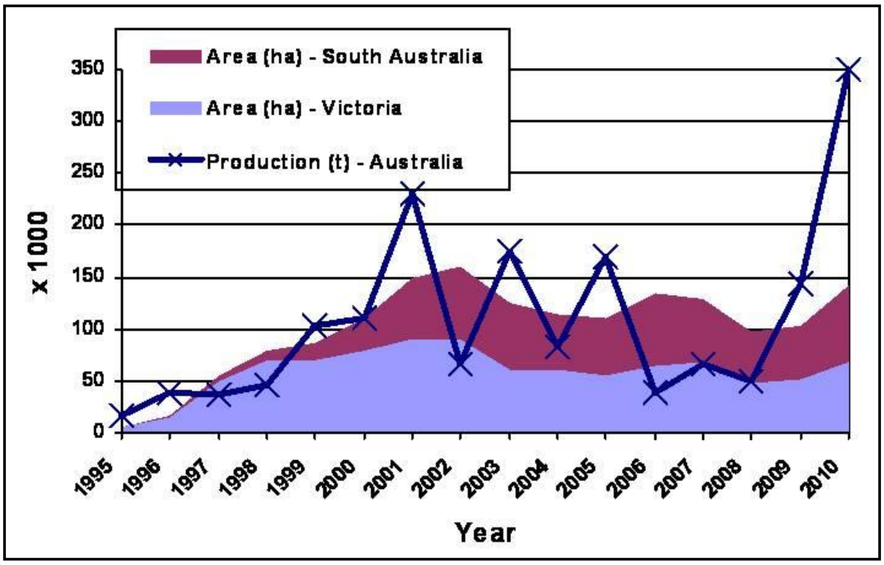


Figure 1. Trends in lentil area (ha) and production ('000 t) in Australia 1995 to 2010 (Source: Pulse Australia and ABARE, 2010 is a production estimate PBA Lentil)

[1]Victorian Department of Primary Industries (VDPI), Horsham, Australia (Michael.Materne@dpi.vic.gov.au)
[2]South Australia Research and Development Institute (SARDI), Adelaide, Australia
[3]Grains Research Development Corporation (GRDC), Kingston, Australia
[4]Pulse Australia, Naracoorte, Australia

Agronomic and disease management experiments have focused on maximising the yield and quality of new lentil cultivars. Early sowing (May) gave the highest yields but presented additional issues of weed and disease control, and increased lodging that made harvesting more difficult. Sowing rates of 100-120 plants/m2 have been found to maximise grain yield of lentil in Australia. These are far lower than in similar climatic regions, such as the Middle East, where higher sowing rates maximise straw yield for use as stock feed.

Ascochyta blight and Botrytis grey mould are the major disease constraints to lentil production and quality In Australia. In some areas lentil are grown every second year in rotations and are a key crop in the success of the farm enterprise. These tight rotations have demonstrated the need for cultivars with good disease resistance and management tools for disease. Integrated disease control is now achieved through cultivar selection, delayed sowing, seed testing, and seed and foliar fungicide treatments. However, a decade of below average rainfall has necessitated early sowing to maximise grain yield and restricted the use of delayed sowing for disease control.

Weed control is an on-going concern for lentil farmers, in particular the control of broad-leaf weeds and herbicide resistant annual ryegrass. Evaluation of the effectiveness of a range of broad-leaf herbicides has been undertaken but the choice of suitable chemicals remains limited. Commercial usage has largely followed the practices adopted and promoted by leading consultants and farmers. Pulse Australia has also been active in facilitating the registration of fungicides, insecticides and herbicides and extending a wide range of information.

All sectors of the industry from government, private consultants and farmers have been involved in research and demonstrations that have driven improved on-farm practices in lentil. Lentil production is highly mechanised in Australia and requires cultivars and agronomic tools that facilitate efficient management, particularly harvesting (Figure 2). The importance of farmer involvement in new crops has been clearly demonstrated by the development of specialised machinery, particularly for sowing and harvest. Much of the agronomic information and machinery, such as flexible fronts for harvesters, have been adopted from Canada. Methods have also been developed or refined to control snails, to roll the soil surface to provide a flat seed bed, to optimise harvest timing and quality through chemical desiccation, and to improve the harvest and precision of growing lentil by satellite navigation, and sowing between rows of standing cereal stubble (Figure 1).
Marketability of lentil remains the main driver for the industry with good links between Pulse Australia, researchers, processors, marketers and farmers.

Status of lentil production in Australia

Red lentils are dominating production in Australia with a small but expanding area of green lentils since the release of the large seeded cultivar 'Boomer' in 2006. A run of dry seasons, frosts and heat events during the reproductive phase since 1996 have reduced yields, production and quality in Australia, especially in Victoria. Australian red lentils are exported to a wide range of countries, particularly those of the Middle East and Indian subcontinent. Australian lentils are known as a clean dry product internationally but quality can be affected by seasonal issues such as high temperatures that kill plants prematurely (2009), frost (1998), rain at harvest (2010) or drought (1997, 2002, 2004, 2006-08). Lentils have been a driving force in the development of processing and packing companies in regional Victoria and South Australia. Globally focused companies are now established in Australia and driving improvements in forward contracts, market signals, processing and access to markets for farmers.

Lentil production is predominantly in the medium winter dominant rainfall areas, 350-450mm annual rainfall, of the Wimmera and southern Mallee in Victoria and the Mid North and Yorke Peninsula in South Australia. Production is confined to better areas of south eastern Australia on alkaline, relatively well drained soils. Lentil is less suited to other areas due to low and erratic yields and low profitability. This is due to relatively high sensitivity to low pH, salinity, boron, waterlogging, drought and rain at harvest that is exacerbated by low biomass and height that makes weed control and harvest difficult. Yield and quality can also be unreliable in areas where lentil is better adapted due to soil, climatic and disease constraints. For the area of lentil to increase in Australia they must be economically attractive for farmers to grow relative to other crop options. For this to occur the key adaptation traits that facilitate increased production (level and reliability of production), farming system benefit (e.g. weed and disease management, time for operations) and price (e.g. quality), or reduced cost (e.g. fungicides) must be addressed through improved cultural practices and breeding.

Breeding to consolidate and expand lentil production in Australia

The history of lentil improvement, both internationally and in Australia, is short compared to the major cereal crops. Lentil improvement in Australia was initially based on overseas research, the strategic importation and evaluation of lentil germplasm and local experience. In 1994 a national lentil breeding program, led by VDPI, was established with financial support from GRDC and other interested state agencies, particularly SARDI. It was to focus on local production issues that were not being addressed through germplasm introduction and aimed to efficiently utilise resources in Australia to develop and release improved lentil cultivars for all potential growing regions of Australia. Lentil breeding is now part of Pulse Breeding Australia with new cultivars delivered to farmers through the commercial seed company PB Seeds based in Horsham, Victoria.

Improved understanding of the phenological responses of lentil and interactions with disease has greatly assisted the Lentil Breeding Program in designing a national breeding program that can provide cultivars with superior adaptation to diverse cropping regions in southern Australia. The breeding and research program has strong links with agronomic research through the Southern Pulse Agronomy and Pathology Projects, funded by GRDC and state agencies, and to local and global processing companies. This program strengthened ties internationally, particularly with ICARDA, the USA and Canada.

Lentil is a primitive crop with little investment internationally and many targets to address if lentil is to expand in Australia, including disease, soil, agronomic (weeds and harvest) and climatic (drought, temperature) constraints. Compared to cereal breeding, lentil breeding faces additional challenges in growing the crop (particularly in summer), slow multiplication rates, a lack of available technologies (eg markers, haploids), a lack of capital to implement technologies, limited germplasm enhancement/pre-breeding research and the effect these have on the cost, risk, adoption of technology and the speed of the breeding process. Although Canada is the major export competitor for Australian lentils, competition for production area in each country is with cereal and oilseed alternatives. With a shared vision to overcome the limitations associated with lentil improvement and increase production compared to cereals, there are opportunities to build on the strong collaboration that exists with the Canadian breeding program.

In the first 15 years of the lentil breeding program there has been a discovery phase where key traits for adaptation and quality have been identified and a diverse range of germplasm explored. Diverse crosses and large populations were used to exploit the full potential of lines used in crossing and maintain diversity within the program. The key breeding outputs for this period were:

1. Small seeded red lentil with resistance to the key diseases, ascochyta blight and botrytis grey mould, to reduce the cost and risk of disease control, enable earlier sowing and improve reliability of yield in favourable areas (Nipper).
2. Broadly adapted (temperature responsive for flowering), disease resistant large green lentils to facilitate a green lentil industry where the price for green lentils exceeds that of red lentils (Boomer).

Figure 2. Harvesting lentil in Australia

3. Higher yielding red lentils with improved NaCl tolerance to expand production into drier areas on poorer soils (PBA Flash, PBA Bounty).
4. Early maturing lentils for 'crop topping' weeds, particularly herbicide resistant ryegrass that have high and reliable yield (PBA Blitz).
5. Imidazolinone resistant lentils to expand the range of herbicides available to farmers (e.g. CIPAL0702).
6. Broadly adapted higher yielding, disease resistant red lentils to stabilise production across diverse years (e.g. CIPAL0803).
7. Lentils with an increase in the height of the lowest pods and lodging resistance to increase the efficiency of harvest and reduce harvesting losses, particularly in drier areas (e.g. CIPAL0802).
8. Lentils with improved drought tolerance to expand area by reducing the number of years of economic loss when rainfall is low (e.g. CIPAL0901).
9. Lentils with high yield in short season areas where biomass production is large (e.g. PBA Jumbo and CIPAL0902).
10. Lentils to expand the production of small (eg Nipper) and larger seeded lentils (e.g. PBA Jumbo).
11. Lentils with tolerance to salinity and boron to further expand production into drier areas with poorer soils.

(The next phase of breeding in Australia will focus on combining traits for high and reliable yield, disease resistance (Ascochyta blight and Botrytis grey mould), tolerance to abiotic stresses (boron, NaCl, drought), harvestability (ability to harvest more effectively and faster - increased height, lodging resistance, even ripening, and reduced pod drop and shattering), and early maturity and resistance to herbicides to further improve reliability of yield and the rotational benefits of lentil. Improvements need to be associated with good visual and processing characteristics for each region of the world (e.g. small, medium and large red lentils with rounded shape and uniform size) and quality attributes that facilitate the production of high quality farmer dressed seed without poor colour (disease resistance, avoidance of heat and drought stress), loose seed coats (improved resistance to rain damage at maturity) or contamination by weed seeds (good weed control), varietal purity (one seed coat colour among cultivars) or soil (good harvestability). This process will require an increased focus on controlled environment screening and made more effective when molecular markers are delivered to the Australia breeding program by the GRDC funded pulse molecular marker project at VDPI. This program has strong linkages with CDC research program at The University of Saskatchewan. Breeding research must also maintain close links with industry and remain well integrated with germplasm enhancement, agronomic, pathology and quality research.

Figure 3. Sowing of lentil between rows of standing cereal stubble in Australia

End point royalties, typically $5.00/tonne, were implemented over 10 years ago with the release of Nugget. Farmer acceptance of end point royalties and compliance rates has been relatively high compared to other crops. Increasing royalty returns may enable private models to be investigated for breeding in the future.

Future of lentil production in Australia

Improvements in lentil profitability and expansion are being driven by the ongoing demand for lentil internationally. Meeting this demand will require improved stability of lentil yields in current production areas, and the development of lentil as a reliable high value pulse in drier areas. In addition the breeding programs must be market driven, ensuring that the crop meets the demands of the end-users.

Estimates are that the area of lentils in Australia will increase to 215,000 ha within 5 years. In the short term, a return to improved growing seasons in Victoria would have a major impact on stabilising production. World prices and the relative price of lentils compared to other crop options will also have a large impact. Lentil production is likely to increase in export focused countries such as Australia, Canada, the USA and some consumer countries as profitability increases due to high prices and the impact of research. However demand and prices have been strong for lentil in the last 15 years. Demand is likely to increase in traditional markets such as the Middle East and Indian subcontinent as population size and incomes increase. Lentil will remain a predominant cash crop in the medium rainfall areas of South Australia and Victoria and the opportunity exists for expansion into drier areas of the SE region in the next 10 years. However the release of drought tolerant cultivars with improved harvestability and imidazolinone resistance in the next 2 years will be critical for success by improving reliability and the control of weeds. ■

Use of lentil for forage and green manure

by Vojislav MIHAILOVIĆ[1], Aleksandar MIKIĆ[1]*, Branko ĆUPINA[2], Đorđe KRSTIĆ[2], Svetlana ANTANASOVIĆ[2], Pero ERIĆ[2] and Sanja VASILJEVIĆ[1]

Abstract: Little is known on the use of lentil (*Lens culinaris* Medik.) for forage and manure production. In the field trials carried out in Novi Sad since 2004, it was confirmed that some genotypes have a greater potential for this purpose. The average green forage yield in 15 lentil accessions was 14.8 t ha^{-1}, with maximum of 26.2 t ha^{-1}. The highest forage dry matter yield was 6.3 t ha^{-1}, being 3.4 t ha^{-1} on average. Aboveground biomass in full bloom may contribute with 95 kg ha^{-1} of nitrogen, while straw provide 33 kg ha^{-1} of nitrogen to the soil fertility.

Key words: forage, green manure, lentil, straw

Many annual cool season legumes, such as pea (*Pisum sativum* L.), vetches (*Vicia* spp.) or grass pea (*Lathyrus sativus* L.), are characterized by diverse ways of use. Apart from human consumption, they have their place in animal feeding in the form of green forage, forage dry matter, forage meal, silage, haylage and straw (1). Being rich in nitrogen, annual legumes are also highly appreciated green manure (2). Not much is known on the use of lentil (*Lens culinaris* Medik.) for these purposes, since its primary production for grain (3).

A joint effort by the Institute of Field and Vegetable Crops and the Faculty of Agriculture in Novi Sad has been made since 2004 in examining the potential of lentil for the forage and green manure. Field trials have been carried out at the Experimental Field of the Institute of Field and Vegetable Crops at Rimski Šančevi, (Fig. 1) in the vicinity of Novi Sad, on a rich and calcareous chernozem soil, including the genotypes from the Novi Sad lentil collection (4).

The results of the trials related to forage production confirmed that there were lentil genotypes with a greater potential for this purpose. All the accessions were sown at the same density as vetches, that is, about 180 viable seeds m^{-2}. The average plant height at the stage of full bloom, considered the optimal for balancing forage yield and quality, was 36 cm, while the average number of stems was 4.6 per plant, with 55.6 internodes plant. The average green forage yield in 15 lentil accessions of different geographic origin and status was 14.8 t ha^{-1}, ranging between 6.1 t ha^{-1} and 26.2 t ha^{-1}. The forage dry matter yield varied from 1.4 t ha^{-1} and 6.3 t ha^{-1}, being 3.4 t ha^{-1} on average. In average, the crude protein content in the lentil forage dry matter was about 174 g kg^{-1}. Although the forage yields in lentil are generally much lower in comparison to those in pea or vetches, its use for forage may be justified in certain cases by the use of appropriate genotype and its short growing season.

If used as green manure and incorporated in the soil, the aboveground biomass in lentil in the stage of full bloom may contribute to its fertility with 95 kg ha^{-1} of nitrogen. In some genotypes, the nitrogen yield of aboveground biomass dry matter may reach 175 kg ha^{-1}. In separate trials, the straw yields were measured. They ranged from 1306 kg ha^{-1} to 4841 kg ha^{-1}, with an average of 2960 kg ha^{-1}. The lentil harvest residues may provide additional 33 kg ha^{-1} of nitrogen to the soil fertility, with 54 kg ha^{-1} of straw nitrogen in some accessions. ■

References

(1) Mikić A, Mihailović V, Ćupina B, Đurić B, Krstić Đ, Vasić M, Vasiljević S, Karagić Đ, Đorđević V (2011) Towards the re-introduction of grass pea (*Lathyrus sativus*) in the West Balkan Countries: the case of Serbia and Srpska (Bosnia and Herzegovina). Food Chem Toxicol 49:650-654

(2) Hauggaard-Nielsen H, Peoples MB, Jensen ES (2011) Faba bean in cropping systems. Grain Legum 56:32-33

(3) Vandenberg A (2010) Lentil production, research and development in Canada. J Lentil Res 4:75-77

(4) Vasić M, Mihailović V, Mikić A, Gvozdanović-Varga J, Ćupina B (2010) Genetic resources of lentil (*Lens culinaris*) in Serbia. J Lentil Res 4:50-51

Figure 1. Field trials with growing lentil for forage at Rimski Šančevi

[1]Institute of Field and Vegetable Crops, Forage Crops Department, Novi Sad, Serbia (aleksandar.mikic@ifvcns.ns.ac.rs, aleksandar.mikich@gmail.com)
[2]University of Novi Sad, Faculty of Agriculture, Department of Field and Vegetable Crops, Novi Sad, Serbia

Lentil: An ancient crop for modern times

(2007)

S. Yadav, D. McNeil, and P. Stevenson (eds)

Springer

The lentil is one of the first foods to have been cultivated and has maintained excellent socio-economic value for over 8,000 years. The ancient crop is now a crop for modern times in both developing and developed countries today. The international market in recent years has increased significantly and this crop is gaining an important place in cropping systems under different ecologies. It is grown in over 35 countries, has a broad range of uses around the world, and the different seed and plant types adapted to an increasingly wide range of ecologies makes this comprehensive volume even more important today. This book covers all aspects of diversity, breeding and production technologies, and the contents include: Origin, adaptation, ecology and diversity; Utilization, nutrition and production technologies; Genetic enhancement, mutation and wild relatives; Breeding methods and lensomics achievements; Productivity, profitability and world trade. Hardcover, 462 pages.

Lentil: Botany, production and uses

(2009)

W. Erskine, F.J. Muehlbauer, A. Sarker and B. Sharma (eds)

CABI

The lentil has an ancient origin but is now confronted with issues of food security, poverty, water scarcity and the need to find sustainable agricultural systems in a changing climate. A crop primarily grown in the developing world, it is ideally suited to address these issues through its ability to use water efficiently and grow in marginal environments as well as being high in protein and easily digestible. In the last three decades, the global production of lentils has almost tripled due to larger harvest areas but also more importantly to progress in research and productivity. Chapters outline improvements in production, such as water and soil nutrient management, agronomy, mechanization and weed management. Developments in genetics and breeding are discussed alongside improved knowledge of the lentils origin, domestication, morphology and adaptation. The implementation and impact of this new research at the farm level is also addressed as well as the crops post-harvest processing and nutritional value. Hardcover, 464 pages.

PERIODICALS

Bean Improvement Cooperative Annual Report

http://www.css.msu.edu/bic/Reports.cfm

Journal of Lentil Research

drbrsh@yahoo.co.in

Lathyrus Lathyrism Newsletter

http://www.clima.uwa.edu.au/news/lathyrus

Legume Research

http://www.indianjournals.com/ijor.aspx?target=ijor:lr&type=home

Pisum Genetics

http://hermes.bionet.nsc.ru/pg/

Soybean Genetics Newsletter

http://www.soygenetics.org

EVENTS

IIIrd International Ascochyta Workshop

Córdoba, Spain, 22-26 April 2012
http://www.ascochyta.org/en/index.html

24th General Meeting of the European Grassland Federation

Lublin, Poland, 3-7 June 2012
http://www.egf2012.pl/

12th Congress of the European Society for Agronomy

Helsinki, Finland, 20-24 August 2012
http://www.esa12.fi/

VIth International Conference on Legume Genetics and Genomics

Hyderabad, India, 2-7 October 2012
http://www.icrisat.org/gt-bt/VI-ICLGG/Homepage.htm

First Legume Society Conference

Novi Sad, Serbia, 20-24 May 2013
legume.society@gmail.com

Ascochyta 2012

Technical platforms for progress in research and extension
Córdoba, Spain, 22-26 April 2012

Ascochyta blights are devastating necrotrophic foliar fungal diseases of cool season food and forage legumes. All major cool season food legumes have ascochyta blight as a major disease: faba bean can be severely damaged by *Ascochyta fabae*, lentil by *A. lentis,* chickpea by *A. rabiei;* and *peas* by *A. pisi, Mycosphaerella pinodes* or *Phoma spp.* The organizers of the workshop hope to promote international collaborative research toward developing control measures, including resistant germplasm, against these particularly devastating diseases.

The University of Córdoba (UCO), the Institute of Sustainable Agriculture (IAS-CSIC) and the Institute of Agricultural and Fishery Research and Training (IFAPA) located at Córdoba (Spain) will organize the third International Ascochyta Workshop (**Ascochyta 2012**) on legumes to be held at the University of Córdoba, Córdoba, Spain from **22 to 26 April 2012**.

Ascochyta 2012 will build on results of the first two workshops held at Le Tronchet, France in 2006 and Pullman, USA in 2009 that were focussed on 'Identifying priorities for collaborative research' and 'Global Research Initiatives', respectively. Following previous experience, the third workshop will be organized to maximise exchanges of knowledge/information among participants. Ascochyta 2012 will be directed toward the development of 'Technical platforms for progress in research and extension.'

Thematic sessions will include: pathogen biology and epidemiology, host-pathogen interactions, genetics and breeding for resistance, and disease measurement, modelling and management. Available ´omics´ data and tools including transcript, protein and metabolic studies as well as genome sequencing and annotation and functional mapping will be included in the thematically relevant sessions. All sessions will include an introductory presentation by an invited speaker, short presentations of selected abstracts and general and interactive discussions.

Finally, a special session on screening techniques, with a focus on understanding pathogen variability and standardization of screening procedures including methods of inoculation. Traditional and molecular disease-scoring procedures will be included.

Networking sessions, to foster future interactions among scientists concerned with ascochyta blight of the cool season food legumes, will be organized and led by a chair chosen by the participants. In addition, a **concluding session** to be organized by chairpersons of each session will be used to present the conclusions of the workshop and discuss any developing networks of collaboration.

Pre-registration will begin on 1st June 2011. The registration period and abstract submission will be from **15th November 2011 to 31st January 2012**. The workshop will be strictly **limited to 80** participants and we will give first priority to participants who register and submit an abstract. Participants who register without submitting an abstract will have priority on a first come first served basis. Abstracts that are not presented by an author will not be published in the proceedings or on the website. The **Website, http://www.ascochyta.org/ or http://www.ascochyta.es/** will be available end of January 2011.

Local organizing committee:

Teresa Millan, teresa.millan@uco.es, Juan Gil, ge1gilij@uco.es, Mª Dolores Fernandez-Romero, ge2ferom@uco.es, Adoracion Cabrera, ge1cabca@uco.es, *Dpto. de Genetica, Universidad de Córdoba (UCO), Campus de Rabanales Edificio, C5 2ª planta, 14071 Córdoba, Spain*

Josefa Rubio, josefam.rubio@juntadeandalucia.es, Carmen Avila, carmenm.avila@juntadeandalucia.es, *Area de Mejora y Biotecnologia (IFAPA), Apdo. 3092, Alameda Obispo S/N, 14080 Córdoba, Spain*

Diego Rubiales, diego.rubiales@ias.csic.es, Sara Fondevilla, cr2foaps@uco.es, *Instituto de Agricultura Sostenible (IAS-CSIC), Apdo. 4084, Alameda Obispo S/N, 14080 Córdoba, Spain*

Scientific Committee:

Sabine Banniza, sabine.banniza@usask.ca, Alain Baranger, alain.baranger@rennes.inra.fr, Weidong Chen, w-chen@wsu.edu, Jenny Davidson, davidson.jenny@saugov.sa.gov.au, Sara Fondevilla, cr2foaps@uco.es, Pooran Gaur, p.gaur@cgiar.org, Juan Gil, ge1gilij@uco.es, Muhammed Imtiaz, m.imtiaz@cgiar.org, Mohammed Kharrat, kharrat.mohamed@iresa.agrinet.tn, Teresa Millan, teresa.millan@uco.es, Fred Muehlbauer, muehlbau@wsu.edu, Tobin Peever, tpeever@wsu.edu, Diego Rubiales, diego.rubiales@ias.csic.es, Ashutosh Sarker, a.sarker@cgiar.org, Seid Ahmed Kemal, s.a.kemal@cgiar.org, Paul Taylor, paulwjt@unimelb.edu.au, Bernard Tivoli, bernard.tivoli@rennes.inra.fr

GRAIN LEGUMES

Sponsorship list

EUROPEAN ASSOCIATION FOR GRAIN LEGUME RESEARCH

LEGUME SOCIETY

INSTITUTE OF FIELD AND VEGETABLE CROPS
NOVI SAD, SERBIA
www.nsseme.com

UNIVERSITY OF HELSINKI
HELSINKI, FINLAND
www.helsinki.fi/university

WASHINGTON STATE UNIVERSITY
PULLMAN, WA, USA
wsu.edu

SPANISH MINISTRY OF SCIENCE AND INNOVATION
SPANISH NATIONAL RESEARCH COUNCIL
www.csic.es

Want to help the legume research network in Europe and worldwide?

Support Legume Society and become its sponsor today!

legume.society@gmail.com