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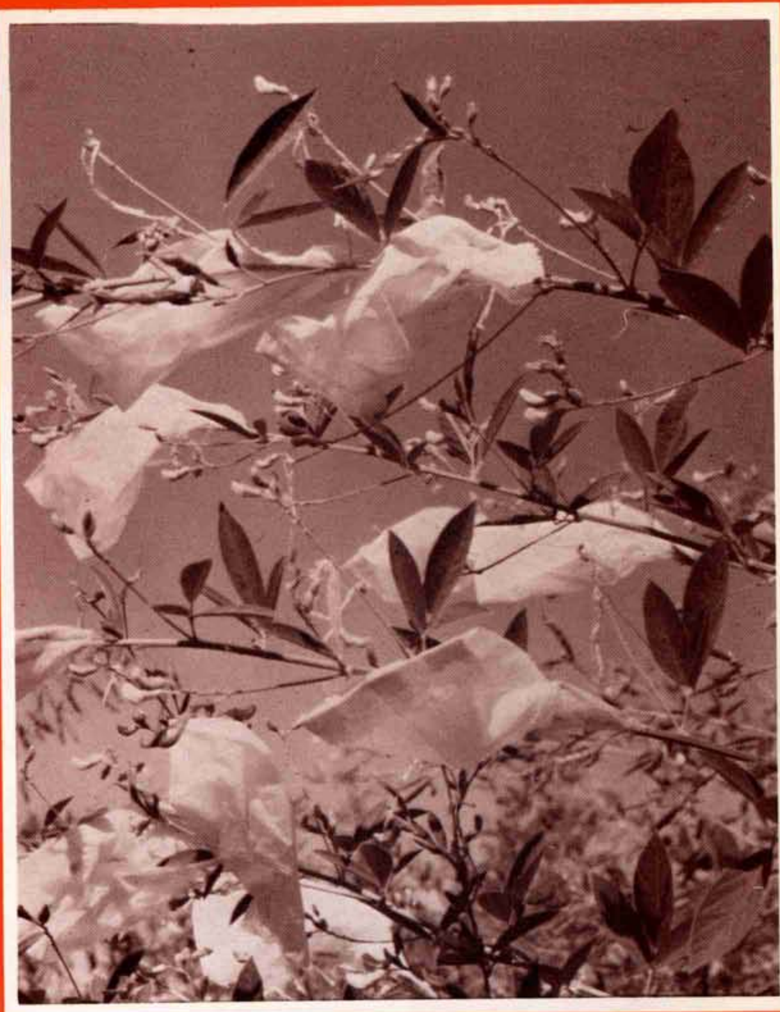

Food Legume Improvement and Development

Proceedings of a workshop held at The University of Aleppo, Syria, 2-7 May 1978

Geoffrey C. Hawtin and George J. Chancellor, Editors

CANADA

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Strategies for the Genetic Improvement of Lentils, Broad Beans, and Chick-peas, with Special Emphasis on Research at ICARDA

Geoffrey C. Hawtin

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With the establishment of ICARDA in 1977, incorporating the food legume improvement program of ALAD, which was originally initiated in 1972 with funding from IDRC, a considerable expansion in the objectives and scope of legume improvement activities became possible.

The overall objective of the food legume breeding program of ICARDA is thus to encourage and support national food legume improvement efforts through:

- the collection, maintenance, development, and distribution of genetic materials of lentils (*Lens culinaris*), broad beans (*Vicia faba*), and chick-peas (*Cicer arietinum*);
- the undertaking of genetic improvement work and applied research in the areas of breeding and genetics, and the widespread dissemination of research results;
- the training of scientists from the national research programs of the region in the techniques and theory of food legume improvement; and
- the building of an international network of food legume researchers to engender increased cooperation and understanding between programs and thereby to facilitate the free exchange of research results and materials.

The International Cooperative Breeding Program

Breeding work is being conducted in Syria and Lebanon to serve the needs of the low and medium elevation Mediterranean-type environments, and near Tabriz in northern Iran for the development of food legumes adapted to the more extreme high elevation conditions. Although these locations represent a considerable range of environments, they are not representative of the entire range of conditions under which broad beans, lentils, and chick-peas are grown throughout the world; from the Andean region of Latin America and the irrigated conditions of Egypt and the Sudan to the "Rabi" production following the monsoon in India and Southeast Asia.

To adequately address the needs of the national programs in all these differing environments, the ALAD Regional Nursery Program has been expanded into an International Cooperative Breeding Program that aims: to provide for the widespread dissemination of promising elite genetic materials; to make available to the national programs materials exhibiting special characteristics (such as disease resistance) for further evaluation, testing, and possibly also hybridization; to disseminate promising early generation segregating material for development under local environments; and to provide a mechanism for the multilocation testing of elite lines to reduce the time necessary for evaluation prior to cultivar release and allow the identification of genotypes with wide adaptability.

The materials distributed by ICARDA under this program include nurseries of selected germ plasm and(or) advanced lines for screening, evaluation, or hybridization; early generation segregating populations (usually F3 bulks); and yield trials.

Lentil Breeding

The lentil improvement program aims to develop materials of both the *macrospermae* and *microspermae* types with acceptable organoleptic and nutritional quality and possessing the following attributes:

A high and stable dry seed yield through:

- an inherently high yield potential
- tolerance to stress conditions (cold, heat, drought, salinity)
- resistance to the major diseases and pests (including *Orobanche*)
- high plasticity;

A wide adaptability, primarily as a result of reduced photoperiod and temperature sensitivity;

A high total biological yield;

Characteristics suited to mechanized harvesting:

- a tall erect growth habit
- resistance to lodging and pod shattering
- pods borne high above the ground.

Disease and Pest Resistance

Lentils are comparatively free from major disease problems. However, the most serious and ubiquitous problem is wilt, a disease that can be caused by a complex of a number of different pathogens including *Fusarium oxysporum* F.sp. *lentis*, *F. orthoceras*, *F. avenaceum*, *Rhizoctonia solani*, and *Sclerotium rolfsii*. Survey work is urgently required to establish the relative importance and distribution of these pathogens, so that breeding efforts can be directed toward developing multiple resistance to the most important species.

The only other disease of major importance in lentils is rust, caused by *Uromyces fabae*, which can be particularly severe in some parts of the Indian sub-continent, but is rarely a major problem in the Middle East. Some sources of rust resistance have already been identified in India, and it is planned to screen for further sources of resistance in the field using artificial inoculation techniques, at a coastal location in Syria, where the disease can be severe.

Breeding for resistance to other lentil diseases, such as downy mildew (*Peronospora lentis*), *Ascochyta* blight (*Ascochyta lentis*), pea enation mosaic virus (PEMV), alfalfa mosaic virus (AMV), bean yellow mosaic virus (BYMV), and pea leaf roll virus (PLRV), will only receive minor attention at present.

Several insect pests have been reported to cause severe losses in lentils both in the field and in store. These include: pod borers (*Etiella zinckinella*), reported to be the major insect field pest of lentils in India; several species of aphids; *Sitona* weevils; and storage pests, such as the lentil beetle (*Bruchus analis*). No good sources of resistance have been reported to any of these pests, although differential reactions to infestation have been observed and there are other encouraging signs that the development of resistant cultivars may be possible. In breeding for resistance to bruchid beetles care must be taken to ensure that resistance is not associated with poor cooking quality.

Initial screening of lentil germ plasm for resistance to the parasitic weed *Orobanche* is under way and cultivar differences in the degree of susceptibility have already been recorded. This work will be continued and expanded in the future.

Wider Adaptability

Lentils are long-day sensitive plants and it is felt that this is an important factor contributing to the very narrow adaptability of most local cultivars. Narrow adaptability severely limits the progress that can be made through breeding, and the development of cultivars with a reduced photoperiod/temperature sensitivity is thus an important objective of the program. In an attempt to achieve this, selections will be made alternately for yielding ability under long-day conditions (in Aleppo or Tabriz), and for earliness and vigour under short days (in Egypt or Ethiopia) in generations following crosses between genotypes adapted to each environment.

Genotypes with wide adaptability can also be identified through the international cooperative trials and nurseries, and in fact several lines identified as being widely adapted in nurseries conducted under the ALAD program have already been included as parents in the hybridization program at ICARDA.

Improved Plant Ideotype

The development of plants with a larger vegetative frame and a high total biological yield is considered to be of great importance in the strategy for lentil improvement. This is primarily because a high total biological yield is indicative of improved efficiency characteristics, such as a high crop growth rate (CGR) and leaf area index (LAI), and will result in a higher total seed yield, providing that the harvest index is not allowed to fall. In addition, larger, more plastic plants might be reasonably expected to be more stable and to have lower optimum seeding rates, thus allowing considerable savings on the very high rates of seed currently used in much of the region. Combined with resistance to lodging such plants would also allow for easier mechanized harvesting, and would furthermore provide an increased volume of straw for animal fodder, which is a very important consideration in many countries. A more vigorous early growth might also increase the crop's competitiveness with weeds.

The identification of genotypes capable of continued growth at the high temperatures that frequently limit the spring growth of present cultivars, might be a useful start on the road to the development of cultivars with a higher total biological yield.

Germ Plasm

The conservation of genetic resources of lentils has received relatively little attention and germ-plasm collections are generally considered incomplete. The ICARDA collection now stands at nearly 4500 accessions and although many countries are well represented (Table 1), more germ plasm is being sought, especially from North Africa, Bangladesh, the

TABLE 1. Origin of lentil and broad bean entries in the ICARDA germ-plasm collections.

Country	No. accessions		Country	No. accessions	
	Lentils	Broad beans		Lentils	Broad beans
Afghanistan	116	89	Japan	–	5
Algeria	8	18	Jordan	38	9
Argentina	3	1	Lebanon	47	14
Bulgaria	2	1	Mexico	24	1
Bolivia	–	1	Morocco	16	13
Canada	1	–	Nepal	10	1
Chile	178	3	Pakistan	24	6
Colombia	10	14	Palestine	1	7
Costa Rica	1	–	Peru	2	1
Ceylon	–	2	Poland	–	12
Cyprus	6	10	Portugal	–	5
Czechoslovakia	1	–	S. Africa	–	1
Ecuador	6	13	Somalia	1	–
Egypt	62	59	Spain	10	62
Ethiopia	359	105	Sudan	1	32
Finland	–	23	Sweden	–	9
France	2	11	Switzerland	–	1
Germany	–	41	Syria	92	38
Greece	53	5	Tunisia	7	38
Guatemala	3	–	Turkey	290	119
Holland	–	98	UK	–	69
Hungary	49	12	USA	–	3
India	1759	7	USSR	65	21
Iran	1006	13	Yemen	3	5
Iraq	20	49	Yugoslavia	22	14
Italy	5	4	Unknown	10	234

USSR, and countries of Central and South America. Special emphasis is being placed throughout west Asia on the collection of wild *Lens* species. Descriptors are currently being developed, the data will be computerized, and it is intended to produce a complete germ-plasm catalogue in the near future.

Breeding Methodology

Most of the cultivars released throughout the world to date have been derived by selection from germ plasm as opposed to hybridization programs. The degree of further genetic improvement possible by continued selection from local germ plasm is expected to be limited in most countries and major yield advances are only expected to result from selections following hybridization.

Lentils are almost completely self-pollinated and artificial cross-pollination is made difficult by the small and delicate flowers. Crossing under field conditions has thus proved particularly difficult. However, high success rates (over 70%) have been achieved from crosses in greenhouses, where the plants are sown in early autumn and flowering is induced, and synchronized, by creating artificial long-day (18–20 hours) conditions during the winter.

Due to the difficulty in crossing, the major part of the ICARDA lentil improvement work follows modified pedigree or bulk population methods. Efforts, however, are being made to develop techniques for making a large number of crosses under field conditions and thereby enabling the use of population improvement methods, such as modified recurrent selection.

Other breeding methods, including induced mutation and interspecific hybridization, will also be considered, especially for the development of specific characters for which genes are not available in the germ-plasm collection. A number of crosses have already been made with the wild species *Lens orientalis* (considered by some to be conspecific with *L. culinaris*) with the main aim of developing drought resistance. Although the two species cross readily, the work is still at an early stage and the usefulness of these wide crosses in lentil improvement remains to be firmly established.

Broad Bean Breeding

The main objectives of broad bean improvement at ICARDA are to develop a range of materials having different maturities and seed sizes together with the following characteristics:

A high and stable dry seed yield through:

- resistance to the major diseases and pests (including *Orobanche*)
- tolerance to stress conditions (cold, heat, drought, and salinity)
- a more efficient growth habit
- increased autofertility
- reduced flower drop;

A wider adaptability;

Resistance to lodging, pod-shattering, and storage pests;

A high total biological yield;

An improved nutritional value, especially increased protein quantity, together with reduced levels of toxic factors, and maintained protein and cooking qualities.

Although the major emphasis of the program is geared to the development of the crop for dry seed production, some attempts will also be made at genetic improvement for the production of green seed and pods.

Diseases and Pest Resistance

Broad beans are particularly susceptible to damage resulting from disease infection. A wide range of diseases, including pathogens of the root rot/wilt complex, chocolate spot (*Botrytis fabae*), *Ascochyta* blight (*Ascochyta fabae*), brown spot (*Alternaria* sp.), powdery mildew (*Erisyphe polygoni* and *Leveiulla taurica*), rust (*Uromyces fabae*), and several viruses, have been reported to cause serious economic losses. Diseases are in general a greater problem under more humid environments than with irrigated production under dry conditions. In recognition of this, ICARDA's program concentrates its efforts toward the development of resistance (multiple where possible) at a humid Mediterranean coastal site near Lattakia. Few good sources of resistance have so far been discovered and it is expected that emphasis will have to be placed upon building up resistance levels through population improvement methods for the accumulation of minor resistance genes. For certain specific diseases the use of induced mutation may also be considered in the future.

The most important insect pests of broad bean are aphids. Differential reactions to infestations of this pest have been observed in the ICARDA germ-plasm collection and breeders elsewhere have reported useful levels of aphid resistance and demonstrated the value of this in increasing seed yields.

Orobanche is also a major problem in this crop, causing serious losses. Several breeders have reported finding useful levels of resistance and the ICARDA germ-plasm collection is currently being grown in artificially infested pots as a preliminary screening for resistance. As with the development of disease and aphid resistance, it is expected that population improvement methods will prove most useful in raising *Orobanche* resistance levels.

Improved Plant Ideotype

The opportunity for alterations in plant growth habit in broad beans is considerable. Although little work has yet been carried out on the establishment of optimum plant ideotypes for different agroecological conditions, types having a greater degree of determinacy, less top growth, a greater synchronization of flowering, reduced height, a canopy structure allowing increased light penetration, and reduced tillering are being sought in initial improvement efforts. Genes affecting all these characteristics are available and are at present being utilized.

Autofertility

Many broad bean cultivars require tripping of the flowers by bees in order to obtain maximum seed set. In the absence of insect pollinators (which can be caused by spraying against insect pests), seed yield may be reduced. However, because most of the autofertile lines so far discovered have originated outside the Middle East and most of the autofertility work has been carried out in northern Europe, the extent of the problem in this region is not yet clear. A selection pressure in favour of autofertility may be applied through the currently used breeding methods involving selfing through bagging or growing the plants in insect-free cages if artificial tripping is not practiced.

Nutritional Factors

One screening of 511 accessions from the germ-plasm collection at ICARDA has resulted in values in excess of 37% protein (N × 6.25, dry weight basis) being recorded. A population of high protein lines was initiated in 1976 and this will be advanced through recurrent selection with S_1 or S_2 testing. Protein levels of greater than 40% with no concurrent loss in yield are considered possible by some researchers.

The occurrence of the disease favism has been widely reported in the Mediterranean region. Little work has been carried out on this problem, but the presence of two pyrimidines (divicine and isouramil) has been tentatively identified as the cause in genetically susceptible humans. Once the causal agents have been firmly established, screening methods can be developed for their estimation and attempts to breed for nontoxic types can be initiated.

Apart from these two positive nutritional improvement aspects, all advanced lines of lentils and chick-peas as well as broad beans will be routinely screened to ensure that their nutritional and organoleptic properties do not fall below acceptable standards.

Germ Plasm

The ICARDA germ-plasm collection contains only 1300 entries, making it the smallest of the food legume collections retained at the centre (Table 1). Efforts are thus continually being made to expand the collection, germ plasm being especially sought from China (which accounts for two-thirds of the world broad bean production), the Indian subcontinent, eastern Europe, and Central and South America. Germ plasm from northern Europe frequently fails to set seed under the conditions of this region and assistance in the maintenance of this material is currently being sought.

Broad beans are a partially outcrossed species. In the 1975–76 nurseries in Egypt, for example, outcrossing ranged from 11% between rows (spaced at 65 cm) and 33% between plants at one location to over 20% between rows and 40% between plants at another. As a consequence of this high level of natural outcrossing, the germ plasm at ICARDA is maintained in two separate collections: a broad-based collection in which no attempt is made to purify accessions except by subdivision; and a working collection of inbred lines, developed through the selfing of individual plants within the broad-based collection.

Breeding Methodology

As a result of their high degree of outcrossing, ICARDA's approach to breeding broad beans involves considering the crop as both self-pollinated and cross-pollinated.

Development of Pure Lines

Since its initiation at Tel Amara (Lebanon) in 1975, the hybridization program has involved approximately 750 field crosses. Both bulk population and pedigree methods of selection are being followed and compared. No pollination control is normally attempted in early generations; but a separate system, involving the bagging of one or two plants in each progeny row and basing selection of the selfed plants on the performance of the open pollinated family, is currently being tested. This method allows a more rapid increase in homozygosity, enabling the required levels of phenotypic uniformity to be achieved in fewer generations and at the same time permits selection for high autofertility.

There is some evidence of inbreeding depression in broad beans, and selection of inbred lines for high yield and autofertility is thus under way among lines derived from the germ plasm. The best selected lines, together with advanced inbred lines from the hybridization program, will be tested for general combining ability (GCA) and synthetic varieties, composed of inbred lines with high GCA's, will be constituted and evaluated.

Population Improvement

A program of recurrent selection has been started and for this purpose three populations were initiated in 1976–77 and a further three during the present cropping season. Following three or four generations of random intercrossing using honeybees in cages, it is proposed to follow either an S_2 testing (4 seasons, 2 years/cycle) system if recombination can be carried out in the off seasons, or an S_1 system (involving 3 seasons and 2 years/cycle) if recombination using honeybees proves to be only feasible in the main season.

It is proposed to develop a series of mainstream populations based primarily on seed size, maturity, and major adaptation group, and another series of subpopulations for particular characters, such as disease, pest, and *Orobanche* resistance, protein content, etc. When the frequency of desirable genes has increased to a sufficient level in these subpopulations, they will be introgressed with the mainstream ones through intermediate "back-up" populations.

Hybrid bulk populations from the recurrent selection program will be distributed to national programs through the international scheme and will serve as a source of genetic variation for the future development of pure lines as well as a basic population for further improvement by mass selection or for direct release.

Male Sterility

All attempts at crossing between *V. faba* and other *Vicia* species have so far proved unsuccessful. Work on this aspect will be encouraged, however, due to the great potential for improvement by this method; for example, one of the closest relatives of the broad bean, *V. narbonensis*, a wild weedy species found in the region, has been shown to have resistance to a number of diseases and pests, including chocolate spot, *Ascochyta* blight, and certain aphid species.

Chick-Pea Breeding

ICARDA and ICRISAT are working very closely to ensure a good coordination of the activities of their respective chick-pea programs: research at ICARDA is emphasizing the kabuli cultivars, and that at ICRISAT mainly the desi types.

The ICARDA chick-pea improvement program thus focuses on the development of kabuli materials with the following attributes:

A high and stable dry yield through:

- an inherently high yield potential
- tolerance to stress conditions (cold, heat, drought, and salinity)
- resistance to the major diseases and pests (*Ascochyta* blight, root rot/wilt, pod borers, and leaf miners);

A wide adaptation;

A high total biological yield;

Characteristics suited to mechanized harvesting.

Winter Planting

Throughout western Asia, chick-peas are, in general, planted in the spring and grown on residual moisture. It has been well demonstrated that autumn planting could dramatically increase seed yield; however, the greatly increased risk of a severe attack of *Ascochyta* blight normally prevents this practice. An autumn-sown trial at Aleppo in 1978 has shown one entry (NEC 2305) to have a moderate level of resistance to *Ascochyta*; all the other entries in the trial were almost completely destroyed by the disease. This entry produced a yield of over 3 tonnes of seed per hectare as compared to the 950 kg/ha produced by the same variety when spring planted.

At low and medium elevations in the region, much of the material tested to date has shown sufficient cold tolerance to survive the winter and so the prospects for increasing yield through autumn-planted varieties appear promising. Special breeding efforts are, however, planned for the Tabriz site to develop adequate cold tolerance for the plants to survive the extreme winter conditions of the high plateau region.

Disease and Pest Resistance

Ascochyta blight is without doubt the most economically important disease of chick-peas throughout the region. Not only does it prevent the practice of winter planting, but it is also a major yield-limiting factor in the spring-sown crop. Resistance to the disease has been reported, but it is almost exclusively confined to desi cultivars.

A preliminary screening nursery at ICARDA in 1977–78, involving 1200 kabuli cultivars, has revealed about 30 entries with a moderate level of resistance and 7 entries that failed to show any disease symptoms at all. Although it is still necessary to confirm these findings at other locations, the indications that resistant kabuli cultivars can be developed seem promising.

The wild species *C. reticulatum* appears to be a promising source of resistance genes, and one accession has been found to be very highly resistant in seedling tests carried out at ICRISAT.

Improved Plant Type

Several lines originating from the USSR are currently being used as a source of genes for the development of a taller, more erect plant type, which would both facilitate mechanized harvesting and should also result in higher yields at high plant population levels. Some progenies of crosses between these lines and locally adapted types appear very promising in this respect.

The "double podding" condition, where two flowers are produced per peduncle instead of the normal one, is a further character that may be important in increasing the yield potential and stability. Research is also under way on this aspect.

Germ Plasm

A world germ-plasm collection has been developed at ICRISAT and it is planned that a duplicate of this collection will be maintained at ICARDA. A subcollection of kabuli types is also being developed at ICARDA as a working collection.

Breeding Methodology

It is estimated that approximately 75% of the chick-pea production in the main producing areas arises from unselected landraces and, of the improved cultivars that have been released, almost all have originated from selections from this germ-plasm base.

Chick-peas are comparatively easy to cross under field conditions and with the establishment of both the ICRISAT and ICARDA programs, large-scale crossing can be undertaken, allowing the development of population improvement methods in addition to the pedigree or bulk methods traditionally used in chick-pea breeding.

One approach currently being followed is the introgression of kabuli and desi germ plasm. These two groups have been separated for many hundreds of years and it is therefore probable that the genetic divergences between them are appreciable. The introduction of new "exotic" genes into locally adapted cultivars may thus result in significant yield advances, especially in the improvement of kabuli types, for which the available germ-plasm base is considerably narrower. There is some evidence, however, that coadaptation is important in chick-peas and that wide crossing tends to break up coadapted gene blocks. If this is the case, then backcrossing to the adapted parent would help to prevent excessive adaptation breakdown, while at the same time giving the added advantage of increasing the frequency of genes for acceptable seed characters (the small, coloured seeds of the desi types being unacceptable throughout most of the Middle East). Work on this scheme was started in 1975 with 158 kabuli × desi crosses, and 217 back crosses and three-way crosses were made in 1977. The effectiveness of this method, however, still awaits a more comprehensive evaluation.