Lentil in South Asia

W. Erskine
M.C. Saxena

editors

International Center for Agricultural Research in the Dry Areas

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Lentil in South Asia

Proceedings of the Seminar on Lentil in South Asia, 11—15 March 1991, New Delhi, India

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Contents

Foreword

Lentil is a staple pulse in developing countries, where it complements the cereal-rich diet of the people, particularly those in the low-income group. It is consumed either as a whole seed or after decortication. The milling wastes and the straw provide nutritious feed for animals.

In recent years the world area under lentil has been around 3.0 million hectares, of which half is in South Asia. The crop is a winter pulse grown in a wide range of agroecological zones and cropping systems, diversifying the cereal-based cropping pattern and breaking the nutrient depletion and disease cycles.

The International Center for Agricultural Research in the Dry Areas (ICARDA) has the world-wide mandate for research and training on lentil improvement. Owing to the geographic location of the Center in north Syria and relatively recent start of research on this crop by the national programs in West Asia and North Africa region, much of ICARDA's research efforts have focused on the solution of the problems of growing lentil in the Mediterranean region. Less emphasis has been put on research targeted toward other areas. ICARDA realizes the need to redress this imbalance by extending its research on lentil to South Asia. One of the steps taken in this regard was a seminar on 'Lentils in South Asia' with the involvement of the major national research programs from that region. The seminar was jointly sponsored by the Indian Council of Agricultural Research (ICAR), which has the largest research network on lentil in South Asia, and by ICARDA in the context of an agreement on cooperation between the two organizations. The proceedings of the seminar and its recommendations on future lentil research thrusts and linkages in South Asia are contained in this volume. I hope this will stimulate further research and foster regional collaboration in lentil improvement for the South Asia region.

Nasrat R. Fadda
Director General
ICARDA

Preface

The lentil area in the countries of Bangladesh, Burma, India, Nepal and Pakistan stands at approximately 1.27 million hectares, representing 49% of the total world area, but production in South Asia represents only 38% of the world total because of below-average yield levels. The largest area of lentil in South Asia is in India: approximately 80% of the regional total, but India has recently started importing the crop. Clearly, a major effort in lentil improvement in the region is required if the supply is to meet local demand. It is in India, also, that research on lentil has the longest history in the region. However, in both Bangladesh and Pakistan major strides have been made in lentil research in the last decade. An improvement program in Nepal has recently been initiated.

The seminar 'Lentil in South Asia' brought together key South Asian lentil researchers from Bangladesh, India, Nepal, Pakistan and Sri Lanka, in order to review research accomplished, to plan future priorities and jointly plan a regional network. With recommendations from the meeting of the aims of a regional lentil improvement effort, we now hope to stimulate sources of funding to implement this important research agenda.

The meeting was sponsored by ICAR and ICARDA, and most of its organization was done by a local committee from the Indian Agriculture Research Institute (IARI). We wish to warmly thank the Director General of the ICAR and the Director of IARI for their support and the members of the committee and others for their hard work, without which the seminar would not have been successful.

W. Erskine
M.C. Saxena
Editors

Section 1. Overview

An Overview of the Production and Problems of Lentil in South Asia

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Abstract

The major lentil-growing countries of South Asia are India, Nepal, Bangladesh, Pakistan and Myanmar. The region, with annual production of about 0.9 million tonnes, accounts for about one-third of the world's lentil production. Between 1978 and 1989, there was a high growth rate in production in the region, particularly in India. Countries of South Asia exclusively grow *microsperma*-type, small-seeded lentils except in parts of central India, where *microsperma* bold-seeded varieties are under cultivation. Agroclimatically, the lentil-growing areas of South Asia can be divided into Northwestern Plains, Northeastern Plains, Central Highlands/Plateaux and the *Terai* region. These agroclimatic regions differ in rainfall pattern, period of crop duration, spectrum of diseases and soil types. The predominant crop sequences in different zones are rice/lentil, fallow/lentil and millet/maize/cotton/lentil. To make yield and production advances in the region, appropriate varieties and technologies should be identified for different cropping patterns. To achieve stability and sustainability of yields, genetic diversity from the germplasm collections and from the related wild *Lens* species should be exploited to develop varieties resistant to biotic and abiotic stresses. To facilitate the transfer of production technologies to the farming community, the removal of agrobiological constraints needs the urgent attention of researchers and policy planners alike. Significant increases in lentil production can be accomplished if these bottlenecks are removed and government support is provided through development programs.

Introduction

Lentil (*Lens culinaris*), considered to be one of the oldest food crops of mankind, was first domesticated in southern Turkey. From there it moved west and eastward (Ladizinsky 1979; Cubero 1984). Within the cultivated species of lentil there are two races, *microsperma* and *macrosperma* (Cubero 1981). The *microsperma* with small and rounded seeds are mostly cultivated in South Asia, Afghanistan, Ethiopia and Egypt, whereas the *macrosperma* with larger and more flattened seeds are predominant in southern Europe, North Africa and North and Latin America. However, the two races overlap in their distribution in western Asia and southeastern Europe. Although lentils cultivated in South Asia are exclusively small seeded belonging to the *microsperma* type, bold-seeded varieties are also grown in India and their area is concentrated mostly in Madhya Pradesh and Jhansi Division of Uttar Pradesh. About 40-45% of the total area in India is occupied by bold-seeded *microsperma* types which are predominantly local cultivars.

Production and Area

The major lentil-growing countries in South Asia are India, Nepal, Bangladesh, Pakistan and Myanmar. These countries together produce about 0.9 million tonnes of lentil annually from an area of 1.5 million hectares, which represent about 36% of the world production and 46% of world area for lentil (Anonymous 1990) (Table 1). India, with a production of over 0.65 million tonnes, is the premier lentil-growing country in the region, accounting for 73% of the region's and 27% of the world's production.

The time series data from 1978 to 1989 for lentil area and production for South Asia show an upward trend (Figs. 1 and 2). The triennium averages indicate clearly accelerated growth in production in South Asia during the 12 years ending 1989 (Table 2).

A further study of trends of triennium average indicates that between 1978-1980 and 1987-1989, area and production of lentil in South Asia increased by 25 and 83%, respectively (Table 3). However, during the same period Asia witnessed still higher increases: 81% in area and 167% in production. India with 79% and Nepal with 46% increase in production were major contributors to accelerated production in South Asia. In Bangladesh a recent revision of the statistics has indicated a major increase in area and production. There was an 11% decrease in production during this period in Pakistan.

Table 1. Area and production of lentil in South Asia, Asia and the world during 1987-1989.

Country/ region	Area (1000 ha)				Production (1000 t)			
	1987	1988	1989	Average	1987	1988	1989	Average
Bangladesh	213	216	218	216	149	159	160	156
India	1087	1040	1090	1072	659	660	741	687
Myanmar	3	3	3	3	1	1	1	1
Nepal	107	133	139	126	73	63	65	67
Pakistan	81	76	76	78	32	31	33	32
South Asia	1491	1468	1526	1495	914	914	1000	943
Asia	2605	2694	2548	2616	2070	2286	1847	2068
World	3357	3253	3042	3217	2765	2681	2242	2563

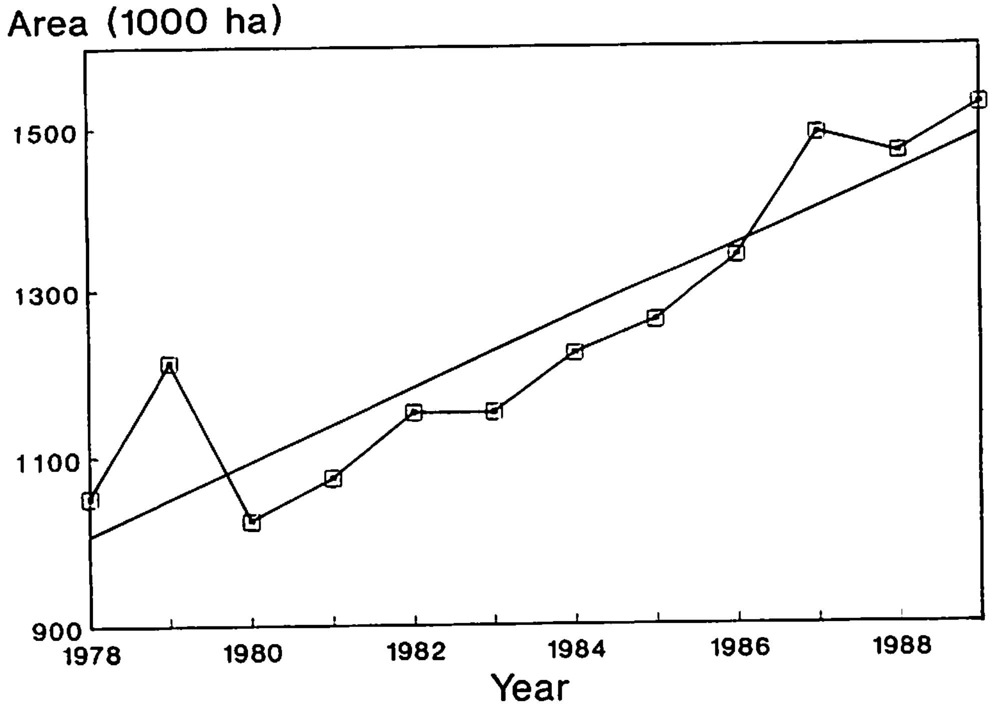

Fig. 1. Lentil area in South Asia from 1978 to 1989 (actual and trend).

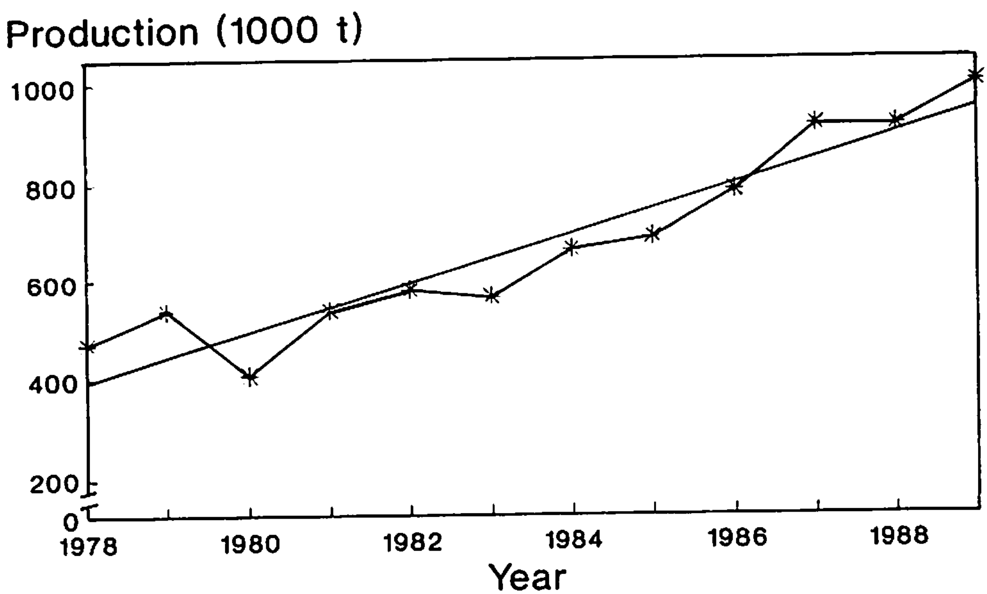

Fig. 2. Lentil production in South Asia from 1978 to 1989 (actual and trend).

Table 2. Triennium averages of area and production of lentil in South Asia, Asia and the world during 1977-1988.

Country/ region	Area (1000 ha)				Production (1000 t)			
	1978-80	1981-83	1984-86	1987-89	1978-80	1981-83	1984-86	1987-89
Bangladesh	83	81	72	216	50	47	49	156
India	917	971	998	1072	383	481	575	687
Myanmar	3	2	3	3	1	1	2	1
Nepal	95	99	123	126	46	49	59	67
Pakistan	94	76	79	78	36	30	26	32
South Asia	1192	1225	1275	1495	516	609	711	943
Asia	1443	1785	2097	2616	774	1164	1474	2068
World	1845	2223	2600	3217	1062	1490	1890	2563

Table 3. Relative change (%) in average area, production and yield in lentil in South Asia, Asia and the world from 1978-1980 to 1987-1989.

Country/ region	Area	Production	Yield
Bangladesh	160	212	20
India	17	79	53
Myanmar	0	0	0
Nepal	33	46	10
Pakistan	-17	-11	8
South Asia	25	83	46
Asia	81	167	47
World	74	141	38

Yield

Lentil yields in South Asia from 1978 to 1989, illustrated in Figure 3, show a remarkable upward trend in the region. Among the countries of South Asia, Bangladesh with 723 kg/ha showed the highest productivity based on the triennium 1987-89 (Table 4). Mean yields in the region on the basis of triennium averages varied from 432 to 631 kg/ha. From 1978 to 1980 and 1987 to 1989, the yield of lentil in South Asia increased by 46% compared with 47% in Asia and 38% in the world (Table 3). Out of five lentil-growing countries in the region, India showed the largest relative change in yield (53%, Table 3).

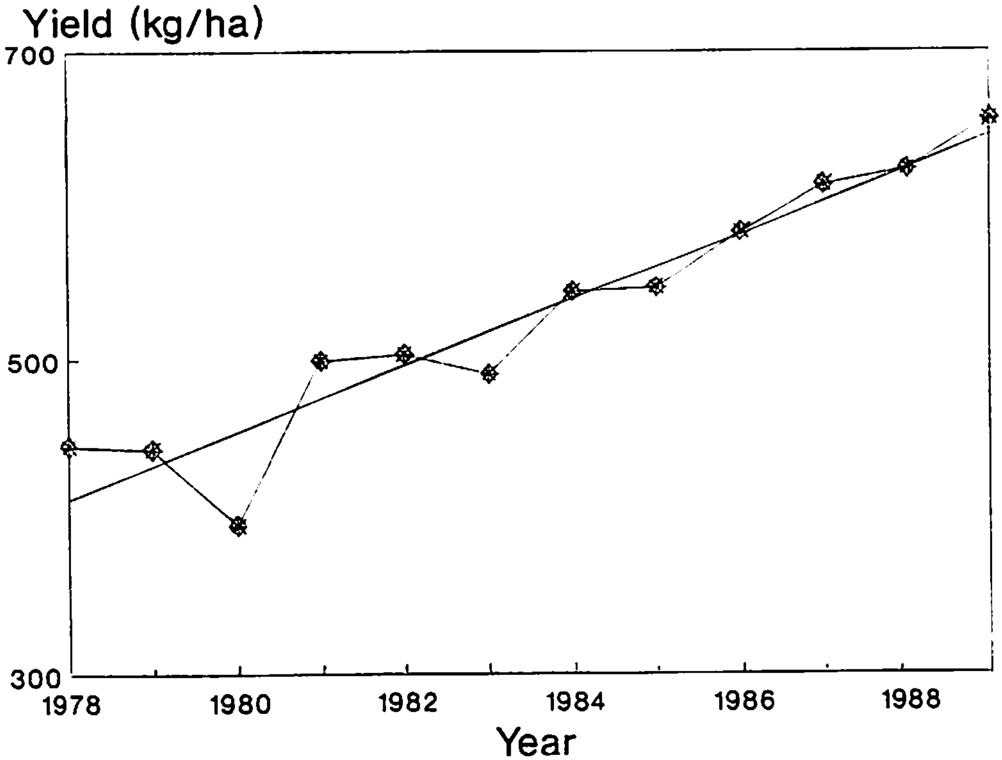

Fig. 3. Lentil yields in South Asia from 1978 to 1989 (actual and trend).

Table 4. Triennium average of yield (kg/ha) of lentil in South Asia, Asia and the world during 1977-1988.

Country/ region	Triennium			
	1978-80	1981-83	1984-86	1987-89
Bangladesh	602	612	684	723
India	418	496	576	640
Myanmar	333	500	500	333
Nepal	484	495	484	530
Pakistan	383	397	331	412
South Asia	433	497	558	631
Asia	536	652	703	790
World	575	670	727	797

Lentil Production Zones

In South Asia lentil is produced on a wide range of soils including sandy loam, alluvial and black cotton soils. It is adapted for cultivation in the region to diverse agroclimates and edaphic conditions at various latitudes and altitudes. Major lentil-producing regions in South Asia can be grouped into four agroclimatic zones.

Northwestern Plains

The region includes Punjab province of Pakistan and the states of Haryana, Punjab and western Uttar Pradesh of India. Small-seeded varieties with 130-140 days maturity, bushy growth habit, profuse branching and shallow root system are adapted to this region. The crop is mostly raised on conserved soil moisture. Although this zone accounts for about 10% of the total area under lentil cultivation in South Asia, it has potential for high productivity as one or two irrigations are applied whenever water is available. Among the diseases that attack this crop, vascular wilt (*Fusarium oxysporum* f.sp. *lentis*) is the major fungal pathogen widespread throughout the region. Rust (*Uromyces fabae*) and Ascochyta blight (*Ascochyta lentis*) also appear on the crop and can cause considerable damage in certain environments.

Northeastern Plains

This is one of the major lentil-growing zones, covering about 35-40% of the total area under cultivation in South Asia. It comprises Myanmar, Bangladesh and eastern Uttar Pradesh, Bihar and West Bengal states of India. The crop is grown either on rice fields under rain-fed conditions or on uplands after jute and other crops. Lentil is also planted in low-lying areas (*tal*) after the monsoon/flood waters recede. Wilt and rust are the major diseases of the crop in this region. However, *Botrytis cinerea* in Bangladesh is also known to cause up to 100% loss of the crop (Gowda and Kaul 1982).

Central Highlands/Plateaux

About 35-40% of the lentil area in South Asia is concentrated in the highlands/plateaux areas of Madhya Pradesh, Uttar Pradesh and Maharashtra states in India. In this region, lentil is mostly monocropped in *kharif* (summer) fallows. Generally, bold-seeded (30-40 g/1000-seed weight) and early maturing varieties of upright growth habit with a few branches and a long tap root are adapted to black cotton soils (vertisols). Fusarium wilt and root rot are the major diseases in this zone.

Terai Region

This region, which includes subtropical areas of the Himalayan foothills of Pakistan, India and Nepal, shares about 15% of the total area under lentils in South Asia. The area under this zone is characterized by high humidity, adequate rainfall and severe winters. Being prone to frost, varieties of this region should possess adequate cold tolerance. Rust and wilt are the common diseases of lentil in this region.

Cropping Systems

In the countries of South Asia lentil is mostly grown during the winter season (October-March) with soil moisture conserved during the preceding monsoon months. Depending upon the cropping system being followed, sowing of the lentil crop starts at the end of September and continues as late as the end of December. To make best use of their resources, the farmers in the region predominantly follow the following crop sequences with lentil as a component.

Rice/Lentil

This sequence, in which lentil is grown as a component of a double cropping system, is very popular in Nepal and in the states of Uttar Pradesh, Bihar and West Bengal and parts of Madhya Pradesh in India. In Bangladesh, late planting of lentil during November-December is done after the harvest of *aman* (late) rice.

The *utera/paira* method is a kind of relay cropping which is quite common in Bangladesh and states of Bihar and West Bengal of India where lentil seeds are broadcast in the standing crop of rice about 2 weeks before the harvest of rice. This helps in better and early establishment of seedlings which later thrive on residual moisture and fertility. In this region, the lentil crop faces strong competition from *Lathyrus*, which is more drought tolerant than lentil.

Fallow/Lentil

Planting of lentil crop after monsoon fallows is very popular in Madhya Pradesh and adjoining areas of Uttar Pradesh where generally bold-seeded lentils are grown. The same practice is followed in eastern parts of the Indian subcontinent where lentil is sown after the monsoon/flood waters recede. In Bangladesh, the practice of planting lentil during October-November in fields kept fallow after the harvest of *aus* rice or highland jute in July-August is quite common.

Pearl Millet/Maize/Cotton/Lentil

In Punjab, Haryana, Rajasthan and Maharashtra states of India and in parts of Pakistan, the lentil crop is taken after the harvest of *kharif* (summer) crops such as millet, maize and cotton. In these areas the lentil crop often benefits from irrigation.

Problems and Research Priorities

Germplasm Exploitation

Yield improvement through genetic means usually comes from exploitation of new germplasm or a trait. Therefore, efforts should be made to encourage the wider use of existing diversity from germplasm collections. To further expand the genetic base, recourse to wild species, *Lens orientalis* and *L. nigricans*, which represent the primary germplasm pool, may also pave the way for transferring some useful characters like disease resistance from wild to cultivated species of lentil.

Yield Stabilization

Instability of yield is one of the major problems of lentil production in South Asia. There remains a need to provide yield stability by developing suitable varieties possessing resistance to diseases such as wilt, root rot and rust that cause fluctuations in yield. Breeding varieties resistant/tolerant to abiotic stresses such as temperature and water should also receive adequate attention by plant breeders to minimize risk in the cultivation of lentil.

Seed Availability Problems

Seed is considered to be a vital input for achieving higher productivity. A wide gap exists between the requirement and availability of quality seeds of improved lentil varieties. Government policies are required to ensure the availability of certified seeds to farmers to achieve high production levels. Any reluctance on the part of seed-producing agencies to multiply and distribute certified seeds may have to be overcome by providing proper incentives at various stages of seed production.

Suitable Varieties for Different Cropping Patterns

As lentil is grown under various cropping patterns and farming systems, the requirement of varieties in terms of their maturity duration, seed size and expected yield levels is different. Farmers need early maturing varieties with late sowing potential for situations in which harvesting of rice is delayed or land becomes available for lentil planting after monsoon floodwaters have receded. More research input is needed to develop improved varieties and better management for the *utera/paira* method of cultivation. Plant breeders should follow innovative approaches to develop plant types with phenological and structural adaptations that can make use of the environment in which they are grown.

Inadequate Use of Inputs

Food legume growers generally have a poor resource base. They have neither the capacity nor the will to apply expensive inputs such as improved seeds, fertilizers and pesticides. Even inexpensive inputs like *Rhizobium* inoculants, which may be well within the reach of these farmers, are often not used. The socioeconomic factors which act as constraints to the acceptance of improved technologies must be removed by suitably subsidizing the cost of inputs.

Poor Transfer of Technology

The advantages of advanced technology such as improved varieties and management packages have not accrued to the farming community owing to lack of development support and extension activities in most of the countries of South Asia. Government agencies should develop proper linkages at different levels so that the technologies can be delivered to the doorsteps of the farmers with the help of well-trained and motivated extension workers.

Government Policies and Support

There is an urgent need for the governments of the various countries of South Asia to develop suitable policies to promote the production of lentil, in particular, and food legumes in general. These policies should aim to tackle all aspects of the problems of lentil production such as strengthening of national capabilities in research, input support services to the farmers, market intervention, credit facilities, etc. Fortunately, governments of some countries of the region have recently shown concern in this direction and have taken measures to increase pulse production. The government of India has formulated a Technology Mission on Pulses, and lentil is one of the five mandate crops on which special research and development efforts will be made to increase production. It is expected that lentil will get the desired push during the eighth plan period, i.e., 1990-95 of the Technology Mission. This mission is required to take a holistic view through the mini-mission approach covering production technology, processing technology, input support to farmers and marketing aspects.

Conclusions

Lentil is an upcoming crop among the food legumes in the world in general and in Asia in particular. Some Asian countries such as India and Nepal have shown rising trends in production and productivity of this crop. The demand of this protein-rich pulse is increasing every year and will continue to increase to feed the ever-increasing population of the region. To meet this challenge, bold policy decisions will have to be made by the governments of the countries of the South Asia region to undertake massive research and development efforts to accomplish yield and production advances in lentil. The approach should cover all related aspects including generation of production and protection technologies, input support services to farmers, post-harvest technology and market support services. Because of the commonality of interests and problems there is a need for regional cooperation among the countries of South Asia with regard to research and development efforts in lentils.

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Section 2. Genetic Resources and Crop Improvement

Genetic Resources of Lentil in India

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Abstract

The Indian gene center is one of considerable diversity in lentil. Over 80% of the total world area under this crop (3.1 million hectares) lies in Asia. The diversity among Indian cultivars indicates that cultivated lentils originated in the mountains of Hindu Kush and the Himalayas. Archeological evidence also shows old Neolithic, Chalcolithic and early historic records of lentil from Bihar, Madhya Pradesh and Maharashtra, respectively. The genetic resources of lentil in India may, therefore, be considered from three different regions for their availability, collection and conservation for use in varietal development programs: 1) the eastern region of the country comprising parts of U.P., Bihar, Bengal and eastern M.P. accounting for 90% of the cultivated area under lentil in India, 2) the Deccan Plateau including Maharashtra and western M.P., where the archeological evidence showed decline of lentil in the Chalcolithic period, and 3) the higher ranges of western Himalayas where germplasm for useful traits like cold tolerance is expected. Systematic collection of lentil germplasm in India, along with other grain legumes, was initiated in 1924. In the second phase, 12 lead centers were identified in an All India Coordinated Pulses Improvement Project in the 1960s for the collection and maintenance of lentil germplasm leading to assemblage of 8482 accessions. In the present context, the National Bureau of Plant Genetic Resources (NBPGR) has the mandate to collect, evaluate and conserve the primitive cultivars and locally adapted landraces through institutional projects and cooperation with other institutes/universities/centers. NBPGR also has conducted several crop-specific and multicrop explorations in selected areas to enrich the lentil gene pool from the Indian gene center. So far, 186 lentil accessions have been kept in the National Repository for long-term storage at -20°C and over 170 collections are ready to be deposited this year. The NBPGR lentil germplasm program also includes introduction and evaluation of exotic germplasm. Presently, 642 active collections of lentil are available at Delhi center of the Bureau while 634 and 500 accessions respectively are maintained at the Regional Stations of Akola and Shimla. During the period 1976-1990, NBPGR has introduced 5836 exotic accessions that have been evaluated at Delhi. About 500 samples are field-evaluated every year including both indigenous and exotic germplasm. Some of the promising primary traits observed in the indigenous lentil gene pool are early maturity, higher 100-seed weight (> 2.5 g) or bold seededness, higher number of pods/plant and higher number of pods/cluster (4-5) with two small seeds/pod.

Introduction

Lens is a small genus consisting of two recognized species, or "crossability groups"—*Lens culinaris* and *L. nigricans*—according to a recent taxonomic treatment (Ladizinsky *et al.* 1984). Within *L. culinaris*, there are three crossable subspecies, namely *L. culinaris* ssp. *culinaris* the cultigen, *L. culinaris* ssp. *orientalis* which is the ancestor of the cultivated lentil and *L. culinaris* ssp. *odomensis*. *Lens nigricans* comprises the crossable subspecies *nigricans* and *ervoides*.

Over 80% of the total world area (3.1 million hectares) under lentil cultivation is situated in Asia. India alone represents 1.05 million hectares, which is 34.1% of the world total. The following states in India account for 90% of the area under lentil cultivation: Uttar Pradesh, Bihar, Bengal and eastern Madhya Pradesh. Grain legumes provide a rich and cheap source of protein to people of vegetarian diets, who constitute the bulk of the population in developing countries. After dried fish, which provides 335 g of protein/kg, grain legumes are the second most important source of protein, with 220-250 g of protein/kg. The pulses are traditionally grown under marginal conditions, such as poor soil moisture and low fertility. Therefore, the selection pressure in pulses has been toward adaptation to these conditions and to biological stresses, including insect pests, pathogens and weeds. The pulse crops, including lentil, have lost a large part of their genetic diversity in the process of adaption to stress environments. However, the availability of fixable genetic loci for their adaptability to stress conditions can be exploited. For example, the majority of bold-seeded lentil accessions are tolerant to cold because of an extended period of natural selection for cold tolerance.

Domestication

The distribution of this genus suggests that the Mediterranean was the probable area of its domestication; however, there are significant differences in the distribution of individual species. The area from western Turkey to northern Iraq (Kurdistan) contains not only all the wild lentils, but also *Vicia lentata*, a dubious species that can be defined as a lentoid 'Vicia'. This region seems to be the cradle of 'Lentoid' characters, viz., flattened pods and seeds.

Lentils are of ancient cultivation in Egypt, southern Europe and western Asia. From these areas they spread northward to Europe, eastward to India and through much of China, and southward into Ethiopia. They have been taken to most subtropical and warm temperate regions and to high altitudes in the tropics. They are also being cultivated in Chile and Argentina (Cubero 1981).

The cultivated lentil is a characteristic species of the Old World belt of the Mediterranean basin. The lentil cultivars conventionally belonged to two groups: small-seeded lentils (ssp. *microsperma* Barul.) with small pods and seeds (3-6 mm), and large-seeded lentils (ssp. *macrosperma* Barul.) with larger pods and seeds (6-9 mm). A seed diameter has been arbitrarily chosen at ICARDA to separate the *macrosperma* from the *microsperma* accessions. The *microsperma* forms are concentrated in the Mediterranean: Spain, Italy (including its islands) and Greece. Small-seeded accessions, with earlier maturity than the large-seeded *macrosperma* types, predominate in the lower altitudes of the Old World: Afghanistan, Egypt, Sudan, India, Bangladesh and Pakistan (Solh and Erskine 1984).

Range of Diversity in India

An exhaustive array of variability in lentil types is noted in India. Variation in the adaptability to soil and climatic conditions, as associated with the size and seed color of different types, has been reported (Shaw and Bose 1929). Also it has been observed that the types grown in the black cotton soils of India (Deccan Plateau) generally have a deep root system, while those of alluvial soils (eastern Gangetic Plains) have a branched, shallow root system with abundant root nodules. Plants of drier regions, like those of the Punjab, have an intermediate root system. The yield potential of deep-rooted types was low and was associated with bold seeds, while those with shallow roots were high yielders, exhibiting profuse branching along with small-seededness.

The genetic resources of lentils in India can be viewed from three different regions, for their availability, collection and conservation: 1) the eastern region of the lentil-growing belt, comprising parts of Uttar Pradesh, Bihar, Bengal and eastern Madhya Pradesh; 2) the Deccan Plateau, particularly Maharashtra and western Madhya Pradesh, where the archeological evidence has shown a decline of the lentil in the Chalcolithic period and where deep-rooted bold-seeded types are predominant, and 3) the higher ranges of the western Himalayas where cold tolerance is more expected. NBPGR has conducted several crop-specific and multicrop explorations in the areas to enrich the lentil gene pool from the Indian gene center.

National Germplasm System

The Bureau with its headquarters located on the Indian Agricultural Research Institute (IARI) campus, New Delhi, has the mandate to take care of plant genetic resources in India, as a nodal organization. It comprises five Divisions: Plant Exploration and Collection, Germplasm Exchange, Plant Quarantine, Germplasm Evaluation and Germplasm Conservation. The experimental farm of the Bureau is located at Issapur village, about 45 km from the headquarters. It has six regional stations located in different agroclimatic regions of the country to suit the requirements for the growing and maintenance of a wide variety of crops. These stations are located at Akola, Bhowali, Jodhpur, Shillong, Shimla and Trichur. These are also responsible for the plant exploration and collection activities. In addition, the Bureau has four base centers situated at Ranchi, Cuttack, Hyderabad and Srinagar, which are mainly oriented toward plant exploration and collection activities in the respective regions. The plant quarantine station at Hyderabad provides quarantine facilities (Fig. 1).

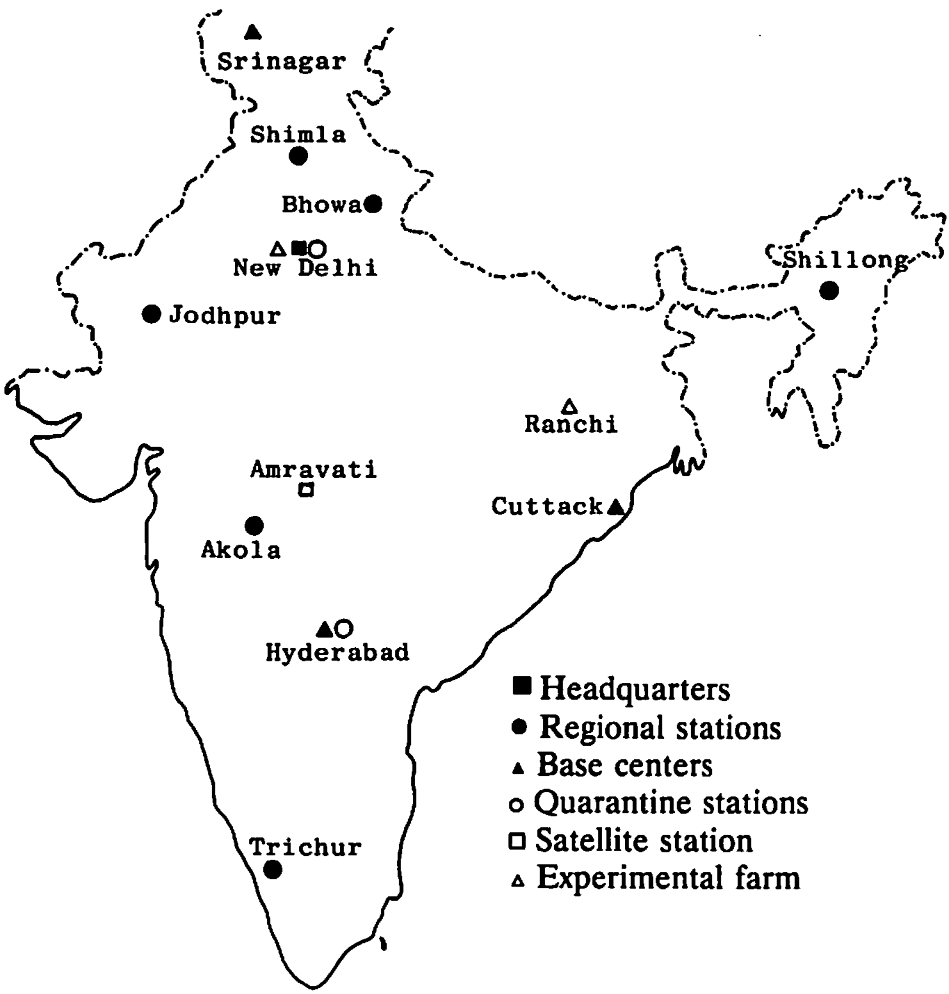

Fig. 1. National Bureau of Plant Genetic Resources Units.

The Bureau coordinates germplasm exploration and collection activities within the country and abroad keeping in view national and regional priorities. The Bureau conducted crop explorations jointly with the crop-based Institutes of the Indian Council for Agricultural Research (ICAR) and Agricultural Universities, and made a large number of collections. The collection is divided into three parts: one part is retained with the collector, one part is used as a working collection for multiplication and preliminary evaluation, and the third part is kept as a reference collection in the National Repository. The Bureau maintains close linkages with the Directorate of Pulses Research (DPR) and helps by providing legume germplasm diversity for further improvement. The DPR helps by organizing research programs through multidisciplinary cooperation among various research facilities administered by the State Departments of Agriculture, the Agricultural Universities and the ICAR Institutes.

Germplasm Collection

Efforts have been made to collect lentil germplasm from a variety of agroclimatic and management conditions to ensure diversity in this crop. Systematic collection of lentil germplasm in India was initiated in 1924, along with other grain legumes. Single plant selections from bulk populations isolated 66 pure types, Type 1 to Type 66 (Shaw and Bose 1929). Some of these are still in use, viz., T-36 and T-8 of Uttar Pradesh.

Other promising and still popular primitive cultivars from pure-line selection among Indian landraces are NP-11, NP-47 (IARI), L-9-12 (Punjab), BR-25 (Bihar) and B-77 (West Bengal). However, these efforts have been localized and scattered over different pulse-growing states. Germplasm collection was also made under a Rockefeller Foundation Regional Pulse Improvement Project. In the second phase, which coincided with the initiation of the All India Coordinated Pulses Improvement Project (AICPIP) in the 1960s, research work on lentils was intensified. Improved cultivars such as Pusa 1, Pusa 4, Pusa 6, T-6, T-36, Pant L-406, Pant L-639 and others developed in India may now be causing the genetic erosion of the landraces which they are replacing. The AICPIP has designated 12 lead centers for the collection and maintenance of lentil germplasm in the country.

The collection of lentil germplasm has a specific significance, as the majority of lentil produced throughout the world are local landraces, and of the few cultivars released, almost all have originated through selection within these landraces. Asthana (1988) reported that 16 indigenous lentil germplasms were selected out of 19 varieties evolved and released during this period. Notable varieties from among these include JLS-1, K-75 and Ranjan. The evolutionary lineage of pulses is more adapted to less sophisticated farming systems. The advanced forms may also find a place there, but in modern capital-intensive agriculture only advanced types can be used efficiently (Smartt 1990). In the case of lentil, wherein changed growth form is less reported and where the majority of the varieties under cultivation are selections from local landraces only, the need for a wide genetic base is highly emphasized for future efforts to improve this crop. The Indian lentils, although constituting a polymorphous group, are generally characterized as being short and pigmented, while also exhibiting small pods, leaves and leaflets. The large-seeded types, belonging to the region of black cotton soils, are generally poor yielders. However, a systematic approach for their collection, categorization and conservation is needed.

In the present context, NBPGR holds the mandate to collect, evaluate and conserve the primitive cultivars and local landraces through institutional projects and cooperation with other crop-based institutes, agricultural universities and state departments. Three clear-cut areas were earmarked for lentil collections. Highest priority was given to the Gangetic Plains of eastern Uttar Pradesh and Bihar (225 accessions), followed by the northwestern hills and plains of Jammu and Kashmir, Himachal Pradesh, Haryana, the UP hills and northern Rajasthan (132), and finally the Deccan Plateau, particularly Maharashtra and the adjoining area of Madhya Pradesh and Gujarat (112). Also, samples were collected from northeast Orissa, Andhra Pradesh, Karnataka and Tamil Nadu. The number of lentil collections is not large, but nevertheless they represent sufficient variability. A number of accessions are being added every year through multicrop and crop-specific explorations. Table 1 provides an account of the collections made by the NBPGR and Figure 2 indicates regions of diversity among these landraces.

Table 1. Lentil diversity collected by the National Bureau of Plant Genetic Resources during the years 1976-1990.

Region explored	1976-1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Andhra Pradesh	3	-	-	-	-	-	-	-	-	3
Bihar	-	-	-	-	11	-	11	35	-	57
Gujarat	4	-	-	-	6	-	-	-	-	10
Haryana	-	-	5	4	4	-	-	-	-	13
Himachal Pradesh	10	-	5	10	5	10	13	11	-	64
Jammu and Kashmir	4	7	-	1	1	-	-	1	-	14
Karnataka	2	-	4	-	-	-	-	-	-	6
Madhya Pradesh	16	45	5	-	-	-	7	7	-	80
Maharashtra	13	-	-	-	4	-	4	1	-	22
Northeastern Hills	-	-	-	1	6	7	-	2	-	16
Orissa	4	-	-	-	-	-	-	-	-	4
Rajasthan	-	-	-	10	20	5	5	1	-	41
Tamilnadu	-	-	-	2	-	-	-	-	-	2
Uttar Pradesh	-	-	34	6	-	15	20	65	28	168
Total	56	52	62	34	57	37	60	114	28	500

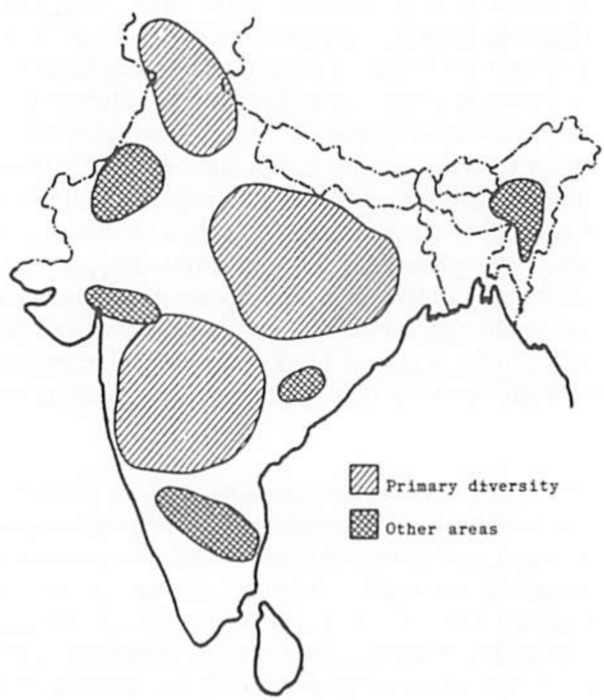

Fig. 2. Areas of lentil collection in India from 1976 to 1990.

Germplasm Introduction

During the period from 1976 to 1990, there were 6066 lentil accessions introduced, particularly from Syria, but also from the USSR, USA, Pakistan and elsewhere. Germplasm consisting of elite materials from ICARDA trials with early maturity, tall growth habit and resistance to Ascochyta blight and other materials of specific requirements for utilization in the improvement of existing lentil materials were introduced. The materials were sent to lentil scientists for evaluation, maintenance and utilization. The details of the introductions are reported in Table 2.

Table 2. Lentil germplasm introduced into India during 1976-1990.

Year	No. accessions introduced	Source
1976-1985	4455	Syria, USSR and others
1986	165	Syria
1987	580	Syria
1988	351	Syria, and others
1989	378	Syria, USA, Pakistan
1990	137	Syria
Total	6066	

Plant Quarantine

The Bureau has the responsibility, on behalf of the Government of India, to exercise all quarantine checks for the exchange of seeds, and of planting materials, for all agrihorticultural crops meant for research purposes. All germplasm material exchanged through the Bureau has to undergo a detailed quarantine examination carried out by the scientists in the disciplines of Entomology, Nematology and Plant Pathology in the Quarantine Division. Healthy material is identified through various techniques such as X-ray radiography and is subjected to disinfestation and disinfection procedures before release. Only healthy seeds are released. Pesticide-treated seeds, where quarantine inspection is not possible, are grown in the Post-Entry Quarantine Nursery, for regular inspection of the crop throughout the growing period, after which the produce of the healthy plants is released to user scientists.

Evaluation Study

The Bureau has designated two Regional stations, Akola and Shimla, in addition to the Headquarters at Delhi for the maintenance, multiplication and multilocational evaluation of lentil. In the case of lentil, the major responsibility for seed multiplication rests with the Bureau's headquarters at Delhi. A part of the collection is retained with the collector, at the Regional Station for multiplication of landraces, particularly those belonging to that region. These collections are grown for maintenance and multiplication, in Delhi, during the first year. Subsequently, these working collections are passed on to the regional stations, Akola and Bhowali, for preliminary evaluation and maintenance.

Field evaluation is conducted at Issapur Farm and other designated locations of the Bureau, in order to identify 13 traits of the lentil. A catalogue is under preparation for the germplasm evaluated over 2 years. A set of these accessions has been kept in the National Repository for long-term storage. The lentil accessions which were evaluated totalled 662 at Issapur, during 1989/90, wherein a wide range of diversity was observed for various morphophysiological traits. A list of elite accessions for important traits is presented in Table 3. Seven accessions had highly vigorous seedlings. In terms of earliness, nine entries flowered in less than 85 days. A further 38 entries attained 50% flowering in 86-90 days. Plant height was less than 30 cm in 19 cases and 30-35 cm in 75 cases. Growth habit was 'very erect' in 44 accessions and 'erect' in 569 germplasm lines. The number of pods/plant was very high (above 300) in 16 accessions, which included both indigenous and exotic materials, and in a further 33 entries the value was 250-300 pods/plant (Table 3).

The most promising accessions identified at Akola for high yield potential, early maturity and bold-seededness were: for high yields, IC-57760, IC-59902, IC-61515, IC-60965 and EC-284107-37 (from ICARDA, Syria); for early maturity, IC-57760, IC-59902 and IC-73120; for large seed size, EC-267534, EC-267553 and EC-280286.

Some of the more promising traits expressed under Simla conditions (> 2000 m above sea level) for the 249 entries of lentil were the dwarf varieties (< 25 cm) IC-82944, IC-83008, IC-025, IC-067 and IC-068. Higher seed weight (> 2 g/100 seeds) was observed for 37 entries. The number of days to flowering was less than 120 in the case of three germplasm lines (IC-82874, IC-877 and IC-893). The maturity of lentil lines was, in general, later than the corresponding maturity at the Delhi location.

Some of the more promising primary traits observed in the indigenous lentil gene pool are: early maturity (NC-57767, NC-66377), higher 100-seed weight (> 2.5 g) bold-seededness (IC-78441, IC-62505, IC-62499 and IC-60375), higher number (4-5) of pods/plant (IC-78528, IC-78507, IC-24090, IC-24089 and IC-24806) and higher number of pods/cluster with 2.0 seeds/pod (IC-98455, IC-98471 and IC-98545).

In all, 1330 active collections of lentil are available with the Bureau at Delhi and at its regional stations. At Akola and Shimla, 634 and 500 accessions, respectively, are maintained. A wide spectrum of variability has been reported. The 8482 *Lens* accessions are maintained at 12 different research stations as designated by AICPIP: Lundhiana, Punjab Agricultural University (1560); Kanpur, DPR (1400); Pantnagar, G.B. Pant University of Agriculture and Technology (1250); Faizabad, ND University of Agriculture and Technology (1175); Kanpur/CS Agriculture University (846); Behrampur (650); Durgapur (217), and Varanasi, Benares Hindu University (52).

Table 3. Categorization of lentil germplasm accessions for some important traits during 1989/90.

	Elite accessions		Promising accessions		
Traits	Value	Number	Value	Number	List of accessions
Earliness (days to 50% flowering)	< =85 days	9	86 - 90 days	38	IC-78397; NC-62518; MRP-120, -132; U22-181, EC-267651, -267553; NC-57767 and IC-78418
Seedling vigor (1-9 scale)	Grade = 1	7			SD1-55, -118, -180, -231, -243A EC-267706, -267669
Plant canopy height (cm)	< = 30 cm	19	30 - 35 cm	75	BDS 7-258, -259, -260, -263; KN-606, -664, -689; DPP-3-65, -230; NKG-254; EC-241473, -241479, -241480, -255483, -267624; NC-62515; IC-22658, -24089, -78551
Growth habit (1-5 scale)	Grade = 1	44	= 2		
Number of pods/plant	> = 300	16	250 - 300	33	SD1-316, D2-84, SD2-90, -156, -202 U22-35, -30; EC-241474, -267584, -255486, -267608, -267613, -267646, -267661, -267664, -225490
Seeds/pod	2 seeds	2			MRP-83; EC-267589

The AICPIP has identified 12 of its centers as lead centers for evaluation and maintenance of *Lens* germplasm. The details of the arrangements are as follows:

1. The base collection of all pulse crops will be maintained at NBPGR under their long-term storage system.
2. The working or active germplasm, comprised of genetic stocks, will be maintained at AICPIP centers located in the different agroclimatic zones of the country.
3. The assigned AICPIP centers will cooperate in the evaluation of the germplasm material and the preparation of the catalogue. Genetic stocks, identified for their desirable traits, will be distributed among the centers for utilization in pulse improvement programs.
4. The exotic germplasm material received from NBPGR will also be evaluated in phases at these centers.
5. The genetic stocks developed through inter- and intraspecific hybridization and mutation will also be maintained at these centers.

A properly evaluated, duly indexed and catalogued germplasm is a boon to the varietal improvement programs. Catalogues for lentil germplasm evaluations are under preparation. Certain guidelines such as passport data and other traits help in the preliminary selection of germplasm lines for specific uses. In India, 16 high-yielding varieties in lentil were the direct result of selections from germplasm. Of these, JLS-1, K-75 and Ranjan are more prominent (Asthana 1988). Wild related species are, in general, considered to be resistant to diseases, pests and other environmental stresses. This is because of co-evolution of host and pathogen pest, and the prolonged adaptability to stress conditions. A systematic study, however, can reveal the exact nature of individual species, or the lines which are relevant for germplasm utilization programs.

Conservation

The Bureau has the national facilities to store the germplasm, including two cold storage enbmodules, running at 4 and -20°C. It has the facilities to process the seed materials to 5-7% moisture content after testing their germination. The initial standard for acceptance of germplasm accessions for long-term storage is 85% of seed germination. The germplasm holdings in the Gene Bank belong to different groups of crops such as cereals, millets, oilseeds, vegetables, etc. This National Repository holds 1575 lentil accessions.

Priorities

The following constitutes a list of immediate priorities:

1. New collections need to be gathered from unexplored areas.
2. All available germplasm at different centers should be pooled, evaluated and

catalogued.

3. Two sets of germplasm should be kept, one in the gene bank for long-term storage at NBPGR, and the other maintained at DPR as a working collection ready for distribution to lentil scientists.
4. All facilities should strengthen efforts to screen the germplasm against viral diseases.
5. A computer-based National Information Network on Plant Genetic Resources needs to be started.

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Progress in Breeding Bold-Seeded Lentil in India

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Abstract

Studies on various aspects of *microsperma* and *macrosperma* revealed that radiosensitivity was more conspicuous at varietal level than the intergroup differences. Vernalization had no effect on *macrosperma* but plants grown under extended light flowered 52 days earlier. Associations between economic traits were studied. Seed size is negatively correlated to seeds/pod and yield. Leaf area can be used as a selection index for seed size even at seedling stage. Six bold-seeded varieties have been recommended for release in different parts of India. A number of indigenous and exotic germplasm collections have been identified as promising. Generally, the Indian bold-seeded lentils are earlier in maturity (115-125 days) while the Mediterranean *macrosperma* are, by and large, late maturing (140-160 days). However, Precoz (ILL 4605) with 1000-seed weight of 45 g and early flowering (65-70 days), made hybridization possible between two major groups. Precoz also shows high combining ability with Indian lentils. Transgressive segregation indicates that gene(s) governing earliness in Precoz are different from those present in Indian lentils. Some of the selections combine earliness and bold seed (up to 55 g/1000 seeds) with reasonably good yield potential.

Introduction

India produces about 666 000 tonnes of lentil from an area of 1.072 million hectares. The bold-seeded varieties contribute nearly 25% of the total production from about 27% of the area under lentil cultivation. There has been little progress in increasing the productivity of lentil. In spite of the fact that improved cultivars are now available, the yield levels per unit area have not shown any conspicuous increase. The major factor responsible for the instability in yield is the cultivation of lentils under conditions of physiological and agronomic stress. It has been suggested that prolonged cultivation of lentil under stress helped in the retention of wild traits such as a high degree of photoperiodic sensitivity and thermosensitivity, delayed maturity, small seed size and excessive vegetative growth.

With the present trend of intensive agriculture in India and the increasing demand for large-seeded lentils, there is an acute need to develop high-yielding, early maturing varieties that also combine bold-seededness and disease resistance. In order to achieve these goals, massive hybridization programs using genetically diverse germplasm collected from India and exotic types (mostly from ICARDA) were initiated at various breeding centers in India. The information presented here was mainly compiled on the basis of the work carried out at the Indian Agricultural Research Institute (IARI), New Delhi, and the Directorate of Pulses Research (DPR), Kanpur.

The main objectives of the lentil improvement program at IARI have been as follows:

- Collection and evaluation of germplasm
- Breeding for high-yielding varieties
- Breeding for early maturing, bold-seeded varieties
- Breeding for disease resistance
- Breeding for high-quality grain
- Investigation of genetic and economic traits.

Collection and Evaluation of Germplasm

The collection of genetic variability is a great asset for any improvement program. We now have a total of about 2000 germplasm accessions maintained at IARI. Of this, about 550 exotic germplasm collections, mostly received from ICARDA, through the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, are of great value.

A large number of indigenous (Table 1) and exotic (Table 2) strains turned out to be valuable donors for the hybridization program. Important traits such as days to flowering, maturity, seed size, disease resistance and several other agronomic attributes are summarized in these two tables. The germplasm collection was earlier classified into different groups on the basis of seed size (Sharma and Kant 1975). Contrary to general belief, it was found that the lentil germplasm contains profuse variability for virtually all important traits.

Induction of Variability

Although variability can be further enhanced through hybridization between distant parents, some very useful morphological and economically important mutations were induced for leaf shape and size, multiflorate inflorescence, fasciated stem, grain size, color, etc. (Sharma and Sharma 1977, 1979a, 1979b).

Five macromutants, namely, SKL 259, a green-seeded mutant (Sharma and Sharma 1977), HR 73-70, HR 32-35, HR 57-60 and HR 26-21 (Hyat Ram 1982), have been isolated from mutation studies. All these mutants, except HR 26-21, were found to be superior to check varieties Pant L-406 and Pant L-639 in yield performance. All these mutations were, however, induced in small-seeded lentil varieties.

Table 1. Promising indigenous germplasm of lentil.

Genotype	Source	1000-grain wt. (g)	Days to flower	Days to maturity	Other attributes
L 3991	IARI	28.5	70	120	Drought resistance
L 830	IARI	22.5	70	120	Drought resistance
L 4076	IARI	30.5	85	136	High yield potential
L 4163	IARI	45	78	132	High yield potential
JLS-1	Jabalpur	28.5	68	118	Drought resistance, high yield potential
Sehore 74-3	Sehore	28.5	74	126	Drought resistance, high yield potential
LG 170	Gurdaspur	26.0	90	140	High yield potential
LG 171	Gurdaspur	26.5	88	138	High yield potential, rust resistance
PL 406	Pantnagar	22.5	86	138	Rust resistance, high yield potential
PL 639	Pantnagar	18.0	88	138	Rust resistance, high yield potential
LG 231	Gurdaspur	24.5	92	145	Rust and blight resistance
LL 147	Ludhiana	-	85	135	Rust resistance
Ranjan	W.Bengal	20.0	68	118	Not known
RAU 101	Dholi	25.5	84	136	Wilt resistance, high yield potential
PL 77-2	Pantnagar	26.0	78	132	Wilt resistance
UPL 175	U.P.	26.5	78	132	Wilt tolerance
Vipasha	Palampur	35.0	98	150	Blight resistance
PKVL-1	-	20.0	65	114	Drought resistance, wilt resistance
K 75	Kanpur	28.5	80	132	High yield potential

Table 2. Promising exotic germplasm of lentil.

ILL	Source	1000-seed wt. (g)	Days to flower	Days to maturity	Other attributes
784 (Giza-a)	Egypt	26.0	77	138	Resistance to rust
8	Jordan	45.0	90	138	-
4605 (Precoz)	Argentina	45.0	68	116	Resistance to rust
4349 (Laird)	Canada	72.5	90	146	Resistance to blight
80S 41139	ICARDA	62.0	80	135	Tall
1	Jordan	45.5	88	146	-
9	Jordan	45.0	90	145	Four-flowered
20	Jordan	42.9	88	140	-
19	Jordan	47.6	88	139	-
6000	ICARDA	62.0	70	125	-
6004	ICARDA	-	65	125	-
6008	ICARDA	59.8	79	130	-
6007	ICARDA	45.8	68	125	-
6036	ICARDA	73.0	70	120	-
6037	ICARDA	61.5	68	124	-
6464	ICARDA	45.0	76	120	-
6465	ICARDA	55.5	71	120	-
6466	ICARDA	50.0	74	124	-
6210	ICARDA	47.1	72	130	-
6813	ICARDA	-	68	116	-
6820	ICARDA	-	70	118	-

Breeding Methodology

The materials developed from the crosses are directed into two streams: the usual pedigree method, and the mass pedigree method of selection. In the latter system, the seeds of bulk populations from F_2 to F_4 generations are sieved and graded into two groups (small-seed and bold-seed populations). The pedigree method is followed in F_5 onward in both small- and bold-seeded populations.

The procedure generally followed at IARI in the pedigree selection method starting from F_2 is given below.

Generation Procedure

F_2 Select 100-200 individual plants.

F_3 Select progeny rows raised from F_2 single plants. Also select 50-60 single plants from each progeny identified as promising.

F_4 Repeat the procedure of F_3 and reduce the number of single plant progenies to 20-30 only.

F_5 Test the selected progenies in a single-row preliminary yield trial. Single plant selection procedure is continued.

F_6 Confirm the performance of single-plant promising progenies in replicated trials, at least at two locations. In this generation the strain is expected to become homozygous for 95% loci.

F_7 Enter the lines selected on the basis of 2 years of yield performance and other attributes into the multilocation trials (Coordinated Trials).

Breeding for High-yielding Varieties

Since the initiation of the All India Coordinated Pulses Improvement Project (AICPIP) in the 1960s, research work on lentil has intensified. Improvement in yield being the primary objective, the emphasis initially was on population improvement through pure-line selection from among the cultivated varieties. Although the pure-line method of plant breeding has certain limitations, it has been instrumental in the development of new cultivars in a short time. As a result the method has played an important role in the improvement of lentil production in India.

Six bold-seeded cultivars of lentil have been released in India to date (Table 3). Lens 4076 and K-75 were released by the AICPIP, and the remaining four varieties—Sehore 74-3, JL-1 (M.P.), Vipasha (H.P.) and Type-8 (U.P.)—were released by the respective State Variety Release Committees. Five of these six varieties result from pure-line selection. Variety Lens 4076 was developed from the cross Pant L-639 X PL 234.

Lens 4076, developed at IARI and identified for release in 1984, has a yield potential of 2.75 t/ha under good management. This yield was obtained from an area of 0.6 ha at the IARI Regional Station, Karnal (Haryana) during *rabi* (winter) 1988/89. Lens 4076 is also the boldest-seeded variety (31.5 g/1000 seeds) among the recently released cultivars. It is moderately resistant to rust and wilt diseases.

Breeding for Early Maturity and Bold Seed

The bold-seeded Indian lentils (1000-grain weight = 25.0-35.0 g) are mainly grown in Madhya Pradesh, the western parts of Bihar and the Bundelkhand region of Uttar Pradesh. In these areas, the lentil is cultivated after the harvest of the rainy season crops (October to March) by utilizing the conserved soil moisture. The other major lentil-growing areas are the Northwestern and Northeastern Plains of India, where it is cultivated after the harvest of rice, which results in late planting. Even under these conditions, lentil is harvested at the normal time without much loss in grain yield.

Table 3. Bold-seeded cultivars of lentil released in India.

Variety	Origin	Parentage	Area of adaptation
Lens 4076	IARI	PL-639 × PL-234	Northwestern Plains and Central Zone
K 75	DPR Kanpur	Selection from Bundel Khand local	Northeastern Plains and Central Zone
Sehore 74-3	JNKVV Sehore	Selection from Sehore local	Central Zone
Vipasha	HPAU, Palampur	Unknown	Himachal Pradesh
JL-1	JNKVV Jabalpur	Pure-line selection from M.P. local	Madhya Pradesh
Type-8	Kanpur	Pure-line selection from Bihar local	Uttar Pradesh

Therefore, there is a need to develop high-yielding, early maturing and bold-seeded varieties that are also insensitive to the photoperiod and thermal regime. The important features of the promising strains developed at IARI are summarized in Tables 4 and 5.

It is evident from Table 4 that when Precoz, or any other early maturing variety evolved by ICARDA, was used as one of the parents in the crosses with early maturing indigenous donors, transgressive segregation was obtained for both earliness and larger seed size. The recent selections LC 68-17-4-2 and LC 94-53-1-2 mature in 100 days, which is 20-25 days earlier than the earliest parent. The grain size has been improved to the 1000-grain weight of 34.8 and 38.4 g, respectively. The average yields of these new strains are comparable with the best check, Sehore 74-3. Another strain, LC 136-4-1A, matures in 118 days, exhibiting a weight of 43.9 g, and is superior to the best check in yield. The maximum seed size (49.5 g/1000 seeds) has been achieved from the cross Precoz × L3991 (selection LC 68-57-1-1). Six new strains from similar crosses, selected for yield and bold grain, with normal maturity, are compared in Table 5. It appears that although there has been no major change in the maturity period compared with variety Lens-4076, the grain weight achieved has increased by about 83% (1000-grain weight 35.9-55.0 g). Also, the new strains LS 106 and LC 187-4-13 have shown reasonable yield

Table 4. Performance of new early maturing and bold-seeded strains of lentil developed at IARI.

Strain	Pedigree	1000-seed wt. (g)	Days to flower	Days to maturity	Average yield (kg/ha)
LC 70-2-1-3	Precoz × PL 639	47.2	57	108	1100
LC 68-1-3-2-2	Precoz × L 3991	49.5	56	108	800
LC 68-44-4-1	Precoz × L 3991	48.5	62	116	950
LC 68-57-1-1	Precoz × L 3991	49.5	60	116	950
LC 94-98-1-1	Precoz × PL 77-12	47.4	56	114	680
LC 94-48-1-1	Precoz × PL 77-12	48.3	67	120	1000
LC 135-4-114	(ILL43 × K 75) × JLS-3	46.2	69	129	1150
LC 136-4-1 A	(ILL4 × 79S 1981) × L 4076	43.9	65	118	1200
LC 94-53-1-2	Precoz × PL 77-12	38.4	50	109	1016
LC 68-17-4-2	Precoz × L 3991	36.8	50	100	1050
Precoz	Not known	40.5	67	118	850
PKVL-1	Selection	24.0	62	112	987
Sehore-74-3	Selection from Sehore local	28.5	73	125	1050

performance compared with the check variety Lens 4076 (Table 5). These findings also suggest that the negative correlations of grain yield with seed size and early maturity can be severed by incorporating appropriate materials in hybridization.

Breeding for Disease Resistance

Rust (*Uromyces fabae*) is the most prevalent disease in the Northwestern Plains of Punjab, Himachal Pradesh and the *Terai* region of Uttar Pradesh because of high humidity, cloudiness or drizzly weather, with temperatures between 20 and 22°C in the months of February and March. Several improved varieties, namely Precoz, LG 171, PL 406, PL 639, Vipasha, LG 231 and LL 147, are good sources of rust resistance. They are being used in the breeding programs at IARI and the other lentil-breeding centers.

Table 5. Performance of promising bold-seeded strains of lentil developed at IARI.

Variety	Pedigree	1000-seed wt. (g)	Days to flower	Days to maturity	Average yield (kg/ha)
LS - 106	ILL 61 × K 75	35.9	85	127	1632
LC 151-4-18	80S 42541 × PL 77-2	44.3	90	138	1462
LC 158-4-7	(L9-12 × Sy LL) × RAU 101	46.2	80	135	1057
LC 187-4-13	RAU 101 × PL 639	42.5	88	137	1625
LC 148-4-2	79 Sh 4809 × PL 639	43.4	91	140	1475
LC 135-4-1	(ILL 43 × K 75) × JLS-3	50.2	75	125	1280
Precoz (Check)	Not known	39.5	66	116	955
Sehore 74-3 (Check)	Selection from Sehore local	28.0	73	122	1033
L-4076 (Check)	PL 639 × PL 234	30.5	87	140	1612

Wilt (*Fusarium oxysporum* f.sp. *lentis*) causes severe damage to this crop in central India. Wilt resistance has been derived from several sources, such as RAU 101, PL 77-2 and UPL 175.

Ascochyta blight (*Ascochyta lentis*) is another important disease which has been alleviated by using LG 231 and Vipasha as sources of resistance.

Breeding for Grain Quality

Grain color, seed size, cooking quality and percent protein are the major grain quality characteristics of lentil. A study on cooking quality and protein content in recently developed varieties was conducted at the Directorate of Pulses Research, Kanpur (Asthana and Suresh, unpublished). It is evident (Table 6) that the bold-seeded varieties

Table 6. Protein content and cooking quality of lentil varieties with different seed size.

Genotype	Cooking time (minutes)	Protein (%)
Small-seeded		
PL - 639	22.5	24.3
PL - 406	26.5	21.9
VL - 1	22.0	23.1
L 9-12	27.5	24.9
Ranjan	27.0	22.9
PL 209	26.0	20.9
BR 25	24.5	23.6
Lens 830	25.0	24.8
B 77	27.0	23.2
Pusa - 4	25.0	25.2
Bold-seeded		
JL 1	29.0	22.1
HPL 5	28.0	22.4
Lens 4076	27.0	23.9
K 75	30.0	27.3
Sehore 34	31.5	20.6
Sehore 74-7	27.5	21.4
Precoz	41.5	23.7

usually take only slightly more time (range 27-29 minutes) to cook than the small-seeded ones (22-27 minutes), except the variety Precoz which takes 41 minutes for cooking. However, there is little difference in the protein content of bold-seeded and small-seeded varieties.

Tyagi and Sharma (1991) reported a mild yet positive correlation ($r = 0.26$) between protein content and seed weight in 32 stable genotypes of lentil. This is interesting, as these two traits are reported to be negatively correlated in cereals (Jain *et al.* 1976). The positive correlation ($r = 0.31$) between seed size and protein per seed also suggests that breeding for large grain in lentil does not necessarily cause any decline in protein productivity (Table 7). The distribution of 32 genotypes on the basis of seed weight and protein content (Fig. 1) indicates that the genotypes L-4294 (No. 32), L-4281 (No. 26), L-4084 (Precoz No.25) and L-4058 (No. 17), which are encircled by a solid line, combine high protein content with large seed size.

Table 7. Observed and expected protein content and its correlation with seed size in lentil.

Line	Source	Origin	1000-seed wt. (g)	Protein content (%)	Protein per 100 seeds (mg)
Pant L-639	India	Pantnagar	18.5	20.87	386
L-4081	Pakistan	ILL-4405	18.6	21.93	408
L-4197	India	LL-1 (Ludhiana)	19.2	27.37	525
L-4177	Ethiopia	ILL-1741	21.3	22.50	479
L-4203	India	B-77 (W. Bengal)	21.4	23.87	511
L-4079	Pakistan	ILL-4402	21.1	20.09	424
L-4160	India	P406 x PL370-2 (selection)	22.6	22.87	517
L-1304	India	-	23.0	28.30	510
L-1268	India	-	24.0	24.68	592
L-4162	India	ILL-118 × L-830	24.5	20.37	500
L-4240	ICARDA	80S 3855 × 75TA 459	24.4	23.59	576
L-4181	Ethiopia	ILL-2022	25.1	21.82	548
JLS-3	India	-	27.0	20.37	550
L-4276	ICARDA	80S 35188	29.7	23.81	707
Sehore-34	India	-	30.5	22.90	698
L-4228	ICARDA	78S13159 × 75TA 14	30.7	24.83	762
L-4058	Ethiopia	ILL-1744	32.0	27.43	878
L-4047	Mexico	ILL-500	32.5	23.00	747
L-4272	ICARDA	80S32623 × 77TA 66	32.9	24.81	816
LC-1-1	India	L 1941 × L 2837	32.5	23.50	764
L-4073	Jordan	ILL 4354	36.3	25.56	928
L-3259	Lebanon	ILL-752	38.1	24.71	942
L-2926	Turkey	ILL-112	39.6	22.12	876
L-4243	ICARDA	80S 41815 × 76TA 3	40.5	22.59	915
L-4084	Argentina	ILL-4605 (Precoz)	40.5	27.15	1100
L-4281	ICARDA	80S 41649 × 76TA271	46.0	26.90	1237
L-4260	ICARDA	80S 9750 76TA 87	46.1	23.37	1077
L-3886	Jordan	ILL-20	48.0	24.12	1158
L-4073	Jordan	ILL-4354	18.0	23.95	1151
L-4017	Jordan	ILL-8	55.0	22.76	1149
L-3034	ICARDA	ILL-254	55.5	24.44	1355
L-4294	ICARDA	80S 41620 ×	70.1	26.60	1922

Correlation: seed size - protein content: r = 0.26; seed size - protein per seed: r = 0.31.

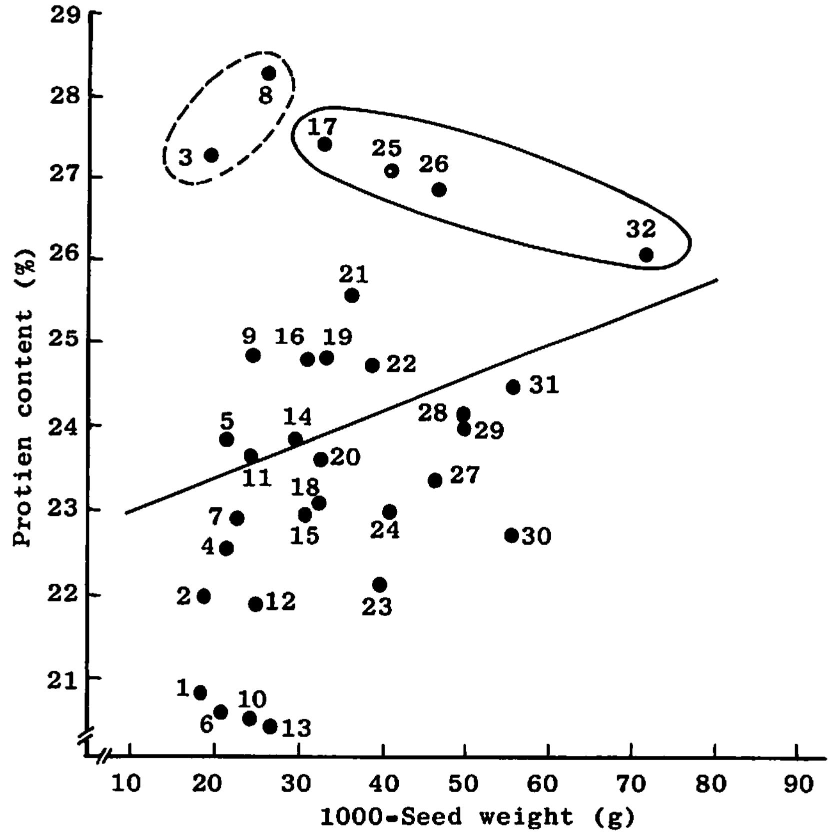

Fig. 1. The regression of 1000-seed weight (g) on protein content (%) over various lentil genotypes in India. Lines with high protein levels are circled.

Genetic Studies of Important Traits

Study on Radiosensitivity

Tyagi and Sharma (1981) reported that differences in radiosensitivity exist within and between *microsperma* and *macrosperma* groups. Varietal differences probably are more conspicuous than the intergroup difference. It is clear from Table 8 that the increase in the dose from 15 to 20 kR in L-3005, which has the smallest seed size (11.0 g/1000 seeds), resulted in a nearly two-fold increase in the shoot damage and a 50% increase in root damage. On the other hand, for the variety Syrian Local Large, having the largest seed size (73.0 g/1000 seeds), the same doses increased root damage five-fold, and root damage more than two-fold. However, L-830 with a medium seed size, showed maximum damage for both root and shoot growth (Table 9).

Table 8. Germination of lentil in incubator (20 ± 2°C) after gamma-ray treatment.

Variety	1000-seed wt. (g)	Germination (%)				
		Control	5kR	10 kR	15 kR	20 kR
L-3005	11.0	100	100	99	98	98
L-3011	12.3	98	99	98	100	98
LL 1	15.0	99	97	96	99	99
L 830	21.5	100	98	100	98	98
L 3991	30.0	97	99	98	96	100
K 75	29.0	100	100	98	100	100
74 TA 260	57.3	84	91	84	87	84
Syr L. Large	73.0	92	93	94	94	95

Table 9. Shoot and root growth in lentil after gamma-ray treatment.

Variety	Parameter of growth	Growth in different treatments (% of control)			
		5 kR	10 kR	15 kR	20kR
L 3005	Shoot	-22.31	-16.64	-25.86	-48.96
	Root	-2.31	+21.39	-35.55	-54.47
L 3011	Shoot	-24.69	-39.11	-50.41	-58.85
	Root	-14.36	-35.84	-48.95	-61.60
LL 1	Shoot	-2.84	-16.56	-41.30	-43.60
	Root	1.03	-21.25	-43.99	-49.33
L 830	Shoot	-26.31	-27.86	-52.42	-57.29
	Root	-3.31	-28.52	-53.66	-62.60
L 3991	Shoot	4.76	-12.07	-42.20	-38.60
	Root	14.86	-8.87	-27.05	-37.46
K 75	Shoot	10.20	-15.64	-28.90	-47.88
	Root	-2.39	31.07	-41.01	-44.48
74 TA 260	Shoot	-11.30	4.45	-1.12	-32.77
	Root	-19.67	-16.97	-25.38	-28.82
Syr L. Large	Shoot	-19.9	-1.69	-10.49	-47.92
	Root	-7.11	-10.77	-23.80	-52.08

Studies on Photoperiod and Vernalization

Observations on the effect of seed vernalization on days to flower and maturity in *macrosperma* lentils are summarized in Table 10.

Tyagi and Sharma (1981) reported that although plants from vernalized seeds did flower slightly earlier than control (maximum difference being 21 days following 4 weeks of vernalization), none of them reached full maturity even at 160 days after sowing. On the other hand, plants grown under extended light flowered (24 h), on an average, 52 days earlier than plants grown under normal daylength.

As shown in Table 11, the treatment with GA-3 did not influence the maturity parameters in any variety. The plants grown under normal daylength with GA treatment did not reach maturity. The effect of longer photoperiod (24 h) was most conspicuous and the plants with and without GA treatment produced flowers after 88.7 and 85.2 days, respectively. The plants in these two treatments matured at the same time (142 days).

Table 10. Effect of vernalization on the time to flower and maturity in lentil.

	Days to flower		Days to maturity	
Vernalization treatment	Normal daylength	Long day	Normal daylength	Long day
Control	137.5	85.2	-	142.6
1 week	129.5	85.2	-	139.9
2 weeks	123.4	81.6	-	135.4
3 weeks	117.7	87.7	-	146.5
4 weeks	116.4	88.7	-	145.8

Table 11. Effect of long day (24 h), gibberellic acid-3 and combination on days to flower and maturity in lentil.

Treatment	Days to flower	Days to maturity
Control	137.5	-
Long day	85.2	142.6
GA-3	135.4	-
Long day + GA-3	88.7	142.9

Studies on Correlations between Economic Traits

The study of the association between number of seeds/pod, 1000-grain weight, and pod and leaf area in 48 genotypes showed that seed size was significantly and positively correlated with pod size (r = 0.85) and leaf size (r = 0.51) (Tyagi and Sharma 1984). As noted in Table 12, correlation was also recorded between pod size and leaf size (r = 0.42). Therefore, leaf size can be used as a fairly reliable index for the selection of seed size in segregating population, even at the seedling stage.

These studies also revealed that number of seeds/pod has a strong negative correlation with 1000-grain weight (r = 0.66), pod size (r = -0.25) and leaf area (r = -0.25).

Another study of the same nature (Tyagi and Sharma 1985) also showed that seed size has a highly significant negative association with number of seeds/pod (r = -0.79). A significant negative correlation between flowering time and 1000-grain weight (r = -0.68) indicated that most of the bold-seeded Indian lentils are early maturing. On the contrary, the Mediterranean *macrospema* lentils are generally late maturing.

Preliminary results from another experiment carried out at DPR, Kanpur on *microspema* × *macrospema* crosses also indicate that an increase in seed weight lowers the number of pods/plant and number of seeds/pod (Table 13).

Table 12. Correlation coefficients between different morphological characters in lentil.

Character	1000-grain weight (g)	Pod area (cm^2)	Leaf area (cm^2)
Seeds/pod	-0.66**	-0.25*	-0.25*
1000-grain weight		0.85**	0.51**
Pod area			0.42**

* and ** significant at 5 and 1% levels respectively.

Table 13. Relationship between 1000-seed weight and pods/plant and seeds/plant in lentil.

1000-seed weight	No. of observations	Mean no. of pods/plant	Mean no. of seeds/pod
25 to 30	6	105	1.65
31 to 35	6	105	1.56
36 to 40	4	91	1.47
41 to 45	2	62	1.30

Studies on several economic traits of 19 lentil cultivars revealed that delayed flowering and late maturity result in accumulation of more dry matter. Higher number of seeds/pod and total quantity of dry matter were accompanied by higher grain yield in most varieties. Harvest index was negatively correlated with earliness, while a harvest index of 40-50% was found to be the best for yield maximization. Total dry matter was significantly and positively correlated with grain yield (Table 14) (Tyagi and Sharma 1985).

Table 14. Range, mean and standard error of important economic traits in lentil.

Character	Range	Mean	SE
Time to 50% flowering	68-95	80.5	8.56
Time to 50% maturity	129-139.5	134.9	10.04
Seeds/pod	1.3 - 1.9	1.12	0.14
1000-grain weight (g)	14.88-32.69	21.98	5.54
Dry matter yield (kg/ha)	3556-6878	5081	980
Grain yield (kg/ha)	1256-2489	1849	347
Harvest index (%)	26.6-45.0	36.8	5.73

Study on Stability of Podding in Lentil under Different Environments

A study on podding potential and its stability, with 12 varieties of Indian lentils in four different environments (see below) carried out at DPR Kanpur in 1986 (Asthana and Suresh, unpublished), indicated that bold-seeded genotypes have fewer number of pods/plant compared with the small-seeded ones (Table 15). The environmental conditions were varied by date of sowing (D_1 = 15 November and D_2 = 22 November 1986), irrigation and interplant spacing (S_1 = 3 cm, S_2 = 15 cm).

The regression coefficient analysis showed that small-seeded genotypes PL-639, LG-224, LH-15 and LG-217 have better stability. Among the bold-seeded genotypes, K-75 and Lens 4076 are more stable with respect to podding potential.

Podding intensity is expected to be directly correlated with number of flowers, but the realization of pod-setting in pulse crops is generally low because of considerable flower drop. The stage from anthesis to pod formation is very sensitive to various macro-environmental and micro-environmental factors. Therefore, it is difficult to assess the actual podding potential under field conditions. However, the following general observations may be drawn from this present study.

Table 15. Stability of podding in lentil under different environments.

Variety	No. of pods/plant					
	D_1S_1	D_1S_2	D_2S_1	D_2S_2	Mean	B_i
Small-seeded varieties						
PL 406	81	210	94	165	138	2.0659
PL 639	70	150	112	183	129	1.4241
LG 224	67	127	93	120	102	0.8634
L 4152	103	219	65	176	141	2.3677
L 1304	153	119	96	142	128	0.1206
LH 15	75	157	81	151	116	1.5250
LG 15	75	118	47	118	90	1.1587
BL 58	127	130	74	108	110	0.4438
Bold-seeded varieties						
JLS 1	44	66	66	68	61	0.2212
Sehore 34	44	55	37	50	47	0.2532
L 4076	48	92	87	97	81	0.5028
K 75	65	129	59	94	87	1.0528

1. Podding potential was higher in small-seeded genotypes than in the bold-seeded ones.
2. With increased interplant spacing, the number of pods/plant increased for both sowing dates.

Study on Genetic Behavior of Flowering

A study was carried out at IARI on the flowering behavior of a *macrospema* variety, Precoz (ILL 4605), and three early maturing indigenous types—L 3991, JLS 3 and Sehore 74-3 (Tyagi and Sharma 1989). The results led to the conclusion that the Indian varieties under study have common gene(s) controlling flowering time in lentil, whereas the gene(s) governing earliness in Precoz are different from and additive to those present in the Indian varieties. This further indicates that the Indian germplasm has a limited range of variability for genes controlling flowering duration in lentil, and there is tremendous scope for increasing the gene pool for this character by intermating the Indian and exotic germplasm lines of lentil. This is already confirmed by the transgressive segregation for earliness and isolation of extra-early genotypes (45-50 days to flowering) from such crosses (Table 4).

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Progress in Breeding Small-Seeded Lentil in India

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Abstract

South Asia has approximately half of the total world area under lentil cultivation and a major proportion of this is in India. There are four distinct regions with specific varietal requirements. More than 20 varieties of small-seeded lentil have been released in different parts of the country. However, most of these are selections from local germplasm. It is only recently that varieties have been developed following hybridization and mutation breeding. Research efforts reviewed in this paper include the nature of genetic variability, the genetics of important qualitative and quantitative traits, character associations among yield and yield-related traits, and physiological traits. In order to improve the efficacy of simultaneous selection, work on selection indices is included in the research. Also discussed are the conventional breeding approaches being followed and the population improvement methods that are likely to be most rewarding. Lentil rust and Ascochyta blight are significant impediments to production. The genetics of resistance to different diseases is reviewed and their sources of resistance listed. Achievements in the form of cultivars developed under the All India Coordinated Pulses Improvement Project for the different states of India are described. Future strategies of varietal improvement involving exploitation of wild species and diverse genetic resources, and recent breeding methodology are outlined.

Introduction

The lentil is one of our oldest food crops. It provides a valuable and balanced protein source which, coupled with its ability to thrive on relatively marginal lands and under adverse environmental conditions, has ensured its survival as a crop. The species is usually divided into two main groups: *microsperma* with small rounded seeds, 2-6 mm in diameter (100-seed weight = 2.5 g), yellow or orange cotyledons and testa of various colors from pale yellow to black, and *macrosperma* with large, more flattened seeds which normally have yellow cotyledons and pale green testa, which may be speckled. The vegetative structure in the latter is more robust than that in the *microsperma* with larger leaflets and bolder pods. The *microsperma* group is generally considered to be the older of the two groups and is the main type cultivated in the Indian subcontinent. The Indian subcontinent is the largest lentil-producing region in the world. The lentil-growing areas in India can be divided into four major zones:

1. The Himalayan foothills (*Terai*)
2. The Northwestern Plains (NWPZ) including Punjab, Haryana, western Uttar Pradesh and northern Madhya Pradesh.
3. The Northeastern Plains (NEPZ) of eastern Uttar Pradesh, Bihar, West Bengal and Assam.
4. The Central Highlands (CZ) of Madhya Pradesh, Uttar Pradesh and Maharashtra.

Varietal Release

Sixteen varieties of small-seeded lentil were released and recommended for cultivation between 1956 and 1987 in different regions of India (Table 1). Of these, three varieties were developed through hybridization, one was obtained by mutation breeding and the remaining 12 cultivars were selections from local landraces. The average yield potential of these varieties ranges from 1000 to 2000 kg/ha against India's average of 680 kg/ha. There is a gap of 300 to 1300 kg/ha between the farmers' yield and research experiments. This gap is largely due to a lack of the appropriate package of practices at the farmers' level, the inadequate supply of quality seeds of the new improved varieties and poor extension to educate the farmers.

Genetic Studies

Magnitude of Genetic Variability

Natural variability

Genetic variability is one of the most important prerequisites for advancement in any breeding program. Reports on the magnitude of genetic variability existing in the germplasm and generated through mutation breeding are summarized in Table 2a,b. Considerable genetic variability has been reported for the following characteristics: seed yield, 100-seed weight, plant weight, days to flowering, number of secondary branches, number of pods, dry weight/plant, harvest index, seedling vigor, hard seeds, epicotyl length, root length and growth period (Sindhu and Mishra 1982; Lakhani *et al.* 1986; Shahi *et al.* 1986; Baidya *et al.* 1988; Ramgiry *et al.* 1989). This natural genetic variability could be exploited through conventional breeding procedures to upgrade yield potential and other desirable traits of lentil in India.

Genetic variability through mutations

The use of mutations resulting from irradiation or chemical mutagens has not received much attention as a breeding method in lentil. However, genetic variability has been created for many quantitative and qualitative characters (Table 2b). Genetic variability has been reported for such quantitative characters as: pod and seed size, plant height, number of branches/plant, number of pods/plant, number of seeds/pod, percent pod-set,

Table 1. Small-seeded lentil varieties released in India.

Variety	Pedigree	Year of release	Features	Area of cultivation
Type 36	Selection from Badaun local	1956	Late maturing (130-140 days); semi-spreading; seeds gray mottled, small (1.7 g/100 seeds); avg. yield 1.5-2.0 t/ha	UP, MP
C 31	Selection from Sonadangar local (Hooghly)		Matures in 120 days; plant tall, spreading; seeds deep ashy, small (1.9 g/100 seeds)	West Bengal
No. 26	Selection from local germplasm		Matures in 125-130 days; flowers violet; seeds dirty ash colored, medium small; avg. yield 1.5-2.0 t/ha	Bihar
No. 27	Selection from local germplasm		Matures in 136-140 days; flowers violet; seeds dirty ash colored, medium small; avg. yield 1.5-2.0 t/ha	Bihar
BR 25	Selection from local germplasm		Matures in 125-130 days; plant type bushy, dark green hairy leaves; flower light pink, seed brickish red with black dots; small seeded (2 g/100 seeds); avg. yield 1.5-2.0 t/ha	Bihar, northeastern hill region
L 9-12	Selection from local germplasm	1962	Matures in 150-160 days; plant semi-erect, profuse branching; seeds bown, mottled, small (1.6 g/100 seeds); good cooking quality; avg. yield 1.0 t/ha	Punjab, UP, Jammu, Kashmir Assam
Type 8	Selection from local germplasm	1967	Matures in 120-125 days; semi-spreading; seeds gray, mottled, medium size (2.1 g/100 seeds); avg. yield 1.5-2.0 t/ha	UP
Pusa 4	Selection from indigenous germplasm	1973	Matures in 130-135 days; tall (50 cm); dark green foliage with pubescence; small seeded (1.9 g/100 seeds); tolerant to wilt and rust; avg. yield 1.3 t/ha	Northwestern Plains, *Terai* region, Central Zone
Pant L406	Selection from P495	1979	Matures in 140 days; widely adapted; semi-spreading; seeds gray mottled, small (1.9 g/100 seeds); resistant to rust; avg. yield 1.5-2.0 t/ha	UP, Bihar, Punjab, northeastern hill region, Assam
Asha (B77)	Local selection from Jorhat	1980	Matures in 120 days; plant tall (35 to 40 cm), spreading; seeds ash, mottled, small (1.6 g/100 seeds); avg. yield 1.4 t/ha	West Bengal, Assam

Table 1. (Continued)

Pant L639	L 9-12 × T 8	1982	Matures in 140 days; semi-spreading; light green foliage, light brown pods, gray mottled seeds (1.7 g/100 seeds); resistant to rust	UP, Bihar, MP, Haryana, Punjab, Delhi, Gujarat, Maharashtra
LL 56	L 9-12 × L 32-1	1982	Matures in 150-160 days; plant erect, branches profusely; grains small, brown with black dots; good cooking quality, avg. yield 1.3 t/ha	Punjab
Ranjan (B 256)	Selection from local germplasm	1983	Matures in 150-160 days; plant type spreading; seeds mottled, small (1.8 g/100 seeds); avg. yield 1.5 - 2.0 t/ha	Punjab, Bengal
VL Masoor 1	Selection from hill landrace	1983	Matures in 165 days; plant medium tall, light green foliage; flowers white; seed black; avg. yield 1.1 t/ha	UP
PL 77-2	Mutant of BR 25	1984	Tolerant to wilt and ascochyta blight; wide adaptation; seeds small (1.9 g/100 seeds); avg. yield 1.2-1.5 t/ha	Eastern UP, Bihar, Bengal
LL 147	PL 284-67	1987	Matures in 145-155 days; profuse branching; high pods/plant; early in flowering; seeds small, medium, olive with dark dotting, attractive with good cooking quality; avg. yield 1.4 t/ha	Punjab

Source: Asthana *et al.* (1986).

dwarfing, early maturity, seed yield, harvest index, days to flowering, internodal length and plant type (Sharma and Sharma 1978a, 1981a,b, 1984; Ravi *et al.* 1979; Dixit and Dubey 1986). Likewise, variability has been reported for qualitative characters such as tendril mutant, large leaflet types, chlorophyll mutant and compactoid (Sharma and Sharma 1978b; Ravi and Minocha 1987; Sarkar and Sharma 1988). Sinha (1989) reported cytoplasmic male sterility in the M_3 population through gamma ray irradiation in the lentil cultivar LL 78.

Mutation breeding has merit if the character is simply inherited, and if suitable screening methods are available to identify that character in large populations of mutagenized material. Mutation breeding is more suited to inducing recessive genes than dominant genes. After treatment, the populations should be handled as in other breeding methods.

Table 2. Magnitude of genetic variability.

a. Natural variability.

Characters studied	Material	Reference
100-seed weight, seed permeability, germination	57 varieties	Shahi *et al.* (1986)
Plant height, 100-seed weight, days to flower, secondary branches, pods/plant, grain yield/plant	30 varieties	Sindhu and Mishra (1982)
Seedling vigor and hard seeds	100 genotypes	Lakhani *et al.* (1986)
Epicotyl length, root length, total seedling length, plant height, growth period, 100-seed weight	8 varieties	Baidya (1988)
Seed yield, days to flower, dry weight/plant, pods/plant	96 genotypes	Baidya *et al.* (1988)
Branches/plant, pod number, seed size, harvest index	21 genotypes	Ramgiry *et al.* (1989)

b. Variability generated through mutations.

Mutagen	Material	Nature of mutant	Reference
Gamma rays	L 235	Large pods, seed size	Sharma and Sharma (1978a)
Gamma rays, NMU†	L 235	Tendril	Sharma and Sharma (1978a,b)
Gamma rays, EMS‡	L 9-12	Increased height, more branches, more pods, seeds/pod, grain yield	Ravi *et al.* (1979)
Gamma rays, NMU	L 235	Dwarf, early maturity, seeds/pod and pod-set percent	Sharma and Sharma (1981a)
Gamma rays, NMU	L 259	Seed yield, early maturity, yield components	Sharma and Sharma (1981a,b)
Gamma rays, NMU	L 259	Yield and yield components	Sharma and Sharma (1984)
Gamma rays, NMU	T 36	Compact branching, reduced height and leaf size, early flowering, dwarf, increased pod number, seed number and yield, branches, plant type, decreased internodal length	Dixit and Dubey (1986)
Gamma rays, EMS	L 9-12, TT 2	Large leaflet, chlorophyll, dwarf, compactoid	Ravi and Minocha (1987), Sarkar and Sharma (1988)
Gamma rays	LL 78	Cytoplasmic male sterility	Sinha (1989)
Gamma rays	HPL 5	High biological yield, harvest index, plant height, days to maturity, days to 50% flowering	Kalia and Gupta (1989)

† Nitrosomethyl urea.
‡ Ethyl methane sulphonate.

Inheritance of Morphological Characters

Since the study of genetics in lentils is in its initial stages, it is desirable that a standardized system of genetic nomenclature be followed in order to prevent unnecessary confusion and duplication. A list of published gene symbols and the characters they influence is presented in Table 3.

Table 3. Inheritance of morphological characters.

Symbol or phenotype	Character	Reference
VP (violet)/*Vp* (white)/*vP* (pink)/*vp* (rose)	Flower color	Lal and Srivastava (1975)
V (white)/*v* (violet)	Flower color	Varma and Nakhtore (1976)
V (white)/*v* (violet)	Flower color	Gill and Malhotra (1980)
Pigmented/green	Hypocotyl	Varma and Nakhtore (1976)
	Large and long pod recessive	Sharma and Sharma (1978a)
	Small seed, small pod recessive	Sharma and Sharma (1978a)
Ten/ten	Normal/tendril leaves	Sharma and Sharma (1978b)
Fn/fn	Flowers/inflorescence	Gill and Malhotra (1980)
glo	'Globe' mutant-compact and reduced branches, seed yield and high harvest index	Gupta *et al.* (1983)
	Resistance to rust dominant	Sinha and Yadav (1989)
	Resistance to rust dominant	Singh and Singh (1990)
O (orange)/*o* (yellow)	Yellow cotyledon, monogenic recessive	Singh (1978)
	Yellow cotyledon, monogenic recessive	Sinha *et al.* (1987)
	Cytoplasmic male-sterile monogenic recessive	Sinha (1989)
	Single recessive gene for earliness	Tyagi and Sharma (1989)

Hypocotyl color

Varma and Nakhtore (1976) observed that hypocotyl color is controlled by a single gene. Green hypocotyl color is recessive to pigmentation and no symbol was proposed. Ladizinsky (1979) made similar findings and proposed the gene symbol *Gs* for purple and *gs* for green hypocotyl.

Flower color

There are several reports from India on the inheritance of flower color in lentil. When Lal and Srivastava (1975) crossed pink with white-flowered lentils, they obtained an F_2 ratio of 9 violet:3 white:3 pink:1 rose, clearly indicating the presence of two independent genes with complete dominance and no epistasis. The gene symbolized for violet flower is expressed only in the presence of *P*. However, *P* produces a pink flower color when *V* is present. The double recessive *vvpp* produces rose-colored flowers. Thus, the homozygous genotypes and phenotypes are *VVPP* (violet), *VVpp* (white), *vvPP* (pink) and *vvpp* (rose).

Varma and Nakhtore (1976) and Gill and Malhotra (1980) obtained the F_2 ratio of 3 violet:1 white flowers in lentil. However, the disparity between the results of different scientists indicates that additional work is needed on the genetics of flower color.

Cotyledon color

In India red-orange cotyledon color is most acceptable to the consumers. Inheritance of cotyledon color is reported to be controlled by a single dominant gene. Orange cotyledon (*O*) is dominant over yellow (*o*) cotyledon color (Singh 1978; Sinha *et al.* 1987).

Stem, branches and tendrils

By crossing mutants, Sharma and Sharma (1978b) found that termination of the topmost 2-3 leaves into tendrils is controlled by a single recessive gene: *ten*. In another study the fa_1 gene was proposed for short, fused, stems and branches, linked with small flower buds which do not open. Similarly, the fa_2 gene symbol was suggested for flattened stem and branches linked with pollen fertility, but no seed-set on selfing (Sharma and Sharma 1983). Both these genes are recessive and showed simple inheritance, but were observed to be linked with flower size and pollen fertility. Further studies are needed to elaborate those findings. In another study, globe mutants, characterized by compact and reduced branches, smaller seed weight and seed yield but increased harvest index, were reported by Gupta *et al.* (1983) and were designated *glo*.

Pod character

Very limited studies on the inheritance of pod characteristics have been reported in India. Sharma and Sharma (1978a) observed that the large and long pods in a mutant derived from lower doses of gamma ray radiation were under the control of a single recessive gene. In the same study, they observed that another mutant with very small pods, derived from higher doses of radiation, was also monogenic recessive to the normal type.

Resistance to rust (*Uromyces fabae*)

Scanty information is available on the inheritance of resistance to rust in lentil. However, Sinha and Yadav (1989) and Singh and Singh (1990) found that in crosses of resistant to susceptible lines, all F_1s were resistant and F_2s gave a ratio of 3:1 (resistant:susceptible), clearly indicating that the resistance was controlled by a single dominant gene. More studies, with different genotypes, are essential to confirm these findings and to assign symbols for alleles of resistance and susceptibility.

Cytoplasmic male sterility

Gamma-ray radiation of lentil variety LL 78 produced a male sterile mutant in the M_2 generation (Sinha 1989). In the M_3 population, segregation into 3 normal:1 sterile male indicated genetic male sterility in some cases. However, M_3 plants were all male sterile, indicating cytoplasmic male sterility (CMS). Further studies are needed to confirm these findings and to transfer CMS into other varieties with a desirable agronomic base. The establishment of genetic male sterility or cytoplasmic-genetic male sterility can open up new possibilities for the exploitation of F_1 hybrids in this pulse crop.

Inheritance of Quantitative Characters

Estimation of genetic parameters for quantitative characters is important because it assists in defining efficient breeding methods. Results of various studies are summarized in Table 4. In lentil, as in most self-pollinated crops, there is a measurable amount of heterosis in F_1 hybrids. Singh and Jain (1971), Sagar and Chandra (1980), Sandhu *et al.* (1981), Bhajan *et al.* (1987) and Tyagi and Sharma (1989) observed heterosis for the numbers of branches/plant, pods/plant and clusters/plant, harvest index and earliness in flowering and maturity, indicating nonadditive genetic variance for these traits.

Sagar and Chandra (1980), Sandhu *et al.* (1981) and Waldia and Chhabra (1989) observed that both additive and nonadditive components of variance are important for the number of branches/plant. Waldia and Chhabra (1989) also found that additive genetic variance is pronounced for pod number only. High heritability estimates were obtained for yield/plant, number of seeds/pod, secondary branches, branches/plant and pods/plant, 100-seed weight, plant height, days to flowering, germination percentage, water uptake, harvest index, plant weight and maturity (Nandan and Pandya 1980; Sindhu and Mishra 1982; Lakhani *et al.* 1986; Singh *et al.* 1989). Low estimates of heritability were also reported for grain yield, seed size, number of seeds/pod, pods/plant and primary branches (Sindhu and Mishra 1982; Ramgiry *et al.* 1989; Singh *et al.* 1989).

In lentil breeding the estimation of additive variance and heritability is important because it helps in formulating appropriate breeding procedures. With high estimates of heritability and a significant additive component, all methods of breeding and selection are appropriate and should be effective. For characters where dominance variance is also important, improvement will require the proper combination of mass, family and progeny-test selection procedures.

Table 4. Inheritance of quantitative characters.

Character	Gene action/ heritability	Reference
No. branches, no. pods, no. clusters/plant, no. seeds/pod, seed weight, grain yield/plant	Nonadditive	Singh and Jain (1971)
	Dominance, overdominance and additive	Sagar and Chandra (1980)
Yield/plant, no. seeds/pod, no. branches/plant, no. pods/plant, 100-seed weight	High heritability	Nandan and Pandya (1980)
Harvest index and grain yield	Additive and nonadditive	Sandhu *et al.* (1981)
No. pods/plant, grain yield	Low heritability	Sandhu *et al.* (1981)
100-seed weight, germination %, water uptake	High heritability	Lakhani *et al.* (1986)
Days to flowering	High heritability	Baidya *et al.* (1988)
Plant height, no. branches/plant, harvest index	High heritability	Ramgiry *et al.* (1989)
No. pods, seed weight and yield/plant	Low heritability	Ramgiry *et al.* (1989)
Days to flowering, days to maturity, plant height, no. secondary branches and pods/plant, grain yield, 100- seed weight	High heritability	Singh *et al.* (1989)
No. primary branches and no. seeds/pod	Low heritability	Singh *et al.* (1989)
Plant height, no. fruiting branches, no. clusters/plant, and seed yield/plant	Additive and nonadditive	Waldia and Chhabra (1989)
No. pods/plant	Additive	Waldia and Chhabra (1989)

Correlations and Path Coefficients

A number of reports are available on the relationships between characters (Table 5). It was observed that seed yield showed positive correlations with numbers of pods/plant, pods/peduncle and secondary branches/plant, plant height, plant weight, harvest index, seed size, days to maturity and dry plant weight (Chauhan and Sinha 1982; Tyagi and Sharma 1985; Balyan and Singh 1986a; Baidya *et al.* 1989; Singh *et al.* 1989).

Table 5. Correlations of different characters with grain yield and path coefficients.

Characters	Material	Reference
Positively correlated with yield: Correlations		
No. pods and secondary branches and plant height	30 genotypes	Chauhan and Shinha (1982)
No. seeds/pod, dry matter yield and harvest index	19 genotypes	Tyagi and Sharma (1985)
Plant weight, no. pods/plant, seed wt., maturity, no. pods/peduncle	48 genotypes	Balyan and Singh (1986d)
Plant height, dry weight/plant, pods/plant	96 genotypes	Baidya *et al.* (1988)
Biological yield	44 genotypes	Rao and Yadav (1988)
Plant weight, no. branches, no. pod and harvest index	21 genotypes	Ramgiry *et al.* (1989)
No. pods and harvest index	Pant L 639, induced mutant lines	Singh *et al.* (1989)
Large effect on yield: Path coefficient		
No. pods	28 genotypes	Singh (1977)
No. pods and branches	49 genotypes	Nandan and Pandya (1980)
Secondary branches, days to maturity, no. pods, 100-seed weight	30 varieties	Chauhan and Sinha (1982)
No. pods	40 varieties	Dixit and Dubey (1984)
No. pods and seed weight	48 genotypes	Balyan and Singh (1986a)
Short plant height, short growth period	6 varieties	Baidya (1988)

In path coefficient analysis, reports indicated that numbers of pods/plant, pods/peduncle, branches/plant, dwarf plant type, short growth period, maturity and seed size showed a large direct effect on grain yield (Singh 1977; Nandan and Pandya 1980; Chauhan and Sinha 1982; Balyan and Singh 1986a; Baidya 1988). Thus, it appears that these quantitative characters are the major components determining grain yield. The relationship between yield and the numerous component characters suggests that selection criteria based on component characters should be given due emphasis to exploit maximum yield potential in lentil.

Genetic Diversity

Dixit (1980), Balyan and Singh (1986b) and Sharma and Luthra (1987) studied genetic diversity in different populations. Statistical distance represents the index of genetic diversity among genotypes of different clusters, so from crosses between genotypes belonging to clusters separated by high estimates of statistical distance it may be possible to select desirable segregants with high productivity.

Stability and Adaptability

A number of genotypes with stable performance over a range of environmental conditions have been reported (Malhotra *et al.* 1971; Pandey *et al.* 1982; Ahmed and Pandey 1983; Bedi 1988; Waldia *et al.* 1988) (Table 6). The reports indicate that some genotypes perform much better in favorable environments, whereas others do better in poor environments. However, the ideal variety should perform well in favorable as well as poor environments (Verma *et al.* 1978). A study of stability and adaptability in segregating populations would be useful in making selections in different environmental conditions to develop stable-yielding varieties.

Table 6. Stability studies in lentil.

No. genotypes studied	Stable genotypes	Reference
47	5 genotypes for yield	Malhotra *et al.* (1971)
31	T 8, P 587, P 114 for yield	Pandey *et al.* (1982)
10	LL 30, LL 1, LL 19, LL 56 for yield	Ahmed and Pandey (1983)
24	LL 147, LG 1, 108 for yield	Bedi (1988)
24	LH 82-7, LH 83-1, LH 83-4, LH 15, LH 162, LH 261, LH 319, L 9-12 and Pant L 639	Waldia *et al.* (1988)

Sources of Disease Resistance

Rust caused by *Uromyces fabae*, wilt caused by *Fusarium oxysporum* f.sp. *lentis* and Ascochyta blight caused by *Ascochyta lentis* are recognized threats to lentil production. Collar rot (*Sclerotium rolfsii*), damping-off (*Rhizoctonia solani*) and wilt caused by *Ozoxonium texanum* var. *parasiticum* also cause yield losses. A number of sources of resistance to these diseases have been reported (Table 7) for incorporation into breeding programs. The mode of inheritance of resistance to wilt and rust is monogenic. The sources listed in Table 8 are based only on field screening, so screening under artificial epiphytotic conditions is necessary to confirm the validity of resistance to a particular disease. On the other hand, variability in *Fusarium oxysporum* f.sp. *lentis* has been reported (Khare and Joshi 1972; Khare *et al.* 1975, 1979), yet stable sources of resistance to different strains of the pathogen have been identified. The inheritance of resistance is simple; therefore, resistance can be easily incorporated by backcrossing. However, the linkages between genes governing resistance to different diseases are not known.

Table 7. Sources of resistance to various diseases of lentil.

Disease	Source	Reference
Wilt (*S. rolfsii* + *Rhizoctonia solani*)	LWS 18, 27, 28, Pusa 3, Pant L 234, J 85 and J 1600	Chandra (1983)
Collar rot (*Sclerotium rolfsii*)	Pusa 1, LP 18, Pant L 638	Mohammed and Kumar (1986)
Wilt (*Ozononium texanum* var. *parasiticum*)	BR 75, Pusa 1, LP 350	Mohammed and Kumar (1986)
Wilt (*Fusarium oxysporum* f.sp. *lentis*)	LWS4, 6, 10, 14, 15, 20, 21, 23, 24, 28 and 50	Chandra (1983)
	Pant L 234, Pant L 639	Saxena and Khare (1988)
Rust (*Uromyces fabae*)	LP 846, UPL 172, -175, E 10, JL 599, -632, -642, -648, -673, -674, -676, -688, -1004	Khare *et al.* (1979)
	PL 234, LP 846, JL 674, JL 1004, Pant L406, ICL44, KL 113 and LG 178	Chandra (1983)
	Immune lines-PL209, PL639, 61 resistant lines	Shukla (1984)
	C 31, Hy 1-1, NP 47, T 36, No. 10511, -10526, -10465, -10475, -10495, -10502, -10506, -10507	Mishra *et al.* (1985)
	LG 13, -41, -60, -103, -108, -112, -120, Pant L406, -639, LL 56, -72, -78	Singh and Sandhu (1988)
	Pant L 406, Pant L639, LG 120, UPL 175	Singh and Singh (1990)
Blight (*Ascochyta lentis*)	Resistant LG 169, -170, -172, -173, -186, -191, -204, -209, -210, -174	Singh *et al.* (1982)

Table 8. Sources of desirable traits and resistance to diseases and insect pests used in breeding programs.

Character	Variety/Strain
Agronomic traits	
Earliness	Sehore 74-3, Ranjan, PDL 4, Precoz Sel. II, JLS 1, Lens 830, PKUL 1, WBL 58
Adaptation	PL 406, Pant L639, L 9-12, L 4076, PL 77-2, K 75
Erectness	Sehore 74-3, JLS 1 and Precoz Sel. II
Yellow cotyledon color	Precoz Sel. II, ILL 4354
Black seed	VL 1
Disease resistance	
Rust	LL 287, LG 170, LG 171, L 4132, LL 199, -299, -278, LG 217, UPL 175, TT 2, RAU 101, CP 212, LL 147, LL 56, PL 639, ILL 419, ILL 154, EC 145482, ILL 462, ILL 978, EC 115634
Wilt	HUL 8, LL 311, PDL 1, PDL 4, LG 220, LG 120, CP 212, GL 534, GL 535, PL 772, RAU 101, PL 234, PL 406, PL 639, LG 171
Blight	LG 231, -220, -221, -178, -186, -60, -112, -170, LL 301, LG 223, -224, -225, LG 23, PL 77-2, RAU 101, PL 639, No. 455
Stem rot	LL 301, LG 221, No.455, LG 128, LL 198, LG 17, LG 171, LG 265, Vipasha, LL 455, PL 406, PL 639, UPL 175, LG 120, PL 772
Insect-pest resistance	
Pod borer	LL 24, -56, -78, -266, LG 175, -178, -182, LG 220, P 202, P 927, P 248 and DH 21

Lentil Breeding Program

Identification of Donors

Based on the performance of different germplasm lines at different centers, donors for various traits have been identified at the national level (Table 8). These lines have been exposed to different biotic and abiotic stresses at different centers and comprise the national genetic nursery (Asthana 1984 to 1990).

National Crosses

Several diverse elite lines have been utilized in the national hybridization program and are being distributed to centers of the national coordinated project (Table 9).

Table 9. Lines being used in the National Crossing Programs.

Line	Attribute
Base parents	
PL 406	Yield, adaptability and tolerance to pod borer
Lens 830	Yield and earliness
L 4076	Yield and adaptation
RAU 101	Yield and earliness
Donors	
LG 231	Tolerance to blight
LL 147	Yield and resistance to rust
PKVL	Earliness
PL 639	Yield and adaptation
Ranjan	Yield and earliness
Sehore 74-3	Yield and earliness

Promising Materials

Promising line strains generated at various centers are under evaluation in different regions of India. The material that outyielded the checks in 1989/90 is shown in Table 10 (Asthana 1990).

Table 10. Performance of some promising lines of lentil in different production zones in India during 1989/90.

Zone†	No. locations	Check	Mean yield (kg/ha)	Promising strains (mean yield, kg/ha)
NWHZ	1	Pant L406	1112	VL4(1475), VL103(1185)
NWPZ	8	Pant L406	1881	PL 81-17(1964)‡
NEPZ	2	Pant L406	1331	HUL 11(1575), HUL 31(1553)‡, HUL 35(1542), L 4145(1508)
EZ§	2	Pant L639	1519	PL 85-50(1609)
CZ¶	2	Pant L406	1550	PL 81-71(2389), PL 81-50(2273), PL 81-78(2231), HUL 31(2170), PL 81-85(2062)

† NWHZ = Northwest Highland Zone; NWPZ = Northwest Plains Zone; NEPZ = Northeast Plains Zone; EZ = Eastern Zone; CZ = Central Zone.
‡ Also performed well during 1988/89.
§ Data for 1988/89.
¶ Data for 1987/88.

Breeding Methods

To date, a majority of the varieties identified locally represent selections from local landraces and from exotic germplasm. Several limited hybridization programs are underway to generate diverse materials through pedigree selection, bulk population methods and mutation breeding. Thus, lentil breeding is a relatively recent endeavor when compared with breeding efforts in other major crops. Further improvement in lentil will depend upon the research efforts following hybridization and selection. This is becoming increasingly important, and there are new, active breeding programs in lentil-growing regions of the country. In most of these programs, yield is of greatest importance. However, there is growing attention to broader adaptation and adaptation to stress environments, as well as resistance to diseases and insect pests. Although there is variation in preference among scientists, the following breeding methods are generally acknowledged as important.

Conventional methods
The following methods are in use:

1. Mass selection
2. Pure-line selection
3. Hybridization; material handled through pedigree selection, bulk population breeding, single seed descent (SSD), backcross method and mutation.

Alternative breeding methods
These methods are important where long-term objectives are implemented and the characters are controlled by many genes with cumulative effects. In such situations, the following methods are more valuable:

1. Cyclical recurrent selection method
2. Diallel selective mating design
3. Shuttle breeding
4. Intraspecific hybridization (*microsperma* x *macrosperma* cross)
5. Interspecific hybridization.

Conclusions

Over the past two decades, there has been a 44.5% increase in area under lentil cultivation in India. Production rose by 97.7% and productivity gained by 37.0% over the same period. Nevertheless, the productivity level of 680 kg/ha achieved is still very low considering the productivity in other countries, for example Egypt (1900 kg/ha), the USA (1430 kg/ha), France (1390 kg/ha) and Turkey (1060 kg/ha). The newly released varieties have not yet reached the farmers. The supply of adequate quantities of improved seed varieties, in addition to the transfer of the production technology and incentive prices to the lentil farmers, can upgrade the productivity of this crop considerably in a short span of 3-5 years. For a long-term program, screening techniques for various biotic and abiotic stresses have to be developed and refined. Information on various physiological parameters has to be generated in order to develop stable varieties for favorable environments and for boosting lentil production. The production potential for future varieties can be substantially improved by following appropriate breeding methodologies like shuttle breeding, or introgression of *macrosperma* germplasm into *microsperma*. Collaboration with neighboring countries and with international institutions like ICARDA, in addition to strengthening India's breeding centers, would be of great value in this regard.

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Discussion

C.S. Saraf
Which stability parameters do you consider best for disease and pest resistance studies?

M.M. Brar
There is no technique available so far, but under greenhouse conditions the disease is developed and screening done.

Genetic Resources and Breeding of Lentil in Pakistan

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Abstract

The lentil breeding program at the Pulses Research Institute, Faisalabad started receiving exotic lines from various countries through ICARDA in 1982. Local collections were also made which resulted in the increase of variability through the build-up of a wide spectrum of germplasm. In all, 696 local and 940 exotic entries were collected from various sources. Germplasm evaluation revealed sources of high yield potential, of earliness in maturity and of Ascochyta blight, Botrytis and rust resistance for use in hybridization. The hybridization program was initiated in 1983/84 to combine desirable traits present in exotic varieties with the adaptability present in the local germplasm. Selected lines have been tested in a series of yield trials and releases will probably be made from this material.

Lentil improvement at NIAB was started in 1986. The program comprised the evaluation of exotic germplasm from ICARDA for important plant characters and the creation of genetic variability through induced mutations and hybridization. Out of more than 1000 germplasm accessions received from ICARDA, 18 accessions were finally isolated on the basis of their higher yield potential, larger seed size, earliness in maturity and wider adaptability. Dry dormant seeds of two varieties each of *microsperma* (Pant L406 and Masoor 85) and *macrosperma* (Precoz and L605) groups were treated with 10-30 kR doses of gamma rays. The varieties exhibited marked differences in their radiosensitivity irrespective of their seed size. Precoz was found to be the most resistant, followed by Masoor 85, Pant L406 and L605. The frequency and spectrum of mutations exhibited a peak at 20 kR, which may be considered as an optimum dose for plant breeding. Varieties of the *microsperma* group showed a higher mutation rate than the *macrosperma*. A wide range of morphological mutants with changes in almost all plant parts were isolated in both the groups. A large number of putative mutants/variants with higher yield and 2-5 weeks earliness in maturity were also identified. Most of these mutants bred true in the M_3. The progenies of crosses between *microsperma* and *macrosperma* varietal groups displayed transgressive segregation for number of days taken to flower and several other quantitative traits. Selected genotypes from the segregating generations are expected to offer tremendous scope for lentil improvement.

Introduction

In Pakistan, lentil is grown as a winter-season crop, usually on an area of about 80 000 ha annually. About 75% of the area is planted in the Punjab province alone (Fig. 1). In Punjab, the lentil area is concentrated in the northeastern districts of Sialkot, Narowal, Gujrat, Rawalpindi, Jhelum and Chakwal where about two-thirds of the total area is sown under rain-fed conditions, with a relatively high rainfall. Low yield potential, susceptibility to diseases and weed infestation are the main production constraints to the lentil crop. All the lentil area was sown with landraces until 1985. With the release of lentil variety Masoor 85, farmers began to switch to it. Genetic sources with high yield potential, wide adaptability, earliness in maturity and resistance to diseases are needed to develop desirable varieties through breeding. To these ends, lentil breeding is being conducted at three institutes in Pakistan, namely the National Agricultural Research Center (Islamabad), Pulses Research Institute (Faisalabad) and Nuclear Institute for Agriculture and Biology (Faisalabad). This paper reviews research on lentil breeding in Pakistan, primarily focusing on research conducted at Faisalabad.

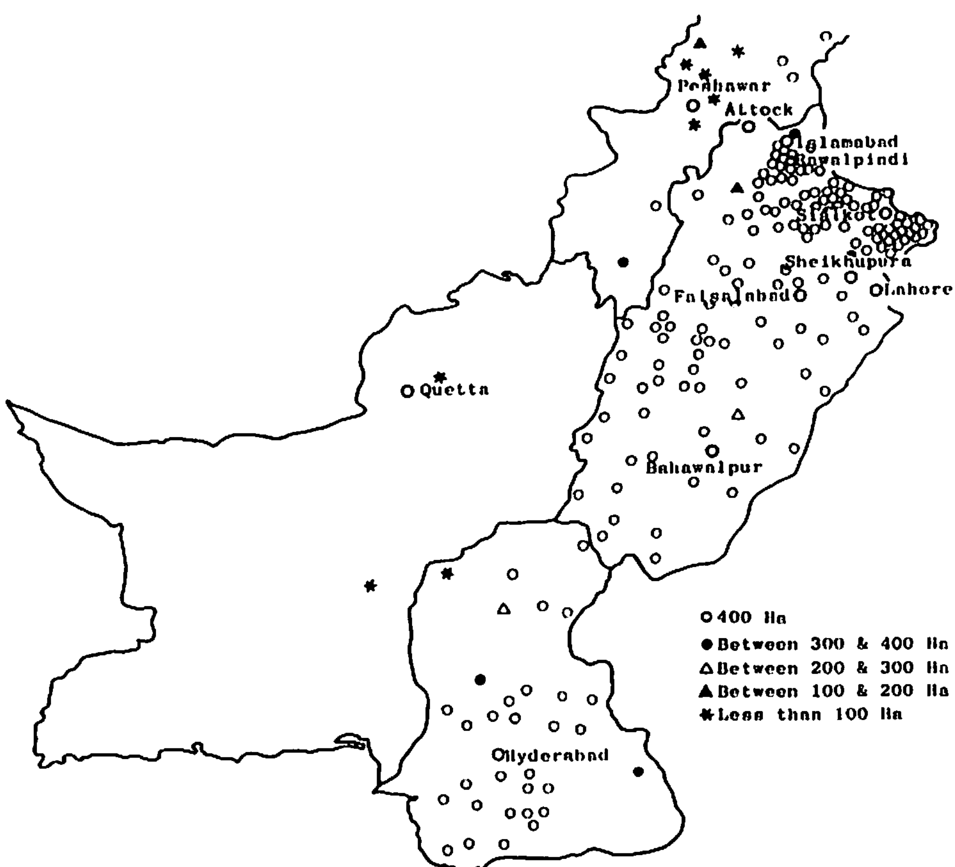

Fig. 1. Lentil production areas in Pakistan.

Pulses Research Institute

Genetic Resources

Variability in the gene pool is the basic requirement for crop improvement through combining desirable traits to achieve potential yields. At the time of the establishment of an independent section on pulses research at Ayub Agricultural Research Institute, Faisalabad in 1971, only 12 varieties and some local germplasm lines were inherited from the Cereal Section, which was previously responsible for research on pulses. Out of that material, the local variety 9-6 was recommended by the Punjab Government and it was released under the name of Masoor 85 for general cultivation in the Province. The pulse program of the Government of Punjab started receiving exotic lines from other lentil-growing countries through the International Center for Agricultural Research in the Dry Areas (ICARDA) in 1982 and local collections from lentil-growing areas of the country were also made, resulting in the build-up of a wide spectrum of germplasm comprising 696 local and 940 exotic accessions (Table 1). This germplasm was evaluated and various characteristics were recorded (Table 2).

Table 1. Germplasm at Pulses Research Institute, Faisalabad collected from various sources.

Source	No. of entries
Local	696
Exotic	940
ICARDA	540
FAO	51
Iran	349

Table 2. Comparison of variability in local and exotic germplasm and newly developed lines at Pulses Research Institute, Faisalabad.

	Type of material		
Characteristic	Local	Exotic	New lines
Days to 50% flowering	94-117	42-139	43-108
Days to maturity	146-164	106-167	111-151
Plant height (cm)	22-75	16-76	25-65
Plant type	SE-E†	P-E†	SE-E†
No. primary branches/plant	6-13	3-11	8-16
No. pods/plant	21-135	17-130	56-149
No. seeds/pod	1-2	1-2	1-2
1000-seed weight (g)	16-21	15-43	22-48
Seed yield (kg/ha)	400-2800	200-3000	1000-3500

† E = Erect; SE = Semi-erect; P= Prostrate.

All the characteristics showed variability except the number of seeds/pod. Exotic entries had a greater range in variation than local ones. Sources for high yield potential, earliness in maturity, and resistance to diseases were selected for use in the hybridization program (Table 3).

Breeding Program

Hybridization was used to incorporate desirable characters into well-adapted varieties. Upon the identification of sources of various desirable traits, the lentil breeding program was started in 1983/84. Crosses were made mainly to combine the high yield potential and wide adaptability of local varieties with the earliness in maturity and resistance to diseases present in exotic varieties from India, Ethiopia and Syria. Segregating populations were handled through the bulk-pedigree method, by bulking the F_2 and selecting single plants in F_3 to F_6. Uniform lines in F_5 and F_6 were bulked (Table 4).

Table 3. Accessions selected at Pulses Research Institute, Faisalabad for various traits.

Character	Accession
High yield potential	9-6, 18-10, 18-12, No.25, No. 162, No. 34, ILL 2580, ILL 3516, ILL 3493 and ILL 1983
Earliness in maturity	ILL 4605, ILL 3278, ILL 5803, ILL 6004, ILL 6007, ILL 6821 and AARIL337
Source for resistance to diseases	
Ascochyta blight	ILL 4605, ILL 6016, ILL 6024 and ILL 6026
Rust	ILL 4605 and X76TA-46
Botrytis	ILL 6004, ILL 6016 and ILL 6024

Table 4. Study of different filial generations of lentil at Pulses Research Institute.

	Crosses/single plants studied					
Year	F_1	F_2	F_3	F_4	F_5	F_6
1983/84	13 (new crosses)					
1984/85	13	8	24	38	23/210	23/191
1985/86	15	11	7	24	38/700	15/81
1986/87	18	9	11	13	15/226	23/200
1987/88	24	16	9	10/601	15/122	23/109
1988/89	38	24	15	10/552	29/375	23/109
1989/90	40	36	24	23/1200	13/426	8/134
1990/91	55	40	36	24/796	19/337	8/85

The uniform lines selected from F_5 and F_6 have been evaluated at Research Stations, Departmental farms and farmers' fields under different agroclimatic conditions in different types of trials each year. Entries with a combination of desirable characters are listed in Table 5.

The seed of promising varieties, exhibiting high yield potential and wide adaptability along with earliness to maturity and resistance to diseases, has been bulked for verification of their performance prior to release for general cultivation. The approved varieties also have been planted in farmers' fields to disseminate the seed among pulse growers.

Future Breeding Strategies for Lentil

1. Development of varieties with better standing ability suitable for high-input conditions.
2. Development of short-duration and cold-tolerant varieties suitable for planting after late harvest of summer crops.
3. Development of varieties with high efficiency in N_2 fixation.
4. Development of varieties with high nutritional value.

Table 5. Outcome of breeding program at Pulses Research Institute.

a. Lines with high yield potential.

		Yield (kg/ha)	
Name	Pedigree	Entries	Check (Masoor 85)
86591	ILL 4354 × ILL 101	2500	2608
87515	ILL 4404 × ILL 2501	2931	2608
87519	ILL 1 × ILL 2573	3222	2608
87528	ILL 5425 × ILL 2501	3181	2608
87529	ILL 5425 × ILL 4380	2756	2608
86642	ILL 2573	3294	2608
88532	(ILL 4605 × ILL 581)-2	3021	2104-2667
88537	(ILL 5562 × ILL 5590)-8	2729	2104-2667
88542	(ILL 5562 × ILL 5590)-29	2833	2104-2667
89503	(ILL 4400 × 18-12)-4	3188	2104-2667
89502	(ILL 4400 × 18)-12	2813	2104-2667
89507	(ILL 4400 × 18-12)-43	2833	2104-2667
89508	(ILL 4400 × 18-12)-44	2917	2104-2667
89510	(Precoz × Masoor 85)	2813	2104-2667
89512	(ILL 4354 × 18-12)-2	2833	2104-2667
89514	(ILL 2578 × No. 162)-3	2917	2104-2667
89518	ILL 1886 × ILL 5673	2708	2104-2667

Table 5. b. Lines with disease resistance.

Name	Pedigree	Disease rating (1-9 scale)
Botrytis blight resistance		
86586	ILL 2526 × ILL 4400	2
86591	ILL 434 × ILL 101	1
86593	ILL 4405 × ILL 101	1
86611	ILL 4405 × ILL 4354	2
88501	(ILL 813 × ILL 25017)-4	1
88507	(ILL 9 × ILL 4380)-2	2
88516	(ILL 4404 × ILL 5162)-1	2
88521	(ILL 2578 × ILL 5071)-2	2
88522	(ILL 2573 × 3416)-1	1
88525	(ILL 8 × ILL-2726)-1	2
88532	(ILL 4605 × ILL 581)-2	2
88534	(ILL 4404 × ILL 2587)-7	2
89503	(ILL 4400 × 18-12)-4	2
89510	Precoz × Masoor 85)-5	2
89511	(Precoz × 18-12)-13	1
Masoor 85 (check)		3
AARIL 502 (susceptible check)		7
Rust resistance		
86591	ILL 4354 × ILL 101	1
87515	ILL 4404 × ILL 2501	1
87519	ILL 1 × ILL 2573	1
88501	ILL 813 × ILL 2501	1
88515	ILL 4605 × ILL 2501	1
89503	(ILL 4400 × 18 12)-4	1
89511	(Precoz × 18-12)-13	1
86603	(ILL 4353 × ILL 4354)-10	1
86610	(ILL 2672 × 4400)-14-17	1
86617	(ILL 4404 × ILL 101)-17-14	1
87518	(ILL 1 × ILL 2573)-10-2	1
87522	(ILL 4605 × ILL 2573)-15-12	1
87524	(ILL 1 × ILL 4377)-26-1	1
87525	(ILL 784 × ILL 4377)-26-1	1
Masoor 85 (check)		2
AARIL 337 (susceptible check)		7

Table 5. c. Early flowering lines.

Pedigree cross	Days to flower
(ILL 8 × AARIL 337)-41-2	80
(ILL 8 × AARIL 337)-42-1	89
(ILL 8 × AARIL 337)-46-1	71
(ILL 8 × AARIL 337)-65-2	89
(ILL 8 × AARIL 337)-69-2	84
(ILL 8 × AARIL 337)-76-1	82
(ILL 8 × AARIL 337)-98-1	81
(Precoz × AARIL 351)-13-2	74
(Precoz × AARIL 346)-27-4	71
(Precoz × AARIL 346)-27-4-1	71
(ILL 9 × AARIL 345)-40-1-1	71
(ILL 9 × AARIL 345)-40-1-2	69
(ILL 9 × AARIL 345)-40-1-3	68
(ILL 9 × AARIL 345)-40-2-1	68
(ILL 9 × AARIL 345)-40-1	71
(Precoz × ILL 5426)-1-2	67
Masoor 85 (check)	101
Precoz (check)	87

Nuclear Institute for Agriculture and Biology (NIAB)

Lentil Breeding

A comprehensive varietal improvement program was initiated at the NIAB, Faisalabad in coordination with ICARDA, Syria during 1986. The program comprised the evaluation of exotic germplasm received annually from ICARDA and the creation of genetic variability through induced mutations and hybridization leading to the selection of genotypes with desirable plant characteristics. This section of the paper reports the progress made in: the identification of promising genotypes from the world germplasm, the radiosensitivity of different varieties of lentil, the spectrum and frequency of chlorophyll and morphological mutations in different dose levels, the induced variability for important plant traits, the performance of some productive mutants/variants in the preliminary yield trails and the variability observed in the F_2-F_4 generations of crosses between *microsperma* and *macrosperma* types.

Germplasm Evaluation

Sixty-six lentil entries were selected out of 1000 lines received from ICARDA in 1986-88. These were tested in replicated trials at NIAB during the 1989/90 season. Among the accessions, ILL5888 and ILL6468 yielded significantly more than the local check Masoor

85, and the yields obtained in other accessions such as ILL6472, 5782, 6463, 4403, 2573, 6805 and 5803 could also be favorably compared with Masoor 85. Some of these accessions after further evaluation may be directly released as commercial varieties. Accession ILL 6821 was notable because of its earlier maturity (3 weeks before the local check), large seed size with red cotyledons and fairly high yield potential. Likewise, accessions ILL6470 and ILL6804 matured almost 4 weeks before the check and produced seeds more than double the size of the local check. The above genotypes, because of their adaptability, can be used in the crossbreeding program. The major constraint to the adaptation of exotic cultivars to local conditions is attributed largely to their sensitivity to bright sunlight and high temperatures prevailing during March and April, i.e., during the flowering and pod-filling stages. The plants turn yellow because of the destruction of chlorophyll by photo-oxidation, which results in shrivelling of the developing seed or sterility, often leading to death of the plants in the more sensitive genotypes like Precoz, as has been observed in tobacco (Malik and Godward 1981). This problem is now being overcome through the hybridization of suitable exotic varieties with local ones.

Induced Mutations

Radiosensitivity of genotypes

Seeds of two varieties each of the *microspema* (Pant L406 and Masoor 85) and *macrospema* (Precoz and L605) groups were irradiated with 10, 20 and 30 kR doses of gamma rays. The effects of different doses of gamma irradiation on seed germination, seedling height and root length of each variety are presented in Table 6 from a replicated trial in petri dishes with 100 seeds/treatment. Germination of the seeds was not impaired even at the highest dose of 30 kR in both varietal groups but there was a progressive decrease in the seedling height and seedling root length with the increase in dose level in all varieties. The growth inhibition was stronger at 20 kR and upward. Reduction in the seedling growth was most drastic in *macrospema* L605 and least in Precoz of the same group. The response of *microspema* varieties Pant L406 and Masoor 85 was between these two extremes, the former being more sensitive than the latter. The retardation in root length was more pronounced than that in shoot in all varieties at different doses. The initial growth in the shoot is largely due to cell elongation, whereas the root growth is mainly dependent on cell division. This differential response of root and shoot to radiation has been reported in lentii by Sharma and Sharma (1986) and Sinha and Chaudhry (1987).

The percentage of plant emergence and plant survival at maturity in all varieties decreased with a corresponding increase in the dose (Table 7). Variety L605 appeared to be the most sensitive, followed by Pant L406, Masoor 85 and Precoz. Considering the relative radiosensitivity of the varieties under study, the lethal dose for 50% of seeds (LD50) of L605 was somewhere between 10 and 20 kR, of Pant L406 a little below 20 kR, of Masoor 85 a little above 20 kR and Precoz between 30 and 40 kR doses. The dose effect on other plant characters such as height, pods/plant and seeds/plant elicited responses similar to those implicit on the basis of survival percentages. There was no relationship of seed size with radiosensitivity in the varieties under study. Sharma and Sharma (1986), Sinha and Chaudhry (1987) and Kalia and Gupta (1989) reported greater

Table 6. Effect of different doses of gamma irradiation on seed germination, seedling height and seedling root length in different varieties of lentil sown in petri dishes at NIAB during 1986.

Variety	Dose (kR)	Germination (%)		Seedling height (cm)		Seedling root length (cm)	
		Actual	% of control	Actual	% reduction	Actual	% reduction
Macrosperma Precoz	0	96	100	11.0 ± 0.7	0	7.2 ± 1.2	0
	10	98	102	10.8 ± 0.9	1.8	7.0 ± 1.3	2.8
	20	96	100	9.4 ± 1.1	14.5	5.9 ± 1.5	18.1
	30	95	99	9.3 ± 1.2	15.5	4.5 ± 1.5	37.5
L605	0	96	100	12.6 ± 0.9	0	7.9 ± 1.1	0
	10	96	100	11.5 ± 1.8	9.7	7.5 ± 1.4	5.1
	20	92	96	8.2 ± 3.6	34.9	4.1 ± 1.8	48.1
	30	88	92	4.8 ± 2.2	61.9	2.5 ± 1.2	68.4
Microsperma Pant L406	0	100	100	13.7 ± 1.1	0	7.0 ± 1.1	0
	10	100	100	13.0 ± 1.2	5.1	6.6 ± 1.7	5.7
	20	97	97	8.7 ± 4.4	36.5	4.2 ± 2.4	40.0
	30	92	92	5.8 ± 3.4	57.7	2.8 ± 1.7	60.0
Masoor 85	0	98	100	13.9 ± 1.1	0	7.4 ± 0.7	0
	10	100	102	13.7 ± 1.7	1.4	6.6 ± 1.5	10.8
	20	98	100	9.8 ± 5.1	29.5	5.0 ± 2.7	32.4
	30	94	96	6.9 ± 4.1	50.4	3.3 ± 2.4	55.4

Table 7. Effect of different doses of gamma irradiation on seedling emergence, plant survival and other important plant characters in different varieties of lentil grown in the field at NIAB during 1986/87.

Variety	Dose (kR)	Emergence† Actual (%)	Emergence† % of control	Survival height‡ Actual (%)	Survival height‡ % of control	Plant height (cm)	Pods/ plant	Seeds/ plant
Macrosperma Precoz	0	88.3 ± 2.1	100	86.7 ± 1.5	100	46 ± 1.6	119 ± 9.9	184 ± 30.5
	10	87.7 ± 2.5	99	81.3 ± 2.1	94	40 ± 4.1	81 ± 26.0	114 ± 45.6
	20	83.3 ± 2.1	94	68.7 ± 2.5	79	38 ± 5.4	59 ± 33.5	82 ± 60.2
	30	70.0 ± 6.0	79	54.3 ± 3.1	63	36 ± 6.3	40 ± 26.1	57 ± 27.8
L605	0	90.3 ± 2.1	100	89.3 ± 2.1	100	49 ± 3.3	185 ± 19.2	256 ± 43.6
	10	79.7 ± 6.4	88	62.0 ± 2.6	69	43 ± 5.0	129 ± 50.0	187 ± 73.3
	20	44.0 ± 6.6	49	31.3 ± 3.5	35	42 ± 5.5	103 ± 65.9	118 ± 110.3
	30	23.3 ± 6.1	26	13.7 ± 3.5	15	39 ± 8.9	81 ± 75.9	97 ± 80.3
Microsperma Pant L406	0	91.7 ± 1.5	100	90.3 ± 2.1	100	56 ± 2.5	202 ± 17.9	360 ± 24.2
	10	83.3 ± 4.9	91	78.3 ± 2.5	87	52 ± 5.5	177 ± 44.3	279 ± 95.8
	20	64.7 ± 5.5	71	42.7 ± 2.5	47	45 ± 7.2	142 ± 57.0	198 ± 131.5
	30	35.3 ± 4.5	39	21.7 ± 3.1	24	44 ± 9.5	120 ± 64.6	160 ± 129.7
Masoor 85	0	94.7 ± 1.5	100	93.1 ± 2.1	100	58 ± 2.1	180 ± 16.9	324 ± 29.8
	10	88.7 ± 2.5	94	80.7 ± 2.1	87	53 ± 6.4	155 ± 35.6	257 ± 61.0
	20	72.3 ± 4.7	76	51.7 ± 2.5	55	50 ± 7.6	150 ± 42.6	234 ± 71.1
	30	45.0 ± 5.3	48	31.3 ± 2.5	34	48 ± 8.0	138 ± 45.6	212 ± 59.6

† Recorded 4 weeks after sowing.
‡ Recorded at maturity.

Table 8. Spectrum and frequency of chlorophyll mutations in the M_2 generation of different varieties of lentil grown at NIAB during 1987/88.

Variety	Dose (kR)	No. M_2 families scored	No. M_2 families segregating	Mutation frequency†	No. M_2 plants scored	Spectrum of chlorophyll mutations					Total no. mutants	Mutation frequency‡
						Xantha	Albino	Viridis	Light green	Dark green		
Macrosperma												
Precoz	0	154	-	-	2750	-	-	-	-	-	-	-
	10	154	3	1.9	2408	7	3	-	1	3	14	5.8
	20	154	6	3.9	1982	6	4	-	2	4	16	8.1
	30	154	5	3.2	1503	5	4	-	2	1	12	8.0
L605	0	154	-	-	2850	-	-	-	-	-	-	-
	10	154	7	4.5	2632	6	7	5	1	1	20	7.6
	20	154	5	3.2	2624	5	6	-	1	1	13	5.0
	30	154	4	2.6	2313	2	3	2	1	-	8	3.5
Microsperma												
Pant	0	167	-	-	4500	-	-	-	-	-	-	-
L406	10	167	7	4.2	4044	10	7	7	1	2	27	6.7
	20	167	13	7.8	3830	9	17	23	2	3	54	14.1
	30	167	8	4.8	3408	9	8	17	-	3	37	10.9
Masoor												
85	0	167	-	-	4550	-	-	-	-	-	-	-
	10	167	6	3.6	4325	7	6	11	2	1	27	6.2
	20	167	10	6.0	4077	13	11	19	1	2	46	11.3
	30	167	7	4.2	3625	8	7	15	2	2	25	9.4

† As percent of M_2 families.
‡ Per 1000 M_2 plants.

radiosensitivity of *macrospema* lentil, whereas Singh *et al.* (1989) reported that the *microspema* variety (Pant L639) was more sensitive than the *macrospema* variety (RAU101) following 5 to 25 kR doses of gamma rays. The difference in the radiosensitivity of varieties of both groups as observed in the present studies may be attributed to the differences in their genetic background (Rajput and Siddiqui 1981; Malik *et al.* 1988).

Spectrum and frequency of induced mutations in the M_2 generation

Chlorophyll mutants. The data on spectrum and frequency of chlorophyll mutations (calculated as a percentage of mutated M_2 progenies and plants) in the two varietal groups are presented in Table 8. The five main types of chlorophyll mutations were observed: xantha, albina, viridis, light green and dark green. Xantha and albina types appeared with highest frequency and were lethal, whereas the light green and dark green types, although fertile, appeared in a very low frequency. Viridis mutants were characteristically yellowish-green in color up to maturity. In the *macrospema* group these mutants appeared only in L605 with a very low frequency, and died during late ontogenesis without producing any seed. In *microspema*, viridis appeared in very high frequency. The plants had slow growth and weak stems with an increased internodal length. These mutants produced few flowers and hence low seed yields. Chlorophyll mutants exhibited a peak at 20 kR in all varieties except L605, in which the peak occurred at 10 kR. The frequency of chlorophyll mutations in terms of percentage of mutated families and per 1000 M_2 plants at different doses was much higher in the *microspema* group than in the *macrospema*, indicating their greater suitability for mutation breeding work. The decline in mutation frequency at 30 kR may be attributed to increased sterility, the phenomenon of diplontic selection and other processes of gamete as well as zygote elimination (Ehrenberg *et al.* 1958; Gaul 1961). The chlorophyll mutations induced through physical and chemical mutagenic treatments also have been reported by Sharma and Sharma (1981) and Dixit and Dubey (1986) in lentils, Singh and Chaturvedi (1980) in mungbean, Malik *et al.* (1988) in mungbean and black gram, and Kharkwal *et al.* (1988) in chickpeas.

Morphological mutants. The mutation frequency for morphological characters, on the percentage of the M_2 family basis, as well as per 1000 of the M_2 plant basis, exhibited a peak at 20 kR in all varieties (Table 9). The average mutation rates (percent M_2 families and plants mutated) were lowest in L605 and highest in Pant L406. Mutation frequency in the *microsperma* varieties on the whole was much higher than that observed in the *macrosperma*. The mutagenic treatments induced a wide range of viable morphological mutations, affecting gross morphological changes in all plant parts such as stem structure, branching, growth habit, plant height, leaf morphology, tendril length and structure, pod size, seed size and coat color. Sterile plants and those showing changes in flower structure were excluded. Mutants were classified into different categories according to the most prominent character, although in most of the mutants more than one character was altered. The maximum number of mutations was noticed for plant height, leaf morphology and growth habit. The plant height mutants were extra tall, semi-dwarfs, dwarfs, stunted and miniature. The mutations in the leaf form included:

Table 9. Spectrum and frequency of morphological mutations in the M_2 generation of different varieties of lentil grown at NIAB during 1987/88.

Variety	Dose (kR)	No. of families segregating	Mutation frequency†	Spectrum of morphological mutations: Height	Growth habit	Branching and stem structure	Leaf	Tendril	Pod size	Seed size	Seed coat	Total no. of mutations	No. of M_2 plants scored	Mutation frequency‡
Macrosperma														
Precoz	0	-	-	-	-	-	-	-	-	-	-	-	2750	-
	10	13	8.4	4	2	-	10	-	8	7	-	31	2408	12.9
	20	18	11.7	6	3	2	13	2	12	3	-	41	1982	20.7
	30	21	13.6	5	3	3	6	-	5	6	-	28	1503	18.6
L605	0	-	-	-	-	-	-	-	-	-	-	-	2850	-
	10	18	11.7	12	3	3	4	2	3	1	-	28	2632	10.6
	20	21	13.6	19	4	4	6	2	2	3	-	40	2624	15.2
	30	12	7.8	8	3	1	1	1	-	1	2	17	2313	7.3
Microsperma														
Pant	0	-	-	-	-	-	-	-	-	-	-	-	4500	-
L406	10	18	10.8	15	6	4	13	2	1	4	-	45	4044	11.1
	20	26	16.8	31	10	11	29	4	12	2	2	101	3830	26.4
	30	23	13.8	19	7	10	27	3	3	8	-	77	3408	22.6
Masoor														
85	0	-	-	-	-	-	-	-	-	-	-	-	4550	-
	10	28	16.8	12	4	3	11	1	3	8	-	42	4325	9.7
	20	33	19.8	32	11	15	16	3	5	12	1	95	4077	23.3
	30	30	18.0	20	17	9	12	3	7	15	-	75	3625	20.1

† Percent of M_2 families.
‡ Per 1000 M_2 plants.

size of rachis, length, breadth and shape of leaflets, number of leaflets, increased hairiness and modification of leaflets into tendrils. The mutations depicting growth habit were compact, bushy and erect. Based upon the similarities found in the spectrum and the frequency of induced mutations, *microsperma* varieties Pant L406 and Masoor 85 can be considered genetically close. In the present studies more than one kind of mutation has been found in the progenies of several single M_1 plants, indicating that more than one or two embryonic initials had taken part in the development of their shoot meristem. Mutants showing changes in various morphological characters induced through radiation or chemical mutagens have been reported by Sharma and Sharma (1979) and Dixit and Dubey (1983) in lentil as well as by Ganguli and Bahaduri (1980) and Malik *et al.* (1986, 1988) in mungbean and black gram. On the basis of present results, 20 kR of gamma rays is suggested as an optimum dose for plant breeding purposes.

Performance of selected mutants/variants in the M_3-M_4 generations

The treated populations in the M_2 generation showed an enormous range of induced variability for various quantitative characters (Sharma and Sharma 1982; Kalia and Gupta 1989). To exploit this variability, 293 variants with increased number of pods, early maturity, erect, upright and compact growth habit, and greater number of primary and secondary branches were selected from different doses in all varieties and grown in individual M_3 rows along with the parents. The majority of these mutant characters were breeding true. The magnitude of the increased range of variability in the M_3 (Table 10), particularly toward the positive side, showed that some extremely useful variability had been induced. The phenotypic coefficient of variation was highest, per plant, for branches, height, pods and grain yield.

Selection for higher yield, early maturity and good plant type was continued in the M_3 generation. Most of the M_4 mutant lines gave higher yields than their respective parents. In the early maturing large-seeded Precoz, selection was mainly directed toward higher yield, nonshattering seeds and tolerance to high temperature. Apart from selecting for higher yield in the small-seeded varieties Masoor 85 and Pant L406, selection was for short plant stature to resist lodging and early maturity. Although most of the early maturing mutants produced relatively low yields, there were several instances where such negative correlation was broken. Mutants 12-8 and 46-2 induced in variety Masoor 85 matured 2 weeks earlier and produced higher yields than the parental type. Similarly, mutant 14-43 induced in Pant L406 matured 3 weeks in advance without any loss in yield. Short-statured, early maturing and high-yielding mutants have been previously reported for lentil by Sharma and Sharma (1978), Dixit and Dubey (1986), Kharkwal *et al.* (1988) and Kalia and Gupta (1989). The yield in early maturing, short-statured mutants can be further improved by increasing the plant population per unit area (Sheikh *et al.* 1982). Mutants identified in the present studies are being further evaluated for yield, seed protein content, quality, disease resistance, and for the feasibility of their direct and indirect use in lentil improvement. The experience gained here clearly demonstrates that mutation breeding can play a pivotal role in augmenting the existing genetic variability.

The genetic behavior of the induced mutants studied so far has indicated a monogenic recessive inheritance pattern. The xantha and sterile tendril mutants could be perpetuated in the heterozygous condition.

Table 10. Range of specific plant characters and yielding ability of lentil induced mutants/variants compared with their parental types in the M_3 generation grown at NIAB during 1988/89.

Character	Parent (Precoz)	Mutant range	CV	Parent (Pant L406)	Mutant range	CV	Parent (Masoor 85)	Mutant range	CV
Days to flower	80.6 ± 1.00	79 - 86	1.71	96.6 ± 1.00	64 - 119	9.94	96.1 ± 1.00	80 - 96	3.64
Days to mature	140.6 ± 0.82	138 - 147	1.30	158.5 ± 1.61	136 - 165	3.97	158.9 ± 1.41	144 - 155	1.56
Plant height (cm)	44.1 ± 2.95	26 - 55	12.48	52.2 ± 2.65	15 - 55	28.27	54.9 ± 2.94	18 - 59	18.24
No. of primary branches/plant	2.3 ± 0.44	1 - 4	21.83	2.45 ± 0.51	1 - 5	31.31	2.45 ± 0.76	1 - 4	31.84
No. of pods/ plant	116.75 ± 13.2	20 - 290	54.08	196.5 ± 19.41	15 - 430	52.61	181.50 ± 20.2	15 - 465	45.56
No. of seeds/pod	1.56 ± 0.17	1 - 2.4	14.71	1.92 ± 0.14	1 - 2	14.79	1.92 ± 0.12	1 - 2	13.65
1000-seed weight (g)	40.35 ± 0.88	24 - 60	8.45	18.5 ± 0.61	11 - 22	11.03	18.7 ± 0.66	18 - 30	11.30
Grain yield/plant (g)	7.07 ± 0.91	2.5 - 21.0	46.45	7.70 ± 1.02	0.8 - 17.7	51.90	7.33 ± 1.14	1.0 - 18.8	44.48

Hybridization

The F_2 populations of crosses between the early flowering large-seeded variety Precoz (40 g/1000-seed wt) and late-flowering small-seeded varieties Masoor 85 and Pant L406 (19 g/1000-seed wt) segregated to produce a wide range of early and late-flowering genotypes. The days to flower far exceeded the parental values of 80 and 110 days, respectively, in both directions. This generated a number of transgressive segregants for earliness (up to 40 days) as well as lateness (up to 142 days). From these populations a large number of segregants were selected, all having early maturity, larger seed size with red cotyledons, tolerance to high temperature and high yield. Their breeding behavior is being studied in F_3-F_4 generations.

The F_2 populations of crosses between another set of large-seeded (ILL 5748, ILL 6024, ILL 5782) and small-seeded (ILL 2580, Pant L406, Pant L639, Masoor 85) varieties also exhibited transgressive segregation for the number of days taken to flower (± 20 days) and for several other quantitative traits. The parental types involved in these crosses, however, flowered more or less at the same time (104 to 110 days). These results indicate that genes controlling time taken to flower in both the varietal groups may be independent and additive. Present results are not in complete agreement with those of Tyagi and Sharma (1989) who reported transgressive segregation only in the F_2 populations of crosses between Precoz and the early flowering indigenous varieties L-3991, JLS-3 and Sehore-74-3, and not between Precoz and the late-flowering Pant L406 or Pant L-72-2. These differences might be due to the reaction of genotypes in different environmental conditions (Summerfield and Roberts 1986). From the progenies of the various crosses presently under observation, it appears that hybridization between *microsperma* and *macrosperma* types will expand the scope for lentil improvement in yield, quality, adaptability and resistance to diseases.

Conclusions

Genetic variability in the *microsperma* varietal group of lentils is extremely low. For lentil improvement, the collection and evaluation of germplasm for important economic characters is necessary in order to identify germplasm suited for direct utilization or for breeding superior varieties.

The lentil germplasm generated and maintained at ICARDA, Syria and its continuous flow to the breeders is of immense value. Of the over 1000 germplasm accessions received from ICARDA and evaluated at NIAB during the past few years, 18 accessions have been found promising for their higher yield potential, larger seed size, early maturity and resistance to rust and Botrytis diseases. Some of these accessions after further evaluation may be considered suitable for release as commercial varieties and others may be used in the crossbreeding program.

Induced mutations in the present study have proved to be a useful complementary source for augmenting the genetic variability. Varieties within the *microsperma* and *macrosperma* groups exhibited large differences in their radiosensitivity, irrespective of their seed size. The LD50 of varieties under study ranged from 10 to 40 kR doses of gamma rays. The frequency and spectrum of induced mutations exhibited a peak at 20 kR, which may be considered as an optimum dose for mutation breeding work. The mutation rate was markedly higher in the *microsperma* group, through irradiation. Apart from chlorophyll mutations, a wide range of morphological mutants/variants showing marked changes in almost all plant parts have been isolated. The majority of the mutant characters were true breeding. A good number of putative variants with higher yield potential, early maturity, reduced plant height and upright growth also have been identified.

The F_2 populations of crosses between *microsperma* and *macrosperma* varieties exhibited transgressive segregation for days to flowering and several other quantitative traits. Identification of suitable genotypes (good combiners) from both the varietal groups will offer immense scope for evolving superior genotypes with respect to yield, maturity, adaptability and disease resistance through hybridization.

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Discussion

P.N. Bahl
Dr B. Sharma from IARI, New Delhi reported that variety Precoz flowers in 65 days at Delhi, whereas you have indicated in your talk that in Pakistan this variety flowers in 80 days. How can such wide differences in flowering be explained?

I.A. Malik
The difference in the time taken to flower by Precoz at Faisalabad, Pakistan and at New Delhi can be largely attributed to environmental conditions. In Pakistan lentil is sown by the end of October or early November, i.e., start of the winter season. During the months of December to mid-February the plant growth is arrested. Later the plants grow speedily and enter the reproductive phase. The temperature during this period at New Delhi may not be that cold, leading to such differences. The number of days taken to flower to some extent can also be reduced if the crop is sown late in the season.

M.C. Tyagi
You have induced an array of beautiful mutants. What is their yield potential?

I.A. Malik
Performance of the mutants has been studied in M_4 generation in preliminary yield trials for Precoz, Pant L 406 and Masoor 85 mutants. Some of the mutants, as shown in the data, matured 2-3 weeks earlier and also gave higher yields than the parents. In others most of the mutants have the same maturity duration but a higher yield than their respective parents.

Genetic Resources and Breeding of Lentil in Bangladesh

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Abstract

Varietal development of the lentil began in Bangladesh during the late 1970s. A total of 318 local and 1200 exotic germplasms have been collected and evaluated so far. One selection (L-5) from within a local collection (BLL-79694) was found superior in yield and maturity among all the genotypes evaluated and has been placed before the National Seed Board for commercial release. The exotic materials did not perform as well, primarily because of late maturity and poor yield, although some were free of rust and Stemphylium disease. International trials, nurseries and segregating materials from ICARDA have been evaluated but with minimal success. The hybridization program initiated in 1984 focuses on the development of rust-resistant, high-yielding varieties through screening various generations. It is suggested that efforts be intensified in the introgression of resistant genes against rust and Stemphylium diseases, and in utilizing *macrosperma* types and wild parents. It is also proposed that ICARDA extend lentil activities in the South Asia region by generating materials of a broader scope to encompass this region. Likewise, ICARDA is encouraged to develop a network to strengthen research on lentil and solve the common problems of this crop in this region.

Introduction

Bangladesh ranks third among the lentil-growing countries of the world (Anonymous 1986). The lentil is the second most important pulse crop in area and production, but stands first in the consumers' preference in this country. It is grown on about 208 000 ha, producing 159 000 tonnes of grain, with an average yield of 763 kg/ha, and contributes about 29% of the total pulses (BBS 1989). The crop is mostly sown in November in the upland rice/fallow/lentil cropping pattern. To a lesser extent, it is often sown in early December following *aman* (late) rice, in which case its yield is reduced substantially by the late sowing, as reported elsewhere (Shaharia 1980; Saxena *et al.* 1983), but this can be compensated for, up to a certain date, with a higher seed rate (Ahlawat *et al.* 1982, 1983).

The existing cultivars are small-seeded types with extremely narrow genetic variability. Variation in plant type is very small within Bangladesh germplasm. Also the varieties are generally low-yielding compared with varieties in other countries. One of the probable reasons is the short winter period (110-115 days) within which the varieties have to complete their life cycle; hence, only short-duration types are adapted.

The local cultivars are susceptible to major diseases such as Stemphylium blight (*Stemphylium* sp.) and rust (*Uromyces fabae*), especially under late-sown conditions, which may cause a yield reduction of up to 70% (Sepulveda 1989). Other minor diseases are collar rot, root rot, wilt and bushy stunt (stunt virus). Farmers grow lentil under rain-fed conditions without inputs because the varieties show negative response to high management inputs like irrigation and fertilizer.

Varietal development of the lentil began at Bangladesh Agricultural Research Institute (BARI) during the late 1970s with the inception of the Pulses Improvement Program funded by the International Development Research Center, Ottawa, Canada. Efforts were initiated at the Bangladesh Institute of Nuclear Agriculture (BINA) to develop suitable high-yielding varieties through mutation breeding. The objectives of the present paper are to review progress and suggest future activities for the improvement of this crop.

Recent Progress

Although research on lentils was initiated during the early 1950s, efforts were confined to the collection and evaluation of local germplasm. A few lines were tested over various locations during the early 1960s (Gowda and Kaul 1982) but the research virtually stopped as the germplasm was not properly maintained. With the initiation of a separate pulse improvement program at BARI in 1970, a fresh start was undertaken. Since then BARI has been working to improve the lentil through conventional breeding approaches. Strategies were adopted to develop high-yielding lentil varieties, within a short span of time, through introduction. Top priorities were given to the collection of local and exotic germplasm, to their evaluation under Bangladesh conditions, and to the selection of desirable ones.

So far, 318 local and 1200 exotic germplasm lines have been introduced from ICARDA, the USA and India (Table 1). All the lines were evaluated and the following observations made. The local collections exhibited a very narrow genetic variability with respect to maturity, seed size, yield and other characters (Sarwar *et al.* 1981). However, one selection from accession BLL-79694 collected from Pabna district of Bangladesh and later designated as L-5 was found superior with respect to yield and maturity among all the local and exotic germplasm evaluated so far. It produced stable yields of around 1300 kg/ha over years (BARI 1984/85, 1986/87) and has been proposed to the National Seed Board for release as a commercial variety. Its characteristics include maturity within 100-110 days, medium plant height (35-40 cm), nontendrillous growth habit, small seed size (1.4-1.6 g/100 seed) and yield potential of 2.5 t/ha (BARI 1983/84). The exotic germplasm did not show much promise; none performed better than L-5 in yield, maturity or disease reaction. The *macrosperma* types did not perform well in this climate, probably because of the short winter. They are late to mature, sometimes producing no

Table 1. Stock of lentil germplasm in Bangladesh.

Year	Local	Exotic†
1979	78	550 ICARDA + 400 India
1980	139	-
1981	101	50 India
1984	-	200 ICARDA
Total	318	1200

† Many exotic lines did not flower at all and most were *macrosperma*.

pods, and are very susceptible to collar rot and wilt diseases (Mia *et al.* 1986). Although some were found to be resistant to rust and Stemphylium disease, no effective selection could be made out of these international trials and nurseries received from ICARDA (LIYT-E, LISN-E, LIF_3T-E, etc.). However, several rust-resistant lines have been developed from the 29 F_3 (LIF_3T-E) received from ICARDA in 1984/85 (103-10, 125-5, 110-78). They are small-seeded, a little longer in duration, and exhibit a yield level at par with or lower than the L-5. Among the selections, some have been included in the hybridization program for rust resistance.

At BINA, efforts were made to induce mutation by applying 30-60 kR doses of ^{60}Co gamma rays. Characters such as pod number and protein content were altered (Shaikh *et al.* 1978). A few phenotypically recognizable mutants were isolated following treatments with NaN_3 + gamma rays, on the basis of higher seed yield from a segregating population. These are under further trials (Shaikh and Rahman 1989).

Present Status

So far only limited success has been attained in selecting or developing desirable genotypes through direct introduction. Therefore, breeding strategies have been revised, and both short-term and long-term approaches have been adopted. The hybridization program, utilizing the best local cultivar along with genotypes resistant to rust and Stemphylium blight, was initiated in 1984/85 with the aiming of incorporating rust resistance into L-5. The segregating generations are screened against rust and Stemphylium blight diseases, using highly susceptible spreader rows (against rust BLL-81149 and Stemphylium BLL-81124) after every five rows of segregating populations. The segregating generations are advanced through individual plant selection from F_3 generation, followed by bulking similar plants within family showing resistance to diseases, similar in maturity and having high podding intensity.

Besides these, ICARDA was requested in 1985/86 to make crosses using L-5 and their rust-resistant lines and to supply us with the segregating populations. In this program,

F_3 seeds of 17 crosses were received and grown in 1989/90. Only 247 individual plants from 6 crosses were selected on the basis of earliness and seed size (PBR 1990). These will be grown in 1990/91 as F_4 families. Other crosses were extremely late in flowering and could not set pods and hence were discarded.

With regard to selection criteria, different results have been reported by various scientists. Seed yield/plant is not a reliable criterion for selection since it has low heritability (Erskine *et al.* 1985; Muehlbauer *et al.* 1985). Singh and Singh (1969) reported high heritability estimates and genetic advance for pod number, seed size and grain yield, and they observed that while pod number had the strongest association with grain yield, seed size had a negative association with grain yield. Likewise other researchers reported the greater contribution of pod number, as well as primary and secondary branches, to grain yield (Islam and Shaikh 1978; Rahman and Sarwar 1982; Sarwar *et al.* 1984; Saraf *et al.* 1985; Rajput and Sarwar 1989; Ramgiry *et al.* 1989; Zaman *et al.* 1989). Muehlbauer *et al.* (1985) concluded that branching pattern and number of fruits to reach maturity are the most important characters to contribute positively to yield. It was observed that seed size is a highly heritable character (Erskine *et al.* 1986; Lakhani *et al.* 1986). Similarly, Smithson *et al.* (1985) inferred that larger seed size (within a certain limit) positively contributes to the yield of the chickpea. Waldia and Chhabra (1989) concluded that the number of pods was the only character that can be improved by simple selection. Therefore, during selection, more emphasis was given to a greater number of pods having slightly larger seed size.

Prospects and Conclusions

In general, average and potential yield of the existing cultivars of pulses are smaller than those of the cereals. Also, success in genetic improvement has been very limited mainly owing to a narrow genetic base, extreme specificity of adaptation, which leads to the use of ineffective exotic germplasm in the breeding program, and emphasis on breeding for yield, which is not a reliable criterion for selection. In addition, the characters contributing to yield sometimes show a large, nonadditive genetic component and poor heritability.

Therefore, the preponderance of nonadditive genetic variation for most yield components, and the specific nature of adaptation, suggest the need to consider approaches which involve the incorporation of trials such as resistance to diseases and pests, as well as tolerance to physical stress factors, into the locally adapted genotypes. The ongoing hybridization program needs to further intensify efforts involving local cultivars. Screening against rust and Stemphylium blight should continue with the spreader row technique, where disease pressure must be ensured by artificial inoculation of fungi cultured in the laboratory. Any standard breeding technique may be followed for handling the segregating population; however, the pedigree method may be adopted in screening against rust since it is reported to be monogenically inherited (Sinha and Yadav 1989).

Effort should be intensified in the introgression of exotic genes from wild parents (Hoffman 1986) and also from *macrosperma* into locally adopted cultivars to improve yield, as reported by Erskine *et al.* (1986).

Finally it is proposed that ICARDA extend its activity on lentil in the South Asia region. ICARDA could further assist by generating segregating populations for South Asian countries, utilizing their landraces as one of the parents. Moreover, the possibility of the establishment of a regional network (like the Asian Grain Legume Network of ICRISAT) could be encouraged to strengthen research and help solve the common problems of lentil in the region.

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Discussion

P.P. Singh
You mentioned that lentil has a narrow genetic base, but other speakers in the morning had emphasized that it has a very wide range of genetic base.

M.M. Rahman
I have mentioned that this narrow genetic base is among Bangladesh germplasm only.

C.S. Saraf
Do you test the germplasm of lentil after rice or in the uplands?

M.M. Rahman
Yes, we tested our germplasm after upland rice, which is the normal time of planting.

Genetic Resources and Breeding of Lentil in Nepal

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Abstract

Lentil (*Lens culinaris* Medikus) is the leading pulse crop in Nepal. Area and production have more than doubled within the past few years and similar increases in export have occurred. The lentil has been grown traditionally as a relay crop in rice with a wide east to west distribution along the southern plains. Genetic resources of lentil consist of locally collected landraces, introductions from neighboring countries and from the International Center for Agricultural Research in the Dry Areas (ICARDA). Although limited lentil improvement activity had begun by 1977, a systematic improvement program, with a clearly defined strategy and methodology, was only undertaken in 1985 with the establishment of the National Grain Legume Improvement Program (NGLIP). Since then five cultivars have been released. One hundred and thirty-seven lentil accessions, mostly local landraces, have been recently characterized and evaluated following the descriptor manual published by the International Board for Plant Genetic Resources. This has revealed great variability in 15 characters for the 124 indigenous accessions included in the study. Lentils are very well adapted and give high yields in nontraditional high-altitude areas (up to 1800 m). This has a great significance as hills and high-altitude valleys occupy about 68% of the country's arable land, and fertility levels of the hills are declining. Lentil grown in Nepal and cultivars released so far are mainly of the *microsperma* types. *Macrosperma* types, introduced from ICARDA and elsewhere, were found to be unadapted in traditional plains areas. However, they have shown promise at higher altitudes. The NGLIP has been mainly dependent upon introduced breeding materials for the development of improved cultivars. There is a need to begin a crossing program within the country for the development of high-yielding, short-duration cultivars, as well as *macrosperma* types, adapted to Nepal's highly varied environment.

Introduction

Nepal's widely varied agroclimates permit the growth of many crop species, ranging from the warm subtropical to the temperate-zone crops. There are more than a dozen grain legume species which have significance in the country's cropping systems. Grain legume crops rank fourth in area after rice, maize and wheat. Lentils are the leading grain legume and are widely grown from the east to the west, across the southern plain of

Nepal. Farmers grow traditional cultivars without any inputs or other improved management practices, and thus the yield is generally low.

Research on grain legume crops is recent, since early emphasis was given to cereal improvement. However, advances toward the generation of improved technology on grain legume crops, particularly lentils, have been made.

This paper describes the status of the lentil in Nepal and its importance. It reviews the research conducted on the genetic resources available, as well as current breeding methods.

Status of Lentil

Area, Production and Yield

Lentil is the leading pulse crop of Nepal. There has been a sharp expansion in area and production within the last 6 years, an increase of 271 and 437%, respectively (Table 1), and some increases in the yield have occurred. Yields, however, are still low and are attributed to farmers using low-yielding cultivars and their negligence of improved practices, in addition to biotic and abiotic stresses.

Table 1. Area, production and yield of lentil in Nepal from 1983/84 to 1988/89.

Years	Area (1000 ha)	Production (1000 t)	Yield (t/ha)
1983/84	44.3	17.0	0.380
1984/85	98.6	58.4	0.590
1985/86	103.2	61.2	0.593
1987/88	107.3	73.1	0.683
1988/89	112.8	63.1	0.559
1988/89	120.4	74.4	0.620

Source: Department of Food and Agricultural Marketing Services, Nepal

Importance

The lentil is the most important pulse crop and is mainly grown in the southern belt of the country. The cropping intensity of Nepal is generally high, ranging from 100 to 300%, the average being 180%. The lentil, through its adaptation in the marginal areas, plays an important role as a relay crop in increasing the cropping intensity. Lentils are mainly utilized as *dhal* (a thick soup) and thus form an important high-protein ingredient of the daily diet of the majority of Nepalese. However, lentil straw and pods also are important as fodder for animals.

The importance of lentil as an export commodity is increasing. In recent years, there has been a declining trend in the traditional export commodities like rice and jute, while the export of lentil is increasing. In 1987/88 alone, Nepal exported 16 000 tonnes of lentil (worth about USD 19.5 million) to third world countries. Export demand for lentil is still rising.

Cropping Pattern

Lentil is grown predominantly as an associated or relay crop with cereals and oilseeds. It is often intermixed with crops like wheat, barley, mustard and linseed in the central and the eastern part of the country. In the western part, it is mainly grown as a sole crop, both in the upland area where maize is commonly grown, and in the lowland area where rice is the main crop. With late rice, lentils are relay planted 2 to 3 weeks before the rice harvest. This relay planting is very important to maintain a high productivity level, as yield declines with any delay in planting and moisture becomes limited for germination and emergence. The most common cropping patterns involving lentil are as follows:

Land type	Cropping pattern
Rain-fed upland	Maize and upland rice followed by lentil Maize and soybean followed by lentil
Partially irrigated lowland	Rice followed by lentil Rice followed by lentil or other winter crops
Irrigated lowland	Rice followed by rice/lentil (relayed)

Research on Lentil

Agricultural research, in general, is a relatively new national undertaking in Nepal and concentrated initially on a few major cereal crops. Some experiments on grain legumes have been conducted since 1972. These early research efforts were successful in identifying the constraints to production, as well as focusing attention on grain legumes. In 1985, a Consultancy Report on Pulses Improvement in Nepal was prepared (Rachie and Bharati 1985), which became a major source for identifying research needs and for generating the interest of national and other donors. As a result, the National Grain Legumes Improvement Program (NGLIP) was established in 1985 with support from the

United States Agency for International Development (USAID), the International Development Research Center (IDRC) and the International Agricultural Research Centers (IARCs). Linkages between NGLIP and various IARCs were strengthened and a strategy and methodology for the improvement of research on grain legumes was developed.

Prior to 1985, grain legume research activities were mainly confined to a few stations such as Parwanipur Agricultural Station (PAS) and Khumaltar Agricultural Farm (KMLF). Now, NGLIP has a nation-wide responsibility. It has expanded its research network and currently operates at three levels: the main center (National Grain Legumes Improvement Program, Rampur, and Khumaltar Agriculture Farm - KMLF), the subcenters (Tarahara Agricultural Station - TAS, Parwanipur Agricultural Station - PAS, Nepalgunj Agricultural Station - NAS, Pakhribas Agricultural Center - PAC and Lumle Agricultural Center - LAC) and the testing centers (Hardinath Agricultural Farm - HAF, National Oilseed Development Programme - NODP, Bhairahawa Agricultural Farm - BAF, Kabre Agricultural Farm - KAF, Jumla Agricultural Station - JAS, Doti Agricultural Farm - DAF and Surkhet Agricultural Station - SAS). These operational sites represent almost all kinds of agroecological conditions in the country. The geographical and meteorological data of these operational sites are given in Table 2.

Table 2. Description of the various locations involved in NGLIP research activities.

Farm/Station	Category	Latitude (N)	Longitude (E)	Elevation (m)	Rainfall (mm)
Rampur	Main center	27.37	84.25	228	2000
Khumaltar	Main center	27.40	85.20	1360	1200
Tarhara	Subcenter	26.42	87.16	200	1700
Parwanipur	Subcenter	27.04	84.58	115	1150
Nepalgunj	Subcenter	28.04	81.37	190	1300
Pakhribas	Subcenter	-	-	1760	2250
Lumle	Subcenter	28.18	83.48	1675	5100
Kankai	Testing center	-	-	206	3000
Hardinath	Testing center	-	-	19	1600
Belachapi	Testing center	-	-	-	-
Nawalpur	Testing center	27.48	85.37	-	-
Bhairahawa	Testing center	27.32	83.28	120	2000
Kabre	Testing center	27.60	86.30	1700	1900
Jumla	Testing center	29.17	82.10	2387	600
Doti	Testing center	-	-	620	903
Surkhet	Testing center	28.36	81.37	450	150

Methodology for Cultivar Development

The steps followed by the NGLIP in the development of improved cultivars are as follows:

1. Local germplasm is collected. Exotic cultivars and advanced lines are also introduced.
2. Collected and introduced accessions are evaluated in observation nurseries in two environments; one in *Terai* plains with a warm subtropical climate, and the second in mid-hills and valleys with a cool subtropical climate.
3. Superior material, identified from the nurseries, is evaluated in a multilocational Initial Evaluation Trial (IET).
4. Entries selected from the IET are evaluated in the Coordinated Varietal Trial (CVT) at several locations across a range of environments.
5. The most promising and widely adapted entries identified in the CVT are finally tested in the Farmer's Field Trial (FFT) in collaboration with the Farming System Division at outreach sites of the regional stations, and with extension workers.
6. Based on overall performance and farmers' preference, selected cultivars are proposed for release to the National Varietal Release Committee. Sufficient quantities of breeders' seeds are produced and maintained by NGLIP.

The breeding and other research methodology are outlined in Figure 1.

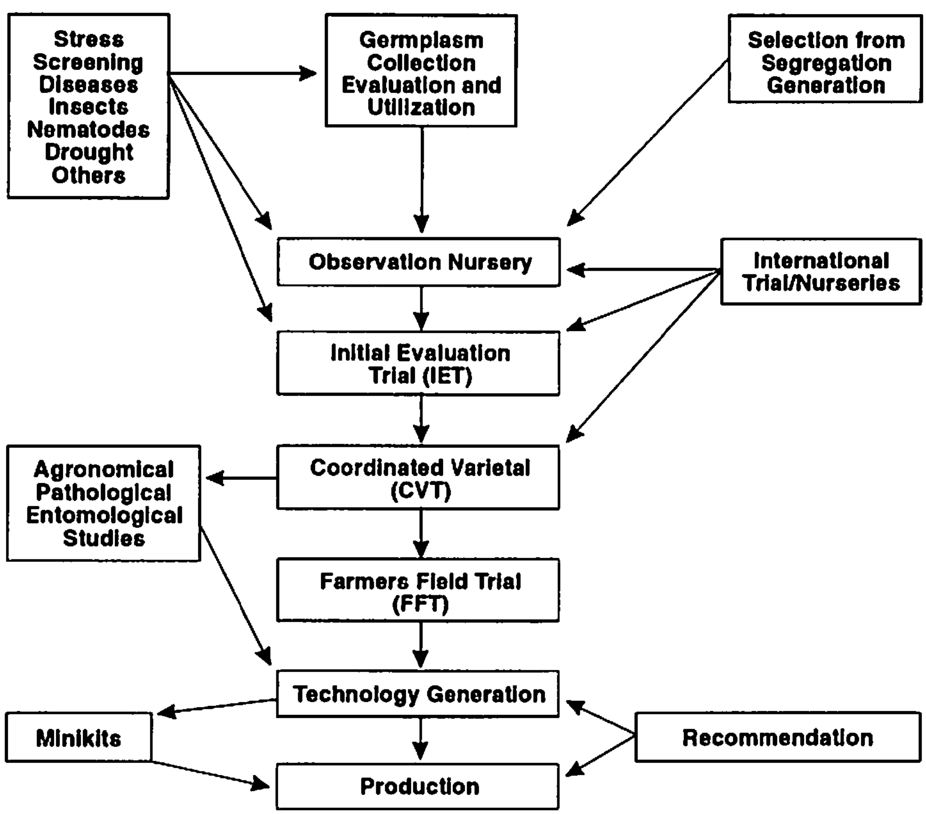

Fig. 1. Schematic of breeding and research methodology in use at NGLIP.

Genetic Resources

Since the initiation of the lentil improvement program, efforts have been concentrated on widening the genetic resource base in the country through collection and introduction from the neighboring countries and ICARDA.

Local Germplasm Collection and Maintenance

The importance of local germplasm collection has been recognized since the beginning of the research on lentil in 1977. Sporadic collections and evaluations continued and by 1987, 53 landraces were collected. However, the first systematic collection was undertaken in 1988. The collection trip covered the southern plain *Terai*, from the eastern to the central part of the country. In this trip, 43 samples were collected from 11 out of 75 districts. The second collection trip was undertaken in 1989 to complete the collection from the remaining lentil-growing areas of the country, which covered the southern plain area from the central to western regions. This trip was sponsored by ICARDA and 118 samples were collected (Upadhyaya and Bharati 1989) during the trip.

Germplasm accessions were previously maintained through annual regeneration. As a result, certain losses occurred because of poor management, the mixing of plots and from the effects of biotic and abiotic factors. At present, 255 lentil accessions have been stored in the long-term cold storage facility at ICARDA, in the medium-term storage facility at the Plant Genetic Resources Unit of the Agricultural Botany Division at Khumaltar, Nepal and in the upright freezers at the NGLIP headquarters at Rampur.

Characterization and Evaluation

A study to characterize and evaluate collected lentil germplasm was conducted during the winter of 1988/89. There were 137 accessions included in the study, 124 of which were indigenous. A nonreplicated augmented design with a repeated check cultivar was used. The study was conducted at two locations, Rampur and Khumaltar, representing *Terai* and mid-hill valleys respectively. Data were taken according to the procedures described in the descriptor manuals published by the International Board of Plant Genetic Resources, Rome (IBPGR 1985). Detailed results have been compiled in a recent publication (Furman and Bharati 1989). Results showed that the majority of the local accessions have erect to semi-erect growth habit, dense leaf pubescence, medium to large leaves (15 to ≥ 30 mm long), prominent tendrils, brown dotted seed testa, and orange to red seed color. Other characters recorded in the study are presented in Table 3.

Table 3 shows the considerable variability among local lentil germplasm. Examination of the collected data revealed that the frequency distribution was not quite normal and it showed the existence of extreme examples. The results of the study are very valuable to plant breeders in Nepal and elsewhere in the identification of useful material for utilization in breeding.

Table 3. Summary of characters observed for 137 lentil accessions in the characterization and evaluation study conducted in 1988/89.

Characters	Minimum value	Maximum value	Mean	Standard deviation
Days to 50% flowering	82	115	95.7	7.72
Days to maturity	129	142	135.4	2.67
Plant height (cm)	19.3	60.7	41.6	8.26
Number of pods/plant	0.7	210.5	80.6	40.32
Number of seeds/pod	1.1	2.1	1.7	0.27
100 seed weight (g)	0.9	2.4	1.5	0.24
Grain yield (Mt/ha)	0.252	2.47	1.18	0.39

Varietal Improvement

Nepal has been continuously introducing exotic lentil materials from India, Bangladesh, Pakistan and ICARDA. These introductions have been systematically evaluated since 1985 as outlined in Figure 1. Breeding and testing, conducted since 1985, have led to the identification and release of five lentil cultivars so far. The highlights of that work are described in the following paragraphs.

1985/1986

A total of six trials were carried out in seven locations representing various agroecological regions of the country: Germplasm Observation Nursery (GON), Lentil International Screening Nursery - Small Seeded (LISN-S), Lentil International Screening Nursery - Large Seeded (LISN-L), International F_2 Yield Trial (Early), Initial Evaluation Trial (IET) and Coordinated Varietal Trial (CVT). Results of the above trials are as follows (NGLIP 1988a):

1. Entries LL-1 and Pant L-538 were found promising in the multilocation trial. A number of elite lines were selected from the International Trial and GON. Also, two lines from ICARDA (ILL 4402 and ILL 4404) were identified with high mean yield and were promoted for on-farm testing.
2. Entries included in the LISN-L trial did not show promise, since they were late to mature and most did not produce any seed. However, two entries (ILL 5816 and ILL 5824) gave encouraging results, with a satisfactory yield.
3. In the F_3 trial, selections were made at Khumaltar from the crosses involving 845-9, 845-327 and Precoz-2.
4. Entries 76A-66136, T-31 and 80S-29677 gave high yields (1520 - 2180 kg/ha) in GON.

1986/87

Six trials (LISN-E, LISN-L, IET, CVT, FFT and two GON) were conducted at various locations. Highlights of results are as follows (NGLIP 1988a):

1. Entries Pant L-538, LL-1, ILL-4404 and ILL 4402 gave high yields when averaged across locations. Entry Pant L-536 yielded very well at hill locations (Khumaltar and Kabre).
2. Lentils planted in hills produced higher yields than in the *Terai* Plains. A maximum yield of 2640 kg/ha was obtained from Pakhribas.
3. Cultivars Simrik, Sindoor and Sishir, released in 1986, showed no differences in yield, nor any notable variability for other agronomic characteristics. Hence, merging them to develop a new, mixed cultivar was suggested after conducting replicated testing.

1987/88

The following trials were conducted for the year 1987/88: three GONs, consisting of one local, one exotic small-seeded and one exotic large-seeded; one Elite Lines Observation Nursery; one LISN-S-84; one IET; one CVT; one Pre-release Varietal Trial, and one FFT. In addition, 800 mini-kits of newly recommended cultivars were distributed. Highlights are as follows (NGLIP 1988b):

1. The performances of cultivars LG-7 and ILL 4404 were outstanding, both in research stations and in farmers' fields. Therefore, these cultivars became the candidates for release. Other promising entries were Pant L-406, Pant L-866, Pant L-538 and LL-1.
2. The three released cultivars (Sindoor, Simrik and Sishir) gave very high yields (> 3 Mt/ha) in high hill locations. The wide adaptation of the released cultivars was a very encouraging finding for the extension of lentil cultivation in new, nontraditional hilly areas.

1988/89

The breeding program for the year 1988/89 consisted of: four GON, one International Screening Nursery, one lentil International Yield Trial, one IET, one CVT, one Pre-release Varietal Trial, one FFT and the distribution of 800 mini-kits. Highlights are as follows (NGLIP 1990a):

1. Lentil lines LG-7 and ILL 4404 maintained their consistency as improved cultivars. Other promising entries after multilocation testings were Pant 258, LL-1 and LO 222-9.
2. Lentil materials of Mediterranean origin performed poorly this year. However, at Jumla (a high-altitude farm: 2387 m above sea level), some large-seeded entries exhibited very positive results.
3. Many plants and lines from different crosses and introductions were selected for further evaluation. The better performing ones were Pant 258, Pant L-406, ILL 3527 × ILL 1744, ILL 353 × ILL 2578, ILL 4404 × ILL 16 and introductions from

Ethiopia and India.
4. Entries LG 7 and ILL 4404 were released during this year and were renamed Simal and Sikhar, respectively.

1989/90

The following trials were conducted: one Observation Nursery, one International Screening Nursery, three IETs (one large-seeded at Jumla, one consisting of ICARDA materials selected in Nepal, one normal set) and one CVT. The results have been summarized (NGLIP 1990b):

1. ILL 6824, ILL 6817, ILL 6256 and ILL 6818 were found promising at Khumaltar in LISN-E.
2. Entries ILL 6949, ILL 6996, ILL 7000 and ILL 8475 proved to be better at Khumaltar in LISN (small-seeded). However, those entries performed badly at Rampur.
3. Some entries with Mediterranean origin like ILL 5588, ILL 6207, ILL 6449 and ILL 4401 gave encouraging results at Jumla.
4. In the IET (ICARDA lines), some promising entries were 87 S 19052, 87 S 19052, 87 S 19092, 87 S 99111 and 87 S 19076.
5. In IET (Normal), several genotypes were outstanding: Maher, LN 0038, LG 171, LG 198 and Agril.
6. In multilocational advanced testing (CVT), T 31, LG 222-9, LL-1 and ILL 2580 showed wide adaptability and gave higher yields.

Summary and Conclusions

The lentil is the most important grain legume crop in terms of area and production, contribution to human and animal nutrition, and as a soil fertility restorer. It is traditionally grown in the low-lying plains area of the country. The predominant cropping patterns are relay planting in rice fields and sequence cropping in maize fields.

The lentil improvement program, which started on a small scale in 1971, received more emphasis and research attention after the establishment of the NGLIP in 1985. Systematic local collections, introductions from various sources and evaluations have been continued with a more clearly developed methodology since then. The breeding program has led to the identification and release of five cultivars. The performance of three of these is shown in Table 4.

Local landraces are mainly small-seeded and high-yielding, large-seeded types need to be identified and recommended. Thus, the NGLIP, with the objective of identifying high-yielding and adapted large-seeded types, has provided more attention to screen and select the early generation materials from ICARDA in Nepal. This work has shown some promise in high-altitude areas. Hybridization work within the country should be undertaken as a trained lentil breeder becomes available. Until then, it is recommended that selected parents from Nepal be sent to ICARDA for crossing. The early generation

Table 4. Yield (kg/ha) of three recommended lentil cultivars across seven locations (1986-1988).

	Cultivars			
Locations	Simal	Sikhar	Simrik	Mean
KMLF	757	638	456	617
KAF†	926	1082	1225	1078
NGLIP	568	514	444	509
NAS	1661	1559	1271	1497
BAF	1107	1040	1060	1069
SAS†	1588	1719	1584	1620
PAS	790	992	785	856
PAC†	2669	2417	2365	2484
TAS	856	749	834	813
LAC†	846	857	847	850
Mean	1173	1157	1010	1113

† Hill locations (abbreviations given in text).

materials (F_4 progenies) are brought to Nepal for selection. A close collaboration with ICARDA, such as that which exists between ICRISAT and the NGLIP, is needed for this.

In general, Nepal has great potential to increase production through the development of high-yielding cultivars. Adaptation and higher yields obtained in the nontraditional areas of mid-hills and valleys are very encouraging and thus are valuable to expand the area under lentil cultivation. This can be accomplished easily by replacing winter fallow, which is common in hills and valleys. This particular research finding should be capitalized through large-scale production and backed by an extension program.

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Discussion

B. Sharma
Can you elaborate a little more on the question of very high yields (3 t/ha) in some high-altitude areas of Nepal?

M.P. Bharati
This is the result we get from our multilocation yield trials and may have to do with cooler temperatures during the pod-filling period.

N.B. Baldev
Realising that high-altitude locations give high yields, what needs to be done in the genotype to give equally high yield in the Nepal foothills, keeping in mind that more land is available in the latter areas?

M.P. Bharati
Distribution of land mass is more at high altitude in Nepal. Breeding high-yielding genotypes, earlier plants and input responsiveness are some possibilities to get high yields from the foothills.

C.S. Saraf
Have you observed any difference in the nodulation pattern in hills, mid-hills and *Terai* in lentils to explain the yield differences?

M.P. Bharati
Nodulation is poor in hills and mid-hills compared with the *Terai*. Higher yields in hills may be due to the residual effect of farmyard manure applied in the preceeding maize crop.

M.C. Saxena
Could you please indicate the current proportion of total lentil area in *Terai*, mid-hills, and high hills and your guess as to what will be the situation in, say, 5 years time.

M.P. Bharati
The approximate ratio is 60:40 between the cultivated area in mid-hills and *Terai*. Cultivation in Nepal has already been pushed to marginal areas and I do not think this ratio is going to change significantly. However, there are good prospects that lentil area is going to increase in future.

J.S. Brar
You said that wheat area is being replaced by lentil. What is the relative economics of cultivation of wheat and lentil?

M.P. Bharati
I do not have data to support my statement. However, considering the inputs needed for wheat and very low price for wheat compared with lentil, I think lentil cultivation is more profitable in Nepal.

B. Baldev
Within the local collection of germplasm of these early genotypes and late genotypes, what are the yield differences, keeping in mind that duration of the reproductive phase is almost twice in early types?

M.P. Bharati
Early genotypes give higher yields.

B.N. Sharma
What is the system of seed multiplication and distribution of lentil in Nepal? What is the approximate seed replacement rate?

M.P. Bharati
Breeders' seeds are produced by breeders. Foundation seeds are produced in Government Farms and stations and are given as foundation seed to Agricultural Input Cooperation (AIC). AIC produces certified seed on contractual farms with farmers. I do not know the seed replacement rate for lentil; I think it is negligible.

Status of Lentil Improvement in Sri Lanka

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Abstract

Lentil is a popular imported food item in Sri Lanka, because it is not grown locally. With a view to effect import replacement by developing domestic production, studies were started in 1969 aimed at the identification of adapted lentil cultivars. Several such cultivars have now been identified for Sri Lanka and the feasibility of growing lentil in the upcountry wet zone to replace potato in some areas will be investigated.

Introduction

Lentil (*Lens culinaris* Medikus) is grown on about 2.5 million hectares in the world. The Indian subcontinent (India, Pakistan and Bangladesh) produces about 38% of the world's lentil production. Although India has the largest area under lentil it may constitute less than 5% of the total of India's pulse production (Salunkhe *et al.* 1985).

Dry lentils average 28.6% protein (N × 6.25), 3.1% ash, 4.6% crude fiber, < 1.0% ether extract, 44.3% starch, 36.1% amylose, 63.1% total carbohydrate and 4.2 kcal/g gross energy (Bhatty and Wu 1974).

Lentils, split and dehulled, are very popular and widely consumed as a food legume in Sri Lanka. Since Sri Lanka does not grow lentils, it is necessary to import the entire requirement, from India and Turkey, utilizing much foreign exchange (Table 1). If suitable varieties and cultural practices for the cultivation of lentils can be identified, at least some of the country's lentil requirement could be grown in the highland areas of Sri Lanka.

Climatic Conditions and Potential for Cultivation in Sri Lanka

In the world, lentil is grown under widely differing agroecological conditions, from the tropical highlands of Ethiopia to the Canadian prairies. At a single location, the growth of the crop is strongly influenced by factors such as date of planting, weather conditions, and cultivar (ICARDA 1990).

Table 1. Quantity and value of Sri Lankan imports of red split lentil.

Year	Quantity (t)	Value (Rs. millions)†
1978	14875	76.82
1979	24283	145.45
1980	17614	138.16
1981	11118	179.31
1982	14831	172.12
1983	31344	472.56
1984	57901	1003.88
1985	22274	563.37
1986	10270	289.50
1987	20700	448.03
1988	56062	1254.82
1989	44649	1127.64

Source: Imports Department, Co-operative Wholesale Establishment.
† USD 1 = ca. Rs 40 in 1991.

Lentil is essentially a cool-season crop. Although the lentil does not stand drought or salinity, the crop can tolerate temperatures of -14°C. Also, it can be grown on all types of soil such as light loams and alluvials, although well-drained, moderately deep, light black soils and dry sandy soils are most suitable for seed production. Fertile soils produce much vegetative growth but little seed. When grown alone for seed, the crop follows cereals in rotation. In general, inoculation is not essential but may be beneficial when sowing in virgin soils (Doerflier 1976).

The climate of Sri Lanka is characterized by wide variation in rainfall and temperatures. The annual precipitation follows a distinctly bimodal pattern and the country receives rain from two monsoons, i.e., the northeast monsoon (November to January) and the southwest monsoon (May to September). The whole island benefits from the northeast monsoon, while the lowlands of the north and east are usually dry during the southwest monsoon. Climatically, Sri Lanka is broadly divided into three zones: wet, intermediate, and dry (Fig. 1).

The wet zone, which lies in the southwestern sector of the country, receives well-distributed rainfall of 1875 to 5000 mm/year over both seasons. The dry zone, which occupies the major part of the north, east and southeastern sectors, receives about 990 mm, mainly during the major rainy season (*maha*) from early November to late January. The dry season (*yala*) in the dry zone starts in late March and continues until early September with about 410 mm of rain, most of which is received during the months of April and May. The intermediate zone is a transition area between the wet and dry zones

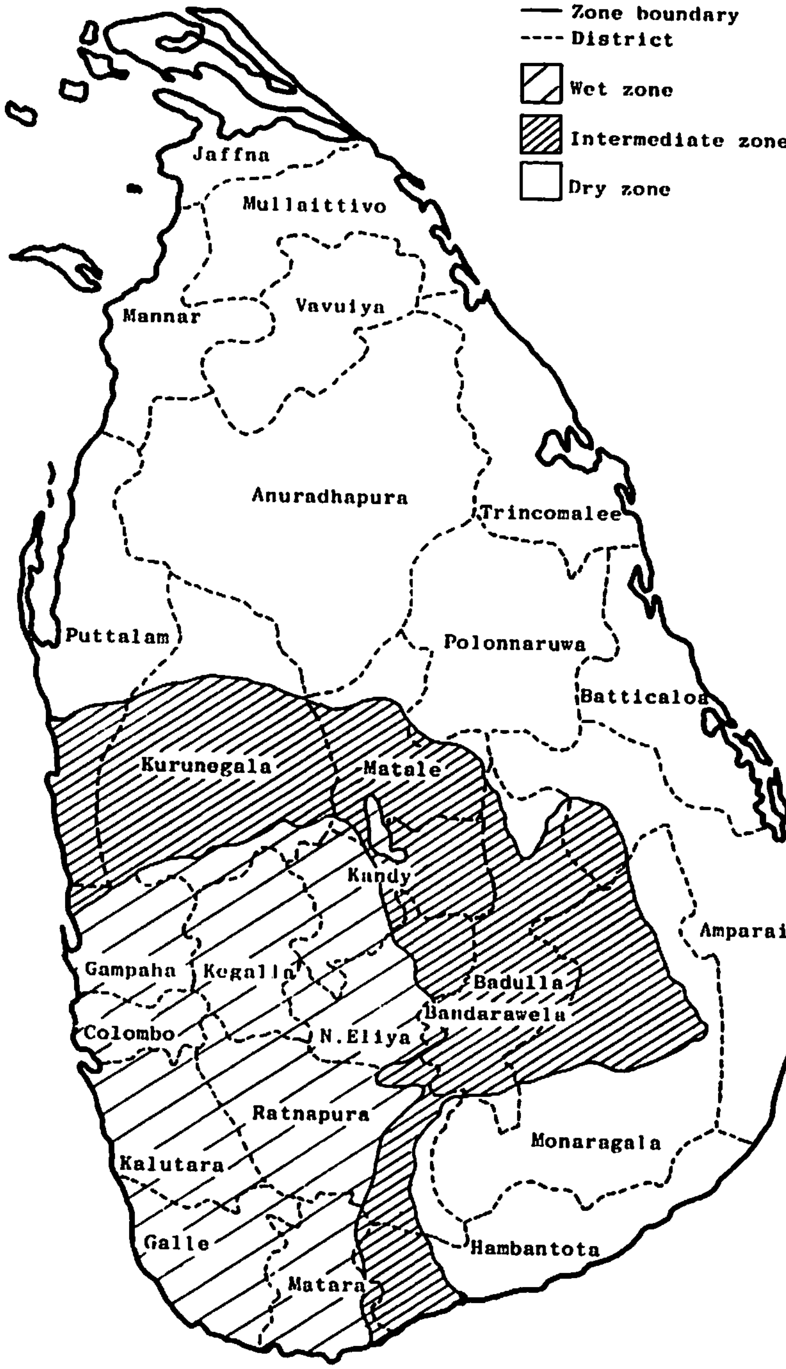


Fig. 1. Agroecological zones of Sri Lanka.

and has a better distribution of rainfall compared with the dry zone: about 1900 mm/year. These climatic zones are further divided into 24 distinct agroecological regions based on rainfall, elevation and soil types.

The total annual rainfall of the upcountry intermediate zone ranges between 600 and 1400 mm. The rainfall peak is in the month of October. The lowest rainfall is in the month of June (Fig. 2). The period between May and August is generally dry. The temperature variation is between 15 and 27°C during the month of May and 12 to 22°C during the month of February.

The cropping pattern of the region varies mainly with water availability. In the lowland areas where water is relatively abundant, cultivators grow three crops/year on the same land. Rice and potato play a prominent role in this cropping system. In the lowlands, normally rice is transplanted during late December to late February and harvested during May to June. In most areas, the potato is the second crop after rice, and is followed by bush-bean, radish and cabbage. In the upland areas where the cultivation mainly depends on rainfall, potatoes are planted in November and harvested in January to February. Crops such as bush-bean and horse gram are generally grown after potatoes, or the lands are kept fallow.

Being a cool-season crop, lentil can be grown after potatoes in the upland areas of Sri Lanka during January and February and hence can fit into existing cropping pattern. At current selling prices, the farmer can get a net return of around Rs. 30 000/ha (USD 1 = 40 Sri Lankan Rs.) with little input.

Studies on Lentil in Sri Lanka

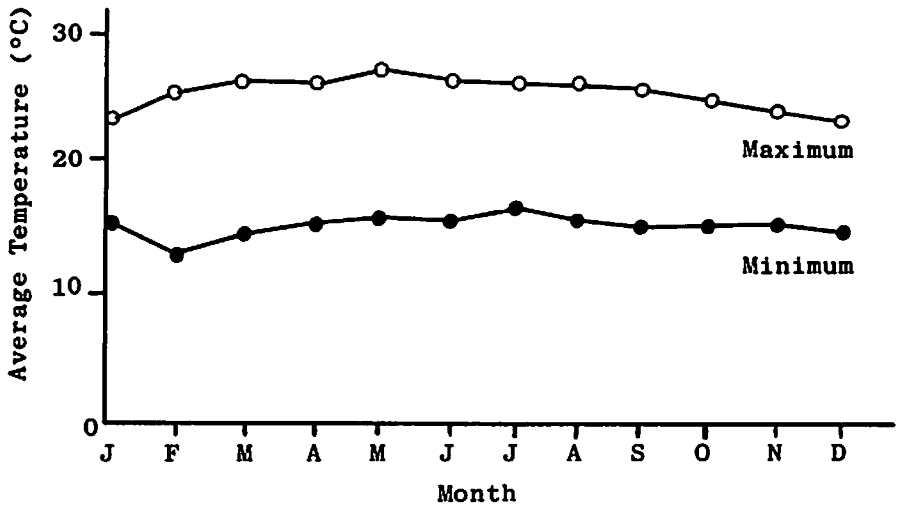
Preliminary studies on lentil in Sri Lanka were started in 1969 at the Agricultural Research Station, Rahangala. Currently, research on lentil is being conducted at the Regional Research Station, Bandarawela (1100 m above sea level) in the Badulla district. Both Rahangala and Bandarawela are situated in the upcountry intermediate zone.

The lentil research program initially aims to identify cultivars/varieties with the following characteristics:

1. High yield and adaptation to a wide range of climatic conditions.
2. Early and uniform maturity.
3. Resistance to pests and diseases.

Research on this crop has been confined to the evaluation of introductions received from lentil research institutes.

The cultivar NP 11 was tested in the later part of 1969 and the early part of 1970. In *yala* season, in 1969, this cultivar produced a seed yield of 575 kg/ha at the Agricultural Research Station, Rahangala, whereas in *yala* season 1970 the same cultivar produced



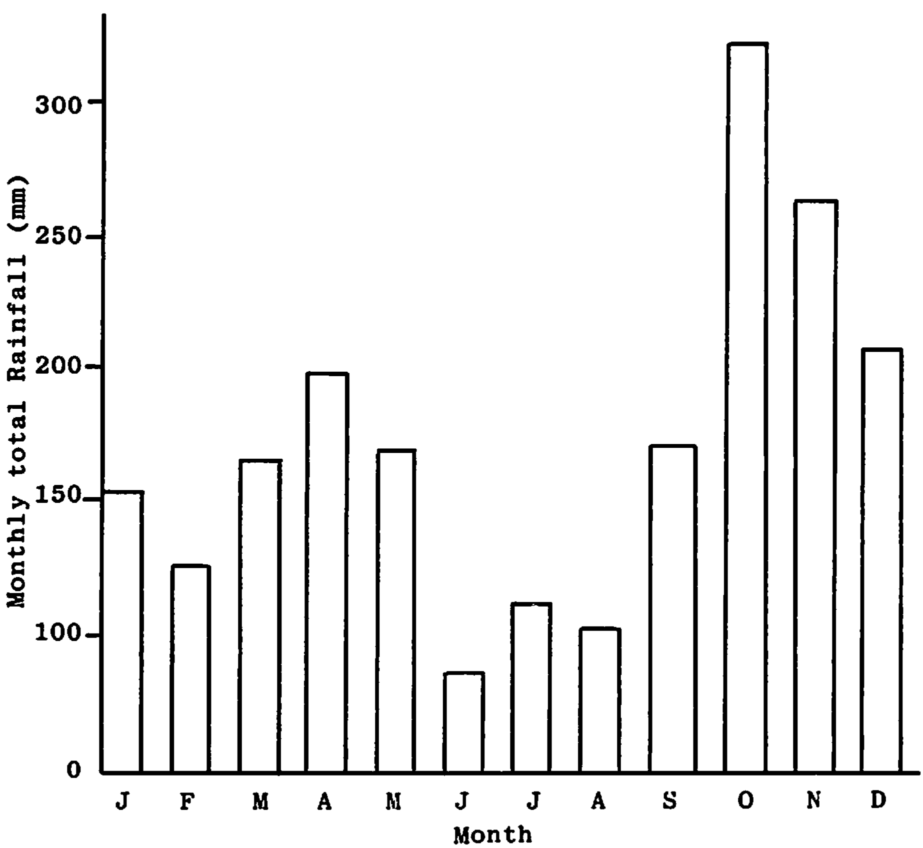


Fig. 2. Distribution of rainfall and temperature at Bandrawela, 1978-1990.

214 kg/ha seed yield at Bandarewala Regional Research Station. In *yala* season 1971, cultivars P 208, P 221 and P 189 gave higher yields than cultivar P 191. The cultivar P 191 was tested in *maha* season 1972/73 and produced a seed yield of 340 kg/ha. Cultivar L 639 was tested for fertilizer response in *maha* season 1981/82 at the research station, Bandarawela, and produced seed yields ranging between 1450 and 1600 kg/ha. This cultivar was planted for seed multiplication at Bandarawela Research Station in *yala* season 1983.

Lentil yield trials also were conducted with breeding lines sent by ICARDA, as shown in Table 2. From these studies, the cultivars that were identified for high yields and good adaptability are shown in Table 3.

In general, average seed yield for the lentil was higher when planted in early January, in *maha* season, compared with *yala*, in which relatively lower rainfall prevails. Although cultivar Pant L 406 produced the highest seed yield of 2000 kg/ha, in 1986/87 in *maha*, it has not performed as well during the dry *yala* seasons. In general, however, cultivars such as Pant L 406, Pant L 630, FLIP 87-65L and L 528 have produced seed yields above 1000 kg/ha, which are comparable to yields in other countries. Table 4 shows plant height and number of days to 50% flowering and to maturity. Plant height of the tested cultivars ranged from 27 to 39 cm. The duration from sowing to 50% flowering ranged from 37 to 48 days, and to maturity from 75 to 106 days.

Table 2. Types of international lentil trials conducted between 1984 and 1990.

Year	Name	No. of lines
1984	Screening nursery-Early	62
	F_3 trial-Early	39
	Yield trial-Early	24
	Screening nursery-Large	49
	Screening nursery-Small	67
1986/87	Screening nursery-Early	47
	Yield trial-Small	23
1987/88	Screening nursery-Early	39
	Yield trial-Early	24
1989	Yield trial-Early	29
	Screening-Early	49
	F_3 trial-Early	32
1990	F_3 trial-Early	32
	Screening nursery-Early	42

Table 3. Yield performance (kg/ha) of some promising lentil cultivars tested from 1986 to 1990.

Cultivar	1986/87 *maha*†	1987/88 *maha*	1989 *yala*†	1990 *yala*
Pant L 406	2000	*	295	*
FLIP 87-65L	1350	*	*	*
Pant L 639	620	1200	494	*
L 528	1200	1274	*	*
L 1278	*	1000	295	*
L 162	*	496	497	*
FLIP 86-1	*	*	519	*
FLIP 89-68L	*	*	*	260
L 5	*	*	*	244

* Not tested.
† *Maha* = rainy season; *yala* = dry season.

Table 4. Some characteristics of promising lentil cultivars.

Cultivar	Plant height (cm)	No. days to 50% flowering	No. days to maturity
Pant L 406	36	37	90
FLIP 87-65 L	35	37	90
Pant L 639	39	37	80
L 528	38	38	90
L 1278	35	37	75
L 162	39	37	80
FLIP 86-39 L	36	37	90
FLIP 89-68 L	30	48	106
L 5	27	37	75

It is essential that the same cultivar be tested for at least three consecutive seasons before a firm recommendation can be made. Therefore, continuous seed availability has to be ensured.

Five new trials, as given below, have been received from ICARDA for 1991.

1. Lentil International F_4 Nursery-Early-91
2. Lentil International Screening Nursery-Small-91
3. Lentil International Screening Nursery-Large-91
4. Lentil International Screening Nursery-Early-91
5. Lentil International Yield Trial-Early-91

Suggestions for Future Studies

The following areas of study on lentils are important for the country.

1. The identification of varieties with wide adaptability.
2. The identification of the most suitable time of planting in both the *maha* and *yala* growing seasons, depending on the area of cultivation.
3. The study of the physiology related to flowering, flower drop, and pod-set.
4. The analysis of pest and disease control.
5. The feasibility of cultivating lentils in the upcountry wet zone, to replace potato in some of the lands, and to initiate the lentil as a rotation crop in the Government farms where a large extent of land is left fallow after potato cultivation.
6. The identification of an economic method of processing lentil to produce dehulled and split seed.

Acknowledgements

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Discussion

M. Rahman
Is it not possible to plant lentil in December so that your crop can have a longer period for its life cycle?

H.M. Ariyaratna
I do not think so. There were not many differences in days to maturity when planted in May compared with planting in December.

M. Rahman
Probably true *microsperma* type instead of bold-seeded type may do well in your climate. What is your experience?

H.M. Ariyaratna
I have no experience, but I think photoperiod-sensitive cultivars may not do well under our climate.

B. Sharma
What is the major direction of lentil improvement programs in Sri Lanka?

H.M. Ariyaratna
The main objective of the lentil improvement program in Sri Lanka is to identify genotypes with high yield and adaptation to a wide range of climatic conditions, early and uniform maturity, and resistance to pests and diseases.

B. Sharma
How do you explain the large yield differences in *maha* and *yala* seasons when the temperature and photoperiod do not differ too much through the entire year?

H.M. Ariyaratna
There is considerable temperature difference between *maha* and *yala* seasons. For example, if potato is planted in May, it has lower tuberization ability than when planted in December because of temperature differences.

C.S. Saraf
Which are the other crops competing with potato and which crops should be replaced, if lentil is to be introduced?

H.M. Ariyaratna
Crops such as cabbage, bean and tomato are cultivated as substitutes for potato. Crops such as bush-bean and horse gram would be replaced by lentil or lentil would be grown on land kept fallow after potato.

M.C. Saxena
What minimum yield level should there be for lentil to become competitive and economically viable?

H.M. Ariyaratna
The farmer needs to be able to obtain 750 to 1000 kg/ha seed yield of lentil for the crop's economic viability.

M.C. Saxena
What quantity of seeds of the promising lines do you have? Would you like to receive more seed for giving to farmers to evaluate? What quantities?

H.M. Ariyaratna
We have a very small amount of seeds of promising cultivars. It would be better if we had more seeds. One kilo of seed of each cultivar is enough for farmers' field trials.

Section 3. Agronomy

Agronomy of Lentil in India

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[4] *Indian Agricultural Research Institute, New Delhi, India*

Abstract

India has the world's largest area under lentil, 1.08 million hectares. In the recent past, lentil has registered significant increases in area due to its popularity in different cropping systems and the development of improved production technology. In India, lentil is cultivated under different agroecological conditions, ranging from the foothills of the Himalayas to the central plateau. It is grown during winter (*rabi*) season under different cropping systems, such as multiple cropping (200-300% cropping intensity) in the irrigated areas of the Northwestern Plains, monocropping (100% cropping intensity) and intercropping in the unirrigated areas of the central region, and relay cropping (200% cropping intensity) with medium maturing rice in the eastern region. The agronomic requirements of lentils vary considerably, depending upon the agroecological conditions and cropping systems in vogue. In the past 25 years, systematic and comprehensive studies on agronomic requirements of lentils have been conducted under the All India Coordinated Pulses Improvement Project (AICPIP) and also under state-run projects. This paper reviews the present status of knowledge about the agronomic requirements of lentils such as suitable genotypes, planting time, seed rates, planting geometry, fertilizer use, biological N_2 fixation, weed control, water management, etc., and also the relevant cropping systems under which it is grown.

Introduction

India has the world's largest lentil-production area—about 1.08 million hectares—giving an annual production of 0.74 million tonnes (Table 1). The cultivation of lentil spreads from the foothills of the Himalayas to the central plateau and the eastern coast. The major lentil-producing states are Uttar Pradesh, Madhya Pradesh, Bihar and West Bengal. These states together contribute 95% of the total production. The agronomic requirements for lentil vary considerably, depending upon the agroecological conditions and cropping systems. In India, lentil is grown as a winter crop under both rain-fed and irrigated conditions.

In the past 25 years, systematic and comprehensive studies on the agronomic requirement of lentil have been made under the All India Coordinated Pulses Improvement Project (AICPIP) as well as state-run projects to develop efficient cropping systems and package

Table 1. Area, production and productivity of lentil in India, 1973/74 to 1988/89.

Year	Area (1000 ha)	Production (1000 t)	Productivity (kg/ha)
1973/74	88.0	39.1	444
1978/79	99.4	34.5	438
1983/84	97.7	53.1	544
1988/89	108.9	74.1	680

technology for different agroecological zones. As a result of this, lentil has registered a significant increase in area, production and productivity in recent years (Table 1). This is due to its increasing popularity in different cropping systems and the adoption of improved production technology. The main components of the improved production technology include: identification of high-yielding and stable genotypes, optimum time of planting, seed rate, plant geometry, seed inoculation with *Rhizobium* culture, adequate and balanced nutrition, efficient water management and effective weed control measures.

Cropping Systems

In India, lentil is grown under different cropping systems such as monocropping, double cropping, relay cropping and mixed cropping. The choice of a particular system depends upon irrigation potential, annual rainfall and its distribution, and the edaphic conditions.

Monocropping

Monocropping (100% cropping intensity) of lentil is practised in unirrigated areas of central India where monsoon rains are insufficient and too erratic to grow a profitable *kharif* (rainy season) crop. The soils of these areas are generally heavy textured and therefore the soil profile, once recharged during the monsoon season, supports a successful crop of lentil. Monocropping is also prevalent in flood-affected and *tal* areas (*diara* land) of eastern Uttar Pradesh, Bihar, West Bengal and Orissa where lentils are planted after receding floods. The soils of *tal* areas are quite fertile because of silt deposits and thus produce a bumper crop of lentil.

Double Cropping

Lentil is a component of double cropping (200% cropping intensity) systems in the Northwestern and Northeastern Plains after a *kharif* crop of maize, sorghum, pearl millet, rice or jute. Lentil is generally grown on those lands that are not ideal for wheat production, either because of poor fertility status or inadequate irrigation facilities. In recent years, however, an increasing awareness about the value of pulses in cropping systems has arisen among agriculturists and farmers, and, consequently, a preference for cereal/legume crop rotation over cereal/cereal rotation is gradually developing. Inclusion of lentil in cropping systems not only provides protein-rich food but also improves soil fertility and economizes nitrogen use in the succeeding cereal crop. Field studies at IARI, New Delhi, during 1975-77 showed that plots seeded to winter grain legumes maintained a higher level of soil fertility (total N and available P) at the time of harvest than those under wheat (Table 2). This could be attributed to biological N_2 fixation and the improvement in physiochemical and microbial conditions of the soil. Among various legumes, chickpea recorded a higher content of total N and available P followed by pea and lentil. The yield of succeeding maize at zero level of N was 2.25 t/ha after lentil, whereas it was only 1.35 t/ha after wheat and 1.66 t/ha after winter fallow (Table 3). The N economy accrued because of winter grain legumes was 18 to 68 kg/ha in succeeding maize (Ahlawat *et al.* 1981).

Table 2. Fertility status of the top 30 cm soil profile as influenced by winter legumes after harvesting at New Delhi, 1975-77.

Winter crop	Total N (%)	Available P (kg/ha)
Chickpea	0.069	12.2
Lentil	0.064	10.8
Pea	0.065	11.1
Wheat	0.048	9.8
Fallow	0.052	9.6

Table 3. Effect of preceding winter grain legumes on yield (t/ha) of succeeding maize crop at New Delhi, 1975-1977.

Winter crop	Yield (t/ha)	N levels (kg N/ha) 0	60	120	Mean yield
Chickpea	1.39	2.40	4.59	5.29	4.09
Lentil	2.44	2.25	3.90	4.97	3.71
Pea	2.71	2.16	3.91	4.68	3.58
Wheat	6.30	1.35	3.15	4.25	2.92
Fallow	-	1.66	3.24	4.65	3.18
LSD (5%)		Winter crops	0.34		
		N levels	0.28		
		Interaction	0.71		

In another study at Khargone in Madhya Pradesh, Ali (1987) reported that sorghum yield was significantly improved with preceding winter legumes (chickpea, lentil and pea). The grain yield of sorghum at zero N level was 2.27 t/ha after lentil, whereas it was only 1.12 t/ha after wheat (Table 4). The beneficial effect of lentil on succeeding cereals has been reported by other workers (Singh and Singh 1986b; Meena and Ali 1987; Prakash and Tandon 1987; George and Prasad 1989).

Table 4. Grain yield (t/ha) of sorghum as influenced by preceding grain legumes at Khargone, 1987/88.

Preceding legume	N levels (kg N/ha)				
	0	30	60	90	Mean yield
Chickpea	2.58	3.44	3.16	2.89	3.02
Lentil	2.27	2.40	2.71	2.58	2.49
Pea	2.38	2.57	3.62	3.40	2.99
Wheat	1.12	1.58	2.39	3.16	2.06
LSD (5%)	0.53				

Relay Cropping

Relay cropping is practised in the lowlands of eastern India where lentil is sown in a standing crop of rice as the latter reaches physiological maturity. This system is also known as *paira* or *utera* cropping. Relay cropping is generally followed in unirrigated areas to make the best use of the residual moisture of rice fields. Medium-maturity rice cultivars are taken under these ecosystems. The seeds of lentil are broadcast in a standing rice crop after the excess water is drained, 4 to 10 days before the rice harvest.

Relay planting has been found to be more productive than planting after the harvest of rice, as the former practice enables better and earlier establishment of lentil seedlings because of an adequate availability of soil moisture which otherwise tends to be quickly lost once the rice is harvested. Roysharma *et al.* (1984) at Dholi in Bihar found that *paira* cropping of lentil produced 1.27 t/ha compared with 0.54 t/ha when planting was done after the rice harvest (Table 5). Further, they noticed that after the harvest of rice, row planting was better than broadcast. Chakraborty *et al.* (1976) at Berhampore in West Bengal also reported high productivity of lentil (2.25 t/ha) under *paira* cropping with *aman* (late) rice.

Table 5. Yield of lentil under different systems of planting, in sequential cropping with rice at Dholi, 1976-80.

Planting system	Yield (t/ha)	
	Grain	Straw
Paira cropping (sown in standing crop of rice)	1.27	1.75
Broadcast sowing after harvest of rice	0.54	0.89
Row sowing after harvest of rice	0.64	0.87
LSD (5%)	0.02	0.03

Mixed Cropping

Lentil is grown both as a pure culture and as a mixed crop. In irrigated areas and under the *paira* system of cultivation, pure culture is generally taken, whereas in rain-fed areas, mixed cropping is common. The major considerations in practising mixed/intercropping in rain-fed areas are an insurance against natural calamities, diversified production under subsistence farming and an efficient use of farm resources.

The most common intercrops are lentil + barley in the Northwestern Plains, lentil + mustard in the Northeastern Plains, and lentil + linseed in the Central Zone. Under these systems, one row of the intercrop is planted after 4 to 6 rows of lentil. In the Northeastern Plains, lentil is also intercropped successfully with autumn sugarcane (Srivastava 1975). Studies on intercropping of wheat and lentil showed that this association was not superior to sole lentil in terms of productivity and monetary return (Prakash *et al.* 1986).

In a study on the associative effect of lentil and mustard on sandy loam soils of Kanpur during 1976-78, Kushwaha (1984) found that intercropping led to economy of 40 kg N and 20 kg P_2O_5/ha compared with fertilizer application in sole mustard.

Genotypes

Lentil genotypes show wide variation with respect to their productivity, stability and adaptability. In India, both small- and bold-seeded genotypes are grown. In the Northwestern and Northeastern Plains, small-seeded (*microsperma*) lentil is widely cultivated, whereas in the Central Zone, bold-seeded (*macrosperma*) genotypes are preferred. However, under the *utera* system, only small-seeded genotypes are adapted. Progress in breeding bold-seeded and small-seeded lentil is covered in this volume by Sharma *et al.* and Verma *et al.*, respectively.

Variation in genotypes with respect to trace element deficiency has been reported. Singh *et al.* (1987) at Pantnagar found that DL 77-2 was more tolerant to zinc stress than Pant L 639 and BR 25. Similarly, Pant L 406 was found more tolerant to iron deficiency than Pant L 639 and BR 25 (Singh *et al.* 1984).

Seed Treatment

Studies on pre-sowing seed treatment with pyridoxin were made by Ansari *et al.* (1990) at Aligarh, Uttar Pradesh. They found that soaking the seeds for 12 hours in a 0.3% aqueous pyridoxin solution significantly improved seedling establishment, growth, yield and uptake of N, P and K. Net assimilation rate with 0.3% pyridoxin was 5.73 g^2/day during 60-90 DAS as against 4.59 g^2/day in untreated plots (Table 6). Increase in nodule number and nitrogenase activity was also noticed with pyridoxin treatment. Seed yield increased by 0.24 t/ha.

Attempts were also made to increase the drought tolerance and seedling vigor of lentils by soaking seeds in water, growth hormones and nutrient solution. At Vadodara, soaking seeds in 0.1% solution of KH_2PO_4 improved productivity (Ali 1988). At Pantnagar, however, soaking seeds in $CaCl_2$, gibberellic acid and water did not prove effective (Srivastava and Khattar 1976). Studies on use of various fungicides have also been made to control seedborne diseases and improve productivity of lentil. Agarwal *et al.* (1976) and Vishunawat and Shukla (1981) observed that Bavistin was most effective followed by Thiram and Captan in increasing seedling emergence and seed yield.

Table 6. Effect of pre-sowing seed treatment on yield attributes, net assimilation rate (NAR) and grain yield of lentil at Aligarh, 1982/83.

Seed treatment	No. pods/ plant	No. seeds/ pod	Seed yield (t/ha)	NAR (g^2/day) 60-90 DAS
Untreated (Control)	59.4	1.70	1.34	5.59
Water soaked	61.1	1.68	1.34	4.84
Pyridoxin, 0.1% solution	71.7	1.82	1.38	4.60
Pyridoxin, 0.3% solution	91.7	1.90	1.58	5.73
Pyridoxin, 0.5% solution	5.17	1.60	1.30	3.95
LSD (5%)	2.3	0.09	0.02	0.27

Planting Time

Planting time has a profound effect on growth, phenological development and the yield of lentils because of changes in the crop environment. Planting time differs from location to location and also within the same location, depending upon the cropping system in which lentils are grown. The optimum temperature for germination ranges between 15 and 25°C. Several experiments have been conducted on planting dates. In the plains of northern India, the optimum time of planting lies between the fourth week of October and mid-November (Singh and Saxena 1982; Ali 1986; Sekhon *et al.* 1986; Singh and Ram 1986).

Dhingra *et al.* (1983) observed that the planting of lentil in the Gurdaspur area of Punjab could be extended up to the end of November without substantial loss in yield. In the foothills too, where the winter is longer and moisture supply is generally better, planting could be extended up to the end of November (Saxena and Yadav 1976). In central India, where lentil is grown on conserved moisture and the winter is short, the optimum time of sowing lies between the second and third week of October. In the northeastern hill region, early October has been found to be the best time of planting (Dwivedi *et al.* 1987). Delay in planting beyond this period causes a progressive decline in yield due to inadequate biomass production, shorter period of crop growth and forced maturity. Lentil yield in a rice/lentil double cropping sequence is often low because of delayed sowing as the fields from medium-maturing rice are vacated late in the season (Saxena 1981).

In multilocation studies under AICPIP, the end of October was found to be the ideal time for planting lentil in the Northwestern Plains, whereas in the Northeastern Plains, it was from mid-November to end of November (Ali 1985). The yield declined by about 14.8 kg ha^{-1} day^{-1} in the Northwestern Plains zone when planting extended up to mid-December (Table 7). In the Northeastern Plains zone, planting beyond the end of November caused yield loss of approximately 30 kg ha^{-1} day^{-1} up to mid-December. In the eastern zone, mid-November planting gave the highest yield (1.39 t/ha) yet the yield declined drastically when planted by the end of November.

Table 7. Effect of planting dates on seed yield (t/ha) of lentil in different agroecological zones (Ali 1985).

	Agroecological zone†		
Planting date	NWPZ (Pantnagar)	NEPZ (Varanasi)	EZ (Kalyani)
30 October	1.95	-	-
14 November	1.72	1.60	1.39
29 November	1.50	1.61	0.66
14 December	1.28	1.29	0.21
29 December	0.71	0.56	-
LSD (5%)	0.19	0.03	0.10

† NWPZ = Northwestern Plains Zone; NEPZ = Northeastern Plains Zone; EZ = East Zone.

In the *utera* system, planting time largely depends upon the cessation of monsoon rains and the maturity of the rice crop. In lowlands, water from rice fields is generally drained by the end of October and lentil seeds are broadcast 4-10 days before the harvest of rice.

Planting Method

In India, lentils are generally sown by broadcasting seeds both under double cropping in the Northwestern Plains and Northeastern Plains, and by *utera* cropping in the eastern zone. However, this system results in poor and uneven plant stand. In the central zone where the crop is raised on conserved moisture, line sowing is practised by dropping seeds behind a country plow. Line sowing is an improved method of planting as it ensures good plant stand, uniform distribution of seeds and ease in cultural operations.

Kher and Dhillon (1982) studied the effect of plant geometry in lentils. They found that bidirectional sowing in row rectangularity of 22.5 x 30 cm gave higher yield than unidirectional sowing. Further, they reported that wider rows were better in the east-west direction. In the *utera* system, there is no scope for line sowing and therefore high seed rates should be used to obtain desired plant stand.

Plant Density and Row Spacing

The response of lentils to plant densities has been variable, depending upon genotypes, planting time and growing conditions. A seed rate of 40 to 60 kg/ha has been recommended under different growing conditions. At Pantnagar, Tripathi and Singh (1987) found that Pant L 406, a small-seeded lentil genotype, gave the highest yield of 2.29 t/ha at a seeding rate of 40 kg/ha, the increase over the seed rate of 20 kg/ha being 0.72 t/ha. An increase in seed rate beyond 40 kg/ha led to significant loss in yield. In multilocation studies under AICPIP during 1986-90, a 60 kg/ha seed rate tended to increase yield at most locations; however, significant improvement in yield was noticed at only two locations out of five (Table 8).

Saraf (pers. comm.) working on plant population requirements and row spacing of the bold-seeded variety Precoz found that 200 plants/m^2 and a row spacing of 20 cm gave the highest yield (1.68 t/ha) on the sandy loam soils of Delhi (Table 9). Increasing population densities beyond 200 plants/m^2 caused significant reduction in yield. Similarly, wider row spacing adversely affected crop yield. However, Dutta (1985) observed that plant densities in the range of 80 to 240 plant/m^2 were alike, indicating thereby greater plasticity in lentil genotypes. Under late-sown conditions, the seed rate has to be increased to compensate for the loss in per plant productivity. Ahawat *et al.* (1982) found that in a 1 December planting, 40 and 60 kg/ha seed rates were at par, but with 15 and 30 December plantings the 60 kg/ha seed rate recorded marked increases in yield over the 40 kg/ha seed rate (Table 10).

Table 8. Effect of seed rate on productivity (t/ha) of small-seeded lentils (Ali 1990).

	Seed rate (kg/ha)		
Location	40	60	CD (5%)
Kalyani	1.30	1.49	0.08
Ludhiana	0.88	0.86	NS
Pantnagar	1.03	1.12	NS
Almora	1.19	1.30	NS
Samba	0.54	0.62	0.03

NS = nonsignificant.

Table 9. Seed yield (t/ha) of lentil cv. Precoz as influenced by plant population at New Delhi.

Row spacing (cm)	Plants/m^2				
	100	200	300	400	Mean yield
20	1.62	1.68	1.54	1.37	1.55
30	1.20	1.25	1.17	1.08	1.18
40	0.66	0.76	0.82	0.70	0.74
50	0.47	0.51	0.52	0.54	0.51
Mean	0.99	1.05	1.01	0.92	
LSD (5%)	Row spacing		0.02		
	Plant density		0.019		
	Interaction		0.039		

Table 10. Seed yield of lentil (t/ha) as influenced by planting dates and seed rate at New Delhi, 1977-79.

	Seed rate (kg/ha)		
Sowing date	40	60	80
1 December	1.63	1.60	1.57
15 December	1.36	1.40	1.46
30 December	0.83	1.07	1.05
LSD (5%)	0.17		

Variation in row spacing may conspicuously affect crop yield. The optimum row spacing differs with genotypes, method of planting, soil moisture availability and length of growing season. The optimum row spacing under normal planting has been found to be 20-30 cm (Saxena and Yadav 1976; Tripathi and Singh 1987) whereas under late-sown conditions, a narrow spacing of 15-20 cm is optimum. Similarly, under low moisture conditions, relatively wider row spacing proves better than under adequate moisture supply.

Studies on depth of planting have shown that 4-5 cm is optimal for seedling emergence, but in dry soils deep placement of seeds is desirable to ensure contact of seeds with a moist soil layer. Seeds placed deep are reported to get less infestation of wilt and also survive relatively better than shallow sown seeds under frost occurrence.

Fertilizer Use

Lentil, in India, is generally grown on soils poor in fertility, and therefore adequate and balanced fertilization is necessary to realize good yields. Studies on the relative contribution of production inputs under different agroecological conditions revealed that in the Central Zone, fertilizer use was the premier input, without which the yield declined by 454 kg/ha over full package, whereas in the Northeastern Plains zone, fertilizer use was next to plant protection (Table 11). This could be explained on the basis of soil fertility status and moisture availability. Since in the Central Zone, the soils are quite poor in available plant nutrients, response to fertilizer application is generally high compared with the alluvial soils of the Northeastern Plains zone. Good response to fertilizer use also has been obtained on high-textured soils of the Northwestern Plains (Ali and Lal 1989).

Table 11. Effect of production inputs on seed yield (t/ha) of lentil (Ali 1985).

	Agroecological zone†	
Production input	NEPZ (7)	CZ (3)
Farmers' practice (Control)	0.66	0.99
Full package of practices (FPP)	1.33	1.53
FPP minus fertilizer	1.02	1.07
FPP minus irrigation	1.21	1.18
FPP minus insect pest and disease control	0.97	1.11
FPP minus weed management	1.07	1.17

† NEPZ = Northeastern Plains Zone; CZ = Central Zone.
Figures in parentheses indicate number of locations.

A lentil crop producing seed at 2 t/ha removes about 100 kg N, 28 kg P_2O_5 and 78 kg K_2O/ha, besides other essential nutrients, and therefore, for sustaining the productivity of the soil, judicious fertilizer application needs to be maintained (Saxena 1981).

Nitrogen

Being a leguminous crop, lentil is capable of meeting most of its nitrogen requirement. Under good symbiotic association, more than 85% of its nitrogen needs are met by biological N_2 fixation. Thus, only a small amount of nitrogen (10-20 kg/ha) as a starter dose has been recommended. Such an application of nitrogen is considered necessary for an early start and seedling vigor (Panwar *et al.* 1977; Sekhon *et al.* 1978; Verma and Kalra 1983; Nema *et al.* 1985; Singh and Singh 1986a; Khaira *et al.* 1989).

The response to applied nitrogen is generally low, particularly when good symbiotic association exists. On light-textured soils low in organic matter, a response of up to 0.2 t/ha has been obtained. Khare *et al.* (1988) reported that in central India, the nitrogen use efficiency (kg seed/kg N) under rain-fed conditions was 9.3 at 10 kg N/ha, which dropped to 2.5 at 40 kg/ha. In multilocation studies under AICPIP, response to 18 kg/ha was 152, 94 and 94 kg/ha in the Northwestern Plains, Northeastern Plains and Central zones, respectively (Table 12). Generally, basal application of nitrogen is done. However, Sharma *et al.* (1984) reported that a crop dressing of 20 kg N/ha also proved quite beneficial.

Table 12. Effect of fertilizer application and inoculation on seed yield (t/ha) of lentils, AICPIP, 1985-89.

	Agroecological zone†		
Treatment	Northwestern Plains	Northeastern Plains	Central Zone
Control (No fertilizer or inoculation)	1.32	0.78	0.62
18 kg N/ha	1.47	0.87	0.72
Inoculation	1.24	0.87	0.71
46 kg P_2O_5/ha	1.51	1.08	0.81
18 kg N + 46 kg P_2O_5/ha	1.53	1.19	0.94
20 kg K_2O/ha	1.35	1.01	0.74
18 kg N + 46 kg P_2O_5 + 20 kg K_2O/ha	1.48	1.14	0.90
20 kg S/ha	1.46	-	0.66
18 kg N + 20 kg S/ha	1.45	-	0.98
18 kg N + 46 kg P_2O_5 + 20 kg K_2O + 25 kg Zn SO_4/ha	1.41	-	0.97

Phosphorus

Most Indian soils supporting lentil are low to medium in available P and therefore the response to applied P is generally high. The optimum dose of P has been found to be 30 to 60 kg P_2O_5/ha under different edaphic and climatic conditions (Singh *et al.* 1981; Singh *et al.* 1983; Akhtar *et al.* 1985; Nema *et al.* 1985; Ali 1986; Azad and Gill 1989). In multilocation trials under AICPIP, response to 46 kg P_2O_5/ha was 196, 202 and 177 kg seed/ha in the Northwestern Plains, Northeastern Plains and Central Zone, respectively. Singh and Marok (1981) determined the P requirement of lentils in relation to available P status of soil. They found significant response to 30, 20 and 10 ppm P_2O_5 on low-, medium- and high P-soils, respectively. The critical level of available P was found to be 15 kg/ha.

Response to a higher dose of phosphorus has been reported. Singh and Singh (1986a) reported that on soils having a high organic carbon value (0.75%), lentil responded up to 80 kg P_2O_5/ha. Similar observations were made by Saraf and Baitha (1979). Sharma *et al.* (1987) conducted pot culture experiments using hill soils of acidic nature. They used 0, 30, 60, 90 and 120 ppm P soils and found that the dry matter production was increased by 1.66, 2.55, 2.70 and 3.70 t/ha over the control, respectively. It was interesting to note that 89% of the soils showed response to 120 ppm P, while the remaining 11% responded to a rate of 90 ppm P. The soil-available P content had a significant positive correlation with yield and P uptake.

The role of P in root proliferation, nodule development and biological N_2 fixation is well recognized. Sharma and Singh (1986) reported that an application of 80 kg P_2O_5/ha significantly increased nodule number, root length and shoot dry matter. Dhingra *et al.* (1988) observed that an application of 20 kg P_2O_5/ha increased nitrogenase activity of intact root nodules from 17 520 to 22 390 nmol h^{-1} g^{-1} nodule dry matter and to 27 391 and 29 170 nmol h^{-1} g^{-1} at 40 and 60 kg P_2O_5/ha, respectively (Table 13).

Table 13. Effect of phosphorus and *Rhizobium* inoculation on nitrogenase activity of intact root nodules of lentil at Ludhiana, 1982/83.

Phosphorus levels (kg P_2O_5/ha)	Nitrogenase activity (nmol h^{-1} g^{-1} dry weight)	
	Uninoculated	Inoculated
0	14 586	20 475
20	18 164	27 117
40	22 285	32 497
60	23 682	34 658

Basal placement is by far the most accepted method of P application in direct sown lentil. Sekhon *et al.* (1983), however, reported that 75 kg P_2O_5/ha, half applied as basal and half as foliar application, gave the highest yield on the sandy loam soils of Punjab. In the *paira* crop, a basal application of fertilizers is not feasible. Sharma *et al.* (1984), working on different methods of P application, observed that a foliar spray of 30 kg P_2O_5/ha in two splits significantly increased seed yield.

Potassium

Most of the soils on which lentils are grown are high in available K and therefore response to applied K is limited. Tiwari and Nigam (1985) observed the response to K on sandy loam soils of Uttar Pradesh. In multilocation trials under the AICPIP, conducted during 1985/86 to 1988/89, the mean response to 20 kg K_2O/ha in the Northeastern Plains was 219 kg/ha but in the Northwestern Plains and Central Zone, the crop did not respond.

Secondary Nutrients and Micronutrients

Among secondary nutrients, sulfur appears to be the most important in grain legumes. The deficiency of sulfur has been recently noticed in coarse-textured soils of the Northwestern Plains under intensive cropping. A crop of lentil producing seed at 2 t/ha removes sulfur at a rate of about 6 kg/ha (Aulakh and Pasricha 1986). In a field experiment conducted at Ludhiana in soil having available S of 8 kg/ha, the yield increment with S at 40 kg/ha over control was 47%. In multilocation studies carried out under the AICPIP during 1985-89 the mean yield increase in response to S applications of 20 kg/ha was 148 kg/ha in the Northwestern Plains. In the Central Zone, sulfur application did not improve productivity. The use of a single superphosphate as a source of P provides adequate S to meet the need of lentils, but the recent shift to diammonium phosphate is likely to aggravate S deficiency and therefore due care has to be taken to supplement S.

The importance of micronutrients—especially Zn, Mo, B and Fe—in lentil production has been recognized in recent years. The increasing cropping intensity and the edaphic conditions under which lentils are grown is likely to limit the availability of several micronutrients. Rao and Sharma (1982) reported that a foliar spray of Tracel (a mixture of micronutrients) improved productivity of lentils in the acidic soils of Himachal Pradesh.

Lentils are highly susceptible to Zn deficiency. Shukursha (1976) observed Zn deficiency when the P:Zn ratio was higher than 400 and the Fe:Zn ratio was higher than 11 in the whole shoot. The application of 5 ppm Zn markedly increased the number and weight of nodules and dry matter production. Chandra and Gangwar (1977) observed acute Zn deficiency in lentil followed by rice. They also noted that the critical limit for available

Zn extracted by different extractants ranged between 0.34 and 1.81 ppm. Gangwar and Singh (1986) reported that a foliar spray of zinc sulfate (0.5% $ZnSO_4 \cdot 7H_2O$ + 0.25% lime) twice (15 and 45 days after emergence) corrected the Zn deficiency and increased dry matter production and yield. Seed coating with Zn at 0.1% by weight also improved dry matter production and yield.

Molybdenum, being an essential component of nitrogenase enzyme, has a vital role in nitrogen fixation and therefore an adequate supply of it has to be maintained. Sharma and Chahal (1983) observed that the application of 15 ppm Mo increased shoot length, root length, number of nodules/plant and nodule dry weight of lentil on the sandy loam soils of Ludhiana, whereas 8 ppm Mo did not show any positive effect. Pal (1986) found that the combined application of P and Mo recorded more seed yield than P alone. Sinha (1988), working on two genotypes of lentil, found that variety Precoz responded significantly to Mo and Fe. Boron had an adverse effect.

Limited response to Fe application has been reported. Singh *et al.* (1985), working on calcareous soil, observed a significant response to 5 kg Fe/ha. A differential response of lentil cultivars to iron also has been found. Singh *et al.* (1984) observed that genotype PL 639 responded to 5 kg Fe/ha, whereas BR 25 and Mo 26 gave highest yields with 10 kg Fe/ha.

Balanced Fertilization

The importance of balanced fertilization has long been recognized to achieve high productivity and fertilizer use efficiency. In multilocation studies under AICPIP, an application of 18 kg N plus 46 kg P_2O_5/ha gave the highest yield in all zones (Table 12). Minhas *et al.* (1987) recommended applying 40 kg N, 90 kg P_2O_5 and 30 kg K_2O/ha to lentil for higher productivity. Verma and Kalra (1983), Tomar *et al.* (1987) and Khare *et al.* (1988) observed that 20 kg N and 60 kg P_2O_5/ha was the optimum dose for lentil.

Biological Nitrogen Fixation

Lentil is nodulated by bacteria from the *Rhizobium leguminosarum* crossinoculation group. The efficiency of the bacteria depends upon soil moisture, pH and nutrient supply. The response of lentil to *Rhizobium* inoculation has been reported by many workers (Ojha *et al.* 1977; Bisen *et al.* 1980; Sandhu 1984; Ali and Chandra 1985; Pal and Ghosh 1986). In general, the yield increment was 10 to 20% over the uninoculated control. Similarly, Sarkar and Pal (1986) reported that on laterite soil, seed inoculation with *Rhizobium*, pelleting of the seed with $CaCO_3$ and liming of soil produced highest seed yields. Pal (1986) found that inoculation alone was effective in increasing seed yield but when used in combination with phosphorus and molybdenum, it brought out positive effects on yield. Sharma *et al.* (1987) in their review article also emphasized that lentil responded to *Rhizobium* inoculation on some sites only.

Dhingra *et al.* (1988) found that the nitrogenase activity increased from 17 520 nmol ha^{-1} g^{-1} of nodule dry matter at 0 kg P_2O_5 to 22 390, 27 391 and 29 170 nmol ha^{-1} g^{-1} under 20, 40 and 60 kg P_2O_5/ha, respectively. The *Rhizobium* inoculation was significant in 3 out of 5 years. Sandhu (1989) further confirmed these results by a reduction of the phosphorus need by 20 kg P_2O_5 with a substitution of *Rhizobium* inoculation.

Differential response of genotypes to inoculation also has been observed. Bhattacharya and Sengupta (1984) evaluated 21 genotypes of lentil and observed that genotypes with a higher percentage of coralloid nodules had better nodulation. Further, they found that genotypes with pink, bold nodules gave high yields. Maiti *et al.* (1988) studied the effect of *Rhizobium* inoculation on entisols in West Bengal. They reported that inoculation improved nitrogenase activity, number of nodules/plant and dry matter yield.

The association of *Rhizobium* and *Azotobacter* has been reported to increase nodulation, quality and yield of lentils (Mallik and Sanoria 1981; Sanoria and Mallik 1981). Rai (1985) studied the associative effect of *Rhizobium* strains and *Azotobacter* on calcareous soils in Bihar. He found that the combination of the two bacteria significantly increased nodule dry weight, nitrogenase activity and grain yield of lentil. He postulated that the hormones produced by *Azotobacter brasilense* and its mutant strains increased the nitrogen-fixation capacity of the host-symbiont association.

The beneficial effect of VA mycorrhizal inoculation in lentil has been reported by Sumanbala and Singh (1985). They found that VAM inoculation improved growth, dry matter accumulation, nodulation and nitrogen fixation, both at low and high levels of available P. More information on this aspect is needed so that a combined inoculation with *Rhizobium* and VAM can be considered for lentil.

Water Management

Lentil requires as much water as wheat or other cereals. However, over 90% of the lentil in India is grown on conserved or residual soil moisture. The water requirement of lentil has been computed by several workers. Sandhu *et al.* (1989) found that the water requirement of lentil was 483 mm under irrigation. Saraf and Baitha (1979) computed the water requirements of lentil under different irrigation treatments by following the soil moisture depletion on a sandy loam soil of north India. The water requirement ranged from 155 mm with a single irrigation to 214 mm with four irrigations, when the crop was timely sown. About 67% of the total soil moisture depletion occurred in the first 0-30 cm soil layer. The second 30-cm soil layer contributed another 25%. Hamoudi (1979), Singh *et al.* (1979) and Rizk (1979) also noted increased seasonal consumptive use of water with an increase in number of irrigations; the values ranged from 150 mm under no irrigation to 242 mm with two irrigations.

Lentil needs one to three irrigations depending upon initial profile moisture, soil texture, planting time and crop duration (Cheena *et al.* 1985). Nema *et al.* (1984,1985) and Singh *et al.* (1988) observed that one irrigation at the pre-flowering stage was adequate.

Response to two irrigations, one each at branching and flowering/pod initiation, has been obtained by several workers (Singh *et al.* 1979; Verma and Kalra 1983; Saraf and Bhatia 1985; Maity and Jana 1987; Mandal and Mahapatra 1988). Singh *et al.* (1983) working on the alluvial soils of north India reported that two irrigations, 30 and 75 days after sowing (DAS), gave highest yields (Table 14). Bisen *et al.* (1980), Singh *et al.* (1981) and Verma and Kalra (1983) found that irrigation at 60 and 105 DAS gave highest yields. The mean seed yield was in the range of 0 to 884 kg/ha over no irrigation (Table 15). In a few cases, a significant increase in yield has been observed with three irrigations, one each at seedling, branching and pod-filling stages (Yusuf *et al.* 1979; Abdullah 1987).

Table 14. Influence of irrigation on yield and consumptive use of water in lentil at New Delhi, 1975-77.

Irrigation	Grain yield (t/ha)	Straw yield (t/ha)	Consumptive water use (mm)
No irrigation	1.92	3.60	168.5
One irrigation (30 DAS†)	2.18	3.76	209.0
Two irrigations (30 and 75 DAS)	2.39	4.14	261.9
LSD (5%)	0.08	0.36	

† DAS = days after sowing.

Table 15. Effect of irrigation on productivity of lentil.

Irrigation	Grain yield (t/ha)		
	Delhi (1978-80)	Meerut (1976-78)	Jabalpur (1976/77)
No irrigation	0.94	1.53	1.00
One irrigation (60 DAS†)	1.25	1.75	1.45
One irrigation (105 DAS)	-	1.74	1.26
Two irrigations (60 and 105 DAS)	1.47	1.94	1.89
LSD (5%)	0.09	0.17	0.21

† DAS = days after sowing.

The irrigation schedule for lentils also has been determined on the basis of soil moisture tension and IW/CPE ratio (irrigation water/cumulative pan evaporation). Hamoudi *et al.* (1983) reported that irrigation at 0.5 atmospheric tension, during both pre- and post-flowering stages, gave highest yields. Murari and Pandey (1984) at IARI, New Delhi, had similar findings.

Irrigation at 0.5 atmospheric tension gave seed yields of 930 kg/ha higher than with no irrigation. Application of straw mulch at 5 t/ha also proved beneficial. Irrigation studies based on the IW/CPE ratio showed that a ratio of 0.6 to 0.8 was ideal for irrigating lentil (Murari and Pandey 1987; Sharma *et al.* 1987).

Weed Management

Weeds cause heavy loss to the lentil crop as they rob the soil of its nutrients and moisture. The magnitude of loss depends upon weed species and their intensity, growing conditions, soil fertility and soil moisture. In multilocation studies carried out under the AICPIP during 1982/83 to 1984/85, the mean yield loss due to weeds was 20% in NEPZ and 23% in CZ (Ali and Lal 1989). However, yield losses as high as 90% have been recorded. Studies of crop-weed competition have revealed that the initial 6-8 weeks are the most critical for lentils (Saraf and Bhoi 1985).

Weeds in lentils are generally controlled by manual weeding rather than by herbicides. Faroda and Singh (1981) and Ahlawat *et al.* (1977) reported that two hand weedings, 25 and 45 DAS, provided satisfactory control of seasonal weed flora. Various herbicides have been evaluated for their efficacy in controlling weeds. Trivedi and Tiwari (1986) at Jabalpur found that isoproturon at 1.0 kg/ha was the most effective followed by terbutryn at 0.80 kg/ha.

Ahlawat *et al.* (1977) at IARI, New Delhi reported that prometryn at 0.50 kg/ha was as effective as two hand weedings. Alachlor at 1.5 kg/ha was next to prometryn. Pre-plant incorporation of fluchloralin at 0.75 kg/ha and a pre-emergence spray of oxadiazon at 0.75 kg/ha also have been found quite effective (Singh *et al.* 1986). Chaudhary and Singh (1987) studied the relative efficacy of herbicidal and cultural methods of weed control in Pant L 406 during 1986/87. They found that pendimethalin at 1.5 kg/ha and oxyfluorfen at 0.3 kg/ha were as effective as two hand weedings 25 and 45 DAS. The yield increment over the unweeded check was 1.37 and 1.22 t/ha (Table 16).

Studies on the effect of herbicides on soil microflora revealed that pendimethalin and terbutryn at the recommended rate of application did not affect soil fungi, bacteria or actinomycetes for an estimated period up to 180 days after treatment (Kumar *et al.* 1987).

Information on weed control in the *utera* system of cultivation is meager because of the practical difficulties in applying pre-emergence herbicides. An attempt was made by Singh *et al.* (1989) at IARI, New Delhi to study the bioefficacy and crop selectivity of

Table 16. Yield attributes and yield of lentil as affected by weed control treatments at Bulandshahar, 1986/87.

Treatment	Herbicide (kg/ha)	Pods/ plant	Seeds/ pod	Yield (t/ha)	
				Grain	Straw
Weedy check	-	30.65	1.70	0.72	1.36
Repeated weedings	-	110.65	2.05	2.54	3.78
Weeding 25 DAS	-	45.65	1.85	1.36	2.32
Weeding 25 and 45 DAS	-	93.90	2.00	2.14	3.26
Fluchloralin	0.5	42.80	1.80	1.20	2.14
Fluchloralin	1.0	49.69	1.85	1.25	2.06
Pendimethalin	0.75	79.90	1.95	1.73	2.71
Pendimethalin	1.5	92.60	2.00	2.09	3.27
Methabenzthiazuron	0.75	53.45	1.85	1.41	2.31
Methabenzthiazuron	1.5	77.20	1.95	1.68	2.65
Methabenzthiazuron	2.0	80.10	2.00	1.81	2.82
Oxyfluorfen	0.10	75.45	1.90	1.54	2.50
Oxyfluorfen	0.20	80.10	1.95	1.69	2.67
Oxyfluorfen	0.30	92.05	2.00	1.94	3.00
LSD (5%)		5.72	0.17	0.20	0.32

promising herbicides in lentils sown after the rice harvest under zero tillage. They found that metribuzin at 0.25 kg/ha controlled most of the weeds and was at par with weed-free plots.

Conclusions

In India, lentil has registered a marked increase in area, production and productivity in recent years. This has been possible because of the development of improved production technology, through intensive and comprehensive research launched under the All India Coordinated Pulses Improvement Project and various state-run projects during the past 25 years, in addition to the increasing interest of farmers in introducing lentils in new cropping systems. The present technology is capable of increasing productivity 2- to 3-fold. The main strategies include: selection of high-yielding and disease-resistant varieties, seed inoculation with *Rhizobium* culture, timely planting, adequate plant stand, application of 15-20 kg N and 40-60 kg P_2O_5/ha, 1-2 irrigations at critical growth stages and prompt plant protection measures.

In some of the agroecosystems such as *utera* conditions, the agrotechnology has yet to be worked out, especially for establishing desired plant stand, applying fertilizer efficiently and controlling weeds. The bold-seeded genotypes also should be developed for the *utera* system.

Lentil-based intercropping systems have been developed for different regions, but information on genotypic compatibility of component crops, spatial arrangements and fertilizer use is meager and needs due attention.

Since the planting of lentils is often delayed until after rice in sequential cropping, efforts should be made to develop suitable agrotechnology to increase productivity under such conditions, which at present is lacking.

In the Central Zone, lentil is grown on residual moisture and often faces moisture stress during the reproductive phase. Studies on seed treatment to reduce drought tolerance, and the development of a post-emergence technique to mitigate the adverse effects of drought, need to be strengthened.

Limited studies have shown a deficiency of sulfur and some micronutrients in lentil-growing areas. More comprehensive studies are needed to develop fertilizer schedules integrating all the essential nutrients.

Biofertilizers are the cheapest source to meet the needs of plant nutrients. *Rhizobium*, *Azotobacter* and VAM have shown encouraging response. More information on compatibility of these microorganisms and their efficient use is needed.

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Discussion

A.A. Miah

You have shown that irrigation can increase the yield of lentil by up to 70%, but our experience in Bangladesh revealed that irrigation or rainfall affects adversely during flowering and causes excessive vegetative growth, incidence of disease, hampers pod-setting and development and reduces yield.

M. Ali

When there is adequate moisture in the soil profile, any amount of rainfall and irrigation is known to adversely affect the productivity of lentil. In the Central Zone, moisture is the most limiting factor and soil moisture stress is often experienced. Under such conditions, irrigation proves very useful.

M.A. Rizk

What are the optimum sowing dates and plant population levels under early and late sowing conditions of Precoz under Delhi conditions?

M. Ali

Information is available for late planting conditions for Precoz. Under late planting, 200 plants/m^2 is optimum. Under Delhi conditions, the optimum time of planting is in the first fortnight of November.

B. Sharma

What is the evidence for P uptake through foliar application? Are there any experiments using ^{32}P?

M. Ali

Labelled P has not been used. The comparison is made with simple fertilizer like urea (N) and compound fertlizer like diammonium phosphate (DAP) (N+P). The improvement in yield with application of DAP over urea for a given dose of N indicates the response to foliar-applied P.

M. Rahman
One light shower at the age of about 30 days of plants helps in better growth and yield compared with flood irrigation at the same age. So the method of irrigation is important, which needs to be developed along with the quantity of water to be applied.

M. Ali
Yes, I agree. The lentil needs only light irrigation. Heavy irrigation may lead to soil compaction and poor aeration and consequently growth repression.

M. Rahman
Some microbiologists claim that when grain is harvested from a legume crop not much N is left in the soil for the next crop. Could you quantify how much N is left in the soil after harvest of lentil?

M. Ali
In our studies, the effect of legumes has been taken as N equivalent which is not only the residual N of preceeding legume but also their favorable effect on the physiochemical condition of soil. Increase in N status of soil due to preceeding lentil has been observed to be 0.016%.

J.S. Brar
Is there any study on the differences in response to *Rhizobium* under rain-fed/residual moisture and irrigated conditions?

M. Ali
Yes, response to *Rhizobium* under rain-fed conditions is lower than under irrigated conditions.

J.S. Brar
What is the optimum time for irrigation to the lentil crop in terms of plant growth phase?

M. Ali
The most critical stage appears to be flowering and pod initiation followed by maximum branching.

S.C. Agrawal
Under *utera* cultivation of lentil you suggested a foliar application of diammonium phosphate (DAP) on lentil in place of soil application. It is thought that only N of DAP is absorbed by the plant and not phosphorus. How will its requirement be met?

M. Ali
When DAP is sprayed, both N and P components are absorbed by plants.

M.C. Saxena
In your IW/CPE ratio recommendation of 0.6 to 0.8 for scheduling irrigation, could you indicate the soil depth/root zone considerations that have been used?

M. Ali
In the IW/CPE approach, irrigation depth is decided on the basis of soil depth and soil texture, and ranges from 4 to 6 cm. The CPE is then decided to arrive at different values like 0.6 or 0.8.

I.A. Malik
There seems to be a very large difference between the national average yield (about 650 kg/ha) and those reported in various experiments (1600-2500 kg/ha). What could be the possible reason for these vast differences in yield?

M. Ali
Farmers grow lentil on marginal levels without inputs like fertilizer, inoculation, irrigation and plant protection measures. Mostly local varieties are grown. On account of these factors, the yield levels in farmers' field are often quite low compared with experimental fields.

I.S. Singh
You mentioned that PL 406 can tolerate iron deficiency better than PL 639. Would you kindly let me know the probable reason for this.

M. Ali
It is a genetic difference.

S.S. Yadav
Why are farmers in the Central Zone not irrigating the lentil under rain-fed conditions?

M. Ali
In the Central Zone, irrigation water is severely limited. Wherever irrigation is available it is utilized for wheat production. Lentil is taken on those lands which do not have irrigation facilities.

S.S. Yadav
What relationship is there between N, P, K application and early growth of lentil?

M. Ali
Fertilizer application leads to early seedling vigor and growth.

Agronomy of Lentil in Bangladesh

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Abstract

Lentil (*Lens culinaris* Medik.) is the most important pulse crop of Bangladesh, ranking second in area and production but first in consumers' preference. It is traditionally grown during the dry winter season on residual soil moisture, under rain-fed conditions with minimum care and a low level of management. Lack of adequate research inputs, inherent low yield potential of the local landraces, poor response to inputs, unstable level of production due to various biotic and abiotic factors, and competition with other profitable crops are the major constraints to increasing its production. Agronomic research carried out so far indicates that timely sowing is the key factor for high yield realization. Other management practices such as proper tillage, weeding, application of chemical and biofertilizers, and plant protection measures can improve its productivity substantially. In addition to mixed cropping and intercropping of lentil with other crops such as wheat, mustard, linseed and sugarcane, the optimum seeding ratio and suitable planting configuration can lead to an appreciable increase in the production of lentil in Bangladesh. Therefore, research on all these aspects needs to be strengthened.

Introduction

Pulses are an indispensable food item for the people of Bangladesh. They play a vital role in supplementing protein in the cereal-based low-protein diets of the country. A large number of pulses are grown and consumed in Bangladesh. The major pulses are grasspea (*Lathyrus sativus*), lentil (*Lens culinaris*), chickpea (*Cicer arietinum*), blackgram (*Vigna mungo*) and mungbean (*Vigna radiata*). Among the pulses, lentil is the most important, ranking second in respect to area and production but first in consumers' preference. Lentil occupies about 29% of the total areas under pulses and produces about 30% of the total pulse production of the country (Table 1).

Constraints to Production

Lentil is a temperate crop, but it is adapted to the cooler regions of the subtropics and tropics. It cannot tolerate extreme cold or heat. The crop has some drought tolerance but it is highly susceptible to excess moisture conditions and various other biotic and abiotic stress factors. Hence, there is lack of stability in the performance of lentil due to climatic hazards.

Table 1. Area and production of lentil and other pulses (5 years average, from 1983/84 to 1987/88).

Crop	Area (1000 ha)	Production (1000 t)	Yield (kg/ha)	Percent of area	Percent of total production
Grasspea	234	167	715	30	32
Lentil	225	159	705	29	30
Chickpea	129	80	754	7	15
Blackgram	73	51	687	9	10
Mungbean	59	34	575	8	6
Pea	22	14	667	3	3
Pigeonpea	6	5	763	1	1
Other pulses	31	19	611	4	4

Source: BBS (1989).

In Bangladesh, lentil is traditionally grown during the dry winter months (*rabi* season) on residual soil moisture, under rain-fed conditions. The crop is usually grown with a low level of management. Seeds are sown without proper land preparation, the application of fertilizer, irrigation, weeding or protection measures and outside the optimum time for sowing. Hence, the average national yield is very low (650-700 kg/ha). However, because of the inherently low yield potential of existing cultivars, the crop is not responsive to inputs. Therefore, it faces serious competition with wheat, *boro* rice, oilseeds, potatoes and other profitable *rabi* (winter) crops, particularly where irrigation facilities are available. As a result, this crop has been pushed to the marginal and submarginal lands of low productivity, where there is little or no scope for the cultivation of other more profitable crops.

Owing to a lack of sufficient manpower and systematic research in the past, no significant progress was made to develop high-yielding varieties and the improved packages of management practices required to achieve higher lentil yields. However, efforts are now being made to improve and augment the productivity of lentil with the available technology.

Cropping Systems involving Lentil

Rice is the major crop of Bangladesh and is grown extensively throughout the year. Hence, all the major cropping patterns are rice-based. A wide variety of cropping patterns is followed in different agroecological zones of Bangladesh depending on land characteristics and soil moisture regimes. The major lentil-growing areas are the greater districts of Faridpur, Rajshahi, Pabna and Jessore. Lentil is generally grown as a monocrop in Bangladesh. Mixed cropping and intercropping of lentil with wheat, mustard, linseed, sugarcane, etc. are also being practised in some areas.

The major lentil-oriented cropping patterns are:

1. *B. aus* paddy rice/fallow/lentil
2. Jute/fallow/lentil
3. *T. aman* (long-season) rice/lentil/fallow
4. Deep-water rice/lentil
5. Fallow (flooded area)/lentil

Sowing Time, Seed Rate and Stand Establishment

Time of sowing is a key factor to achieve high yield in lentil. Sowing time markedly influences the performance of lentil because of the change in those environmental conditions to which the crop is exposed at various stages of phenological development under variable dates. Lentil in Bangladesh is normally sown during the post-monsoon season on conserved soil moisture. In most cases sowing is done from the latter part of November to early December after the harvest of the *aman* rice crop. When lentil is sown after *aus* paddy or jute, sowing can be done by the end of October.

In areas where lentil has to be sown after the harvest of *T. aman* or deep-water *aman* rice, the delay influences crop growth adversely, causing reduction in yield. Winter in Bangladesh is short (100-110 days) and mild; thus, climate imposes a restriction of 110 days on the growth duration of lentil. Delayed sowing, therefore, hampers proper growth and also causes serious disease infestation resulting in poor yield. Khan and Miah (1986) observed that the optimum time of sowing for lentil appeared to lie between the first and third weeks of November (Table 2). They also reported that sowing beyond that period reduced yield drastically.

Table 2. Performance of lentil under different dates of sowing.

Date of sowing	Plant ht. (cm)	Plants /m^2	Pods/ plant	Seeds/ pod	1000-grain wt. (g)	Grain yield (kg/ha)
5 November	33	73c	121a	1.74a	15.01	981abc
10 November	31	96a	116a	1.71abc	15.31	1089abc
15 November	33	85b	121a	1.72ab	16.02	1234a
20 November	33	78c	98ab	1.66abc	15.19	1095ab
25 November	32	62d	73bc	1.59cd	14.57	837bcd
30 November	33	50e	63cd	1.61cd	14.51	623cde
5 December	33	47ef	44de	1.60bcd	14.67	499de
10 December	32	44f	36de	1.50d	14.85	406e
15 December	33	60d	34e	1.38d	14.61	285e

In a column, means followed by the same letter(s) are not significantly different at 5% level of Duncan's Multiple Range Test.

Proper stand establishment is another important factor in determining the yield of lentil. Poor plant stand in the farmer's field is one of the main factors for lower yield. Lack of quality seeds, inadequate soil moisture during sowing time, improper tillage, lower seed rate, weed infestation and the incidence of diseases are responsible for poor stand establishment. Rahman and Miah (1989a) found that the population density of 250 plants/m^2 gave the highest yield of lentil (Table 3). Further investigation in this area, however, needs to be carried out. A seed rate of 35-40 kg/ha gave a higher yield of lentil (Table 4) than lower rates (Anonymous 1990).

Table 3. Effect of plant population on the yield and yield components of lentil.

Plants/m^2					
Initial	Final	Pods/ plant	1000-seed wt. (g)	Yield (kg/ha)	Total dry matter (kg/ha)
50	46	45	15.0	380	1005
75	67	40	15.0	475	1100
100	86	32	14.5	530	1150
125	105	30	15.0	595	1175
150	125	28	15.0	680	1400
175	144	26	15.0	750	1500
200	161	24	15.0	875	1760
250	197	22	14.5	950	2150

Table 4. Performance of lentil at different seed rates and locations.

Seed rate (kg/ha)	Grain yield (t/ha)			
	Ishurdi	Jessore	Faridpur	Joydebpur
40	1.00	0.94	1.20	0.88
35	1.20	0.98	1.00	0.90
30	0.98	0.86	0.89	0.84
25	0.76	0.72	0.76	0.70
20	0.70	0.60	0.68	0.62

Improved Management Practices

Proper land preparation, weed control, irrigation, application of fertilizers and plant protection measures are not usually practised. Although the existing cultivars of lentil are unresponsive to high inputs, improved management practices can lead to an appreciable increase in yield. Research (Maniruzzam and Miah 1989a) revealed that proper tillage accompanied by the application of chemical fertilizers, weeding and disease control can increase the productivity of lentil significantly (Table 5).

Farmers consider lentil as a hardy crop and do not make adequate land preparation, which may encourage severe weed infestation, in turn causing heavy damage to the crop. Lentil cannot withstand weed competition because the plants are slender, weak and do not branch much nor grow tall enough to suppress the weeds. The extent of yield losses due to weed infestation can be up to 90% (Basler 1981). Rahman and Miah (1989b), in an experiment on the weed control of lentil using different herbicides and manual weed control methods, observed that control of weeds either manually or by herbicides is very effective for high yield realization (Table 6).

A number of experiments were conducted by the Soil Science Division of BARI during the years 1980-88 at different locations in the country to find out the optimum fertilizer dose to achieve high lentil yields. Islam (1989) reported that the application of chemical fertilizers with both major and micronutrients can increase the yield of lentil significantly when it is grown in soil with a low nutrient status (Table 7). Irrigation is not usually required for the cultivation of lentil. However, during sowing, if there is a shortage of residual soil moisture in the top layer, one pre- or post-sowing irrigation should be given to ensure proper germination and optimum stand establishment.

Hossain and Khanam (1988) reported that use of effective strains of rhizobial cultures, popularly known as biofertilizers, can lead to a substantial increase in yield of lentil (Table 8). However, until recently this technology has not been made available to the farmers of Bangladesh.

Table 5. Effect of different levels of management on the grain yield of lentil (Maniruzzaman and Miah 1989a).

Level of management	Yield (kg/ha)
Minimum tillage (MT)	563 bc†
Minimum tillage + Hand weeding (HW)	672 bc
Minimum tillage + Fertilizer (F)	682 bc
Minimum tillage + HW + F	812 abc
Conventional tillage	861 ab
Conventional tillage + HW	1028 ab
Conventional tillage + F	861 ab
Conventional tillage + HW + F	979 ab
Conventional tillage + DC‡	801 abc
Conventional tillage + HW + F + DC	1090 a

† Yields followed by the same letter are not significantly different at 5% by Duncan's Multiple Range Test.
‡ DC = Disease control, fertilizer at 20:40:20 kg/ha N-P-K.

Table 6. Effect of herbicides and manual weed control methods on the yield components of lentil.

Treatment	Seed yield (t/ha)	Plants /m²	Pods/ plant	Seeds/ pod	1000-seed wt. (g)	Total DM (t/ha)
Weedy check	0.95	190	25	1.45	16.00	2.40
Weed free by repeated hand weeding	1.45	195	36	1.50	16.50	3.20
Hand weeding twice (30-35 and 55-60 DAE†)	1.40	198	36	1.50	16.50	3.10
Tribunil, 2.0 kg ai/ha	1.08	190	28	1.48	16.00	2.60
Maloran, 1.5 kg ai/ha	1.25	196	30	1.50	16.50	2.85
Bladex, 0.5 kg ai/ha	1.05	185	29	1.45	16.30	2.55
Gesagard, 1.5 kg ai/ha	1.24	195	32	1.50	16.50	2.80
Aretit, 1.0 kg ai/ha + Fusilade, 0.5 kg ai/ha	1.03	180	30	1.46	16.20	2.50
Tribunil, 2.0 kg ai/ha + Kerb‡	1.20	192	32	1.45	16.00	2.78
Bladex, 0.5 kg ai/ha + Kerb	1.16	190	30	1.45	16.00	2.70
Maloran, 1.5 kg ai/ha + Kerb	1.42	197	36	1.50	16.50	3.10
Gesagard, 1.5 kg ai/ha + Kerb	1.45	195	37	1.50		3.12
LSD (5%)	0.10	NS	3.93	NS	NS	0.19
CV (%)	5.80	3.39	9.09	1.62	1.44	5.03

† DAE: Days after emergence.
‡ Kerb at 0.5 kg ai/ha.

Table 7. The response of lentil to chemical fertilizers in soil with low nutrient status.

Added chemical fertilizers (kg/ha)								Yield (t/ha)	
N	P	K	S	Zn	Cu	B	Mo	Grain	Straw
0	0	0	0	0	0	0	0	0.77	1.52
20	60	40	25	5	2	2	1.5	1.45	1.84
20	60	40	25	5	2	2	1.5	1.36	1.57
20	60	40	25	5	2	2	1.5	1.34	1.60
20	60	40	25	5	2	2	1.5	1.25	1.64
20	60	40	25	-	2	2	1.5	1.29	1.53
20	60	40	25	5	-	2	1.5	1.20	1.69
20	60	40	25	5	2	-	1.5	1.18	1.70
20	60	40	25	5	2	2	-	0.99	1.73
20	60	40	25	-	-	-	-	0.96	1.63
20	60	40	-	-	-	-	-	0.92	1.76
20	60	-	-	-	-	-	-	0.85	1.59

Table 8. Grain, straw and nodule weight as affected by *Rhizobium* inoculation and chemical fertilizer in lentil.

Input	Nodule wt. (kg/ha)	Straw yield (kg/ha)	Grain yield (kg/ha)	Increase in grain yield (%)
Control	1.9	840	786	0
N50	1.4	966	930	18.3
P50 K50	1.3	936	912	16.0
N50 P50 K50	1.5	894	918	16.8
Control + Inoculum	2.2	1038	936	19.1
P50 K50 + Inoculum	2.4	1068	1062	35.1

Mixed Cropping and Intercropping

The practice of mixed cropping and intercropping of lentil with crops such as wheat, mustard, linseed and sugarcane is being followed in some parts of the country. Mixed cropping and intercropping avoid the risk of total crop failure. Several studies on these cropping systems with various crop species under different seeding ratios and planting configurations suggested that mixed or intercropping can increase the total productivity per unit area substantially.

Ahmed *et al.* (1987) conducted an experiment on mixed cropping of wheat and lentil under variable seeding ratios. The most compatible, promising and economically profitable seeding ratios for wheat and lentil were found to be 100:50 and 50:100 (Table 9). Rahman and Shamsuddin (1981) in an experiment on intercropping lentil and wheat obtained the highest total productivity, land equivalent ratio (LER) and net return when 30% of wheat seed rate was sown in between lentil rows spaced 30 cm apart (Table 10).

Experimental results (Maniruzzaman and Miah 1989b) on the intercropping of lentil with linseed at different planting configurations also revealed the advantage of intercropping over a sole crop (Table 11). Iqbal (1989) evaluated the performance of mustard and lentil grown in different mixed and intercrop combinations under variable seed rate ratios and planting geometry. The yield advantage was highest (20%) in the mixed cropping of mustard and lentil with the seed rate ratio of mustard 75% + lentil 25%. The next highest yield advantage of 15% was obtained from the intercropping of mustard and lentil with mustard (2 paired rows) + lentil (broadcast). Highest yield advantages of these two cropping systems were associated with higher LER, equivalent yields, net return and benefit cost ratio (Table 12). Lentil is becoming very popular as an intercrop with sugarcane.

Table 9. Effect of mixed and intercropping of wheat and lentil under various seeding ratios on yields (kg/ha).

Seeding ratio	1981/82			1982/83		
	Wheat	Lentil	Wheat equiv.	Wheat	Lentil	Wheat equiv.
Wheat : Lentil						
100 : 25	2730	527	3784	-	-	-
75 : 25	2877	710	4297	-	-	-
50 : 50	1896	893	3682	-	-	-
25 : 100	-	-	-	1444	920	3284
50 : 100	-	-	-	1299	1210	3719
50 : 75	-	-	-	1457	1100	3657
100 : 0	0	3540	-	3540	-	1404
0 : 100	-	1210	-	-	1393	-

Table 10. Performance of lentil and wheat grown in different intercrop combinations.

Treatment	Ratio	Grain yield (kg/ha)		Fraction of a monoculture check		Land equivalent ratio
		Lentil	Wheat	Lentil	Wheat	
Lentil sole (L)	1 : 0	1521	-	-	-	1.00
L + 10% wheat	10 : 1	1510	322.7	0.99	0.22	1.21
L + 20% wheat	5 : 1	1480	482.0	0.97	0.33	1.30
L + 30% wheat	10 : 3	1475	706.0	0.97	0.48	1.45
L + 50% wheat	2 : 1	1460	580.0	0.96	0.35	1.31
Wheat sole	1 : 0	-	1458.7	-	-	1.00

Table 11. Effect of intercropping lentil with linseed in different planting configurations.

Treatment (row ratio)	Grain yield (t/ha)		Land equivalent ratio	Gross return (Thaka/ha)
	Lentil	Linseed		
Sole lentil	0.72	-	1.00	9360
Sole linseed	-	1.20	1.00	4810
Lentil : Linseed-4:1	0.69	0.31	1.22	10270
Lentil : Linseed-1:1	0.47	0.72	1.25	8970
Lentil : Linseed-1:4	0.29	0.90	1.17	7410
Lentil : Linseed-2:3	0.39	0.69	1.12	7800
Lentil : Linseed-3:2	0.47	0.61	1.61	8580
Lentil : Linseed-2:2	0.48	0.70	1.25	9100

Table 12. Relative yields, land equivalent ratio (LER) values, mustard (ME) and lentil (LE) equivalent yields of different treatments.

Treatment combination	Mustard yield		Lentil yield		LER	ME (t/ha)	LE (t/ha)
	t/ha	Rel.†	t/ha	Rel.			
Mustard (sole 100%) broadcast	1.338	1.00	-	-	1.00	1.338	1.115
Lentil (sole 100%) broadcast	-	-	1.206	1.00	1.00	1.447	1.206
Mustard 75% + Lentil 25%	1.204	0.899	0.369	0.234	1.204	1.646	1.372
Mustard 50% + Lentil 25%	0.713	0.532	0.669	0.508	1.086	1.515	1.263
Mustard 25% + Lentil 75%	0.318	0.237	0.998	0.758	1.064	1.515	1.263
Mustard 2 rows + Lentil 5 rows	0.365	0.272	0.950	0.721	1.059	1.505	1.254
Must. 2 paired rows + Le. broadcast	0.447	0.334	0.982	0.746	1.148	1.625	1.354
Mustard + Lentil alternate rows	0.690	0.515	0.652	0.495	1.055	1.472	1.227

† Relative yield.

Research Needs

1. Development of packages of improved management practices for different agroecological zones depending on land characteristics.
2. Existing lentil-oriented cropping pattern needs to be adjusted through cropping system research so that sowing can be done at optimum time.
3. Improvement of the existing mixed and intercropping systems with regard to selection of companion crops, optimum seed ratios, proper planting geometry, etc. for increased productivity and economic return.
4. Improvement of stand establishment technique by efficient utilization of residual soil moisture through the development of low-cost implements.
5. Identification of effective strains of rhizobia and rhizobial inoculation technique.
6. Investigation of the physiological aspects of yield variation under different environmental conditions, which might be helpful for agronomic manipulations.
7. Identification of potential areas for the extension of the cultivation of lentil into the nontraditional regions.

Conclusion

In view of the present situation, the development of high-yielding varieties of lentils resistant to various biotic and abiotic stresses is essential to improve and augment its production. Moreover, the development of a package of modern management practices and the improvement of existing mixed and intercropping systems will go a long way to improving the exploitation of lentil production potential in Bangladesh.

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Discussion

S.S. Lal
Does delayed sowing of lentil result in increased damage due to aphids and pea pod borer?

A.A. Miah
No; in Bangladesh infestation with aphids and pod borer in lentil is not usually found, but delayed sowing causes serious infestation with rust and Stemphylium blight diseases.

K. Singh
Can we increase the plant population beyond 250 plants/m^2 to increase the yield of lentil?

A.A. Miah
Investigation in this area needs to be carried out. However, experimental evidence revealed that there is scope to achieve higher yield by increasing population density.

J.S. Brar
How it is possible to obtain yield differences of more than 1.4 q/ha in sowing the crops between 10 and 20 November?

A.A. Miah
It is possible, because with the variation in planting dates the crop is exposed to different environmental conditions at various stages of phenological development, which influences growth, development and yield markedly.

J.S. Brar
Plant stature is the same in lentil planting on 15 November and 15 December. How would you explain this?

A.A. Miah
Lentil originally being a temperate crop is not very sensitive to variation in temperature, particularly during the vegetative growth stage.

P.P. Singh
The CV value in your weed control trial was very low: 5%. Generally it is not the case with such experiments.

A.A. Miah
I do agree with your observation.

M. Ali
In intercropping of lentil and sugarcane, it is reported that yield of sugarcane is not depressed in Bangladesh but in India there is loss in yield of sugarcane. Could you explain the reasons. What is the yield level of lentil and sugarcane in this system?

A.A. Miah
It is really difficult to explain this difference in results. However, in our experiment only one row of lentil was grown as intercrop between sugarcane crop spaced 1 m between rows. Lower population density of lentil might be the reason for lack of reduction in yield of sugarcane. The yield of lentil obtained from this cropping system varied from 300 to 350 kg/ha.

Agronomy of Lentil in Nepal

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Abstract

Lentil is the most important grain legume crop of Nepal, occupying 45% of the area under legumes. It is grown during the winter on soil moisture conserved during the preceding monsoon season, either as a relay crop with long-duration paddy or in sequence after paddy or maize. It is often intermixed with winter cereals and oilseeds. Studies were conducted at different locations to find the optimum sowing dates and seeding rates, and the most efficient methods of intercropping, weed control and *Rhizobium* inoculation. From the third week of September to the second week of November was the optimum sowing date, depending on the agroecological conditions and cropping systems. A seeding rate of around 40 kg/ha was optimum. Intercropping lentil with wheat and mustard was most profitable and had a high Land Equivalent Ratio. Pre-emergence application of Tolkan 50 WP (isoproturan) was effective against broad-leaved weeds in lentil. Results of microbiological studies in lentil are briefly discussed.

Introduction

Lentil is the most important grain legume crop of Nepal in terms of both area and production. It is one of the exportable agricultural commodities of the country, and is cultivated in about 121 740 ha of land (DFAMS 1990), representing 3.6% of the total cultivated area and 45% of the area under legumes. However, the national average yield of lentil is only 625 kg/ha owing to the use of low-yielding local cultivars in marginal land with a suboptimal level of agronomic practices.

Lentil cultivation is distributed in a broad area between 26° 20' and 29° 25' N latitudes and the crop is grown during winter in *Terai* foothills, inner *Terai* and in some pockets in the mid-hills. At present 97% of area and 96% of production comes from the *Terai* region. It is grown as a relay crop with long-duration paddy, or in sequence after paddy or maize. It is often intermixed with winter cereals (wheat and barley) and oilseeds (mustard and linseed). In recent years, lentil cultivation has become more popular because of high market price and simpler management of the crop than of other pulses.

Research on lentil started on a limited scale as early as 1972, but efforts were intensified after the upgrading of the pulse program to the National Grain Legume Research Program (NGLRP) during 1985. The results of agronomic studies conducted to date are summarized in this paper.

Agronomic Studies

Recognizing that improved crop management techniques could allow large increases in yield, studies on better agronomic practices were recently intensified. Information has been gathered on sowing dates, seeding rates, methods of intercropping, cropping sequences, weed control methods and microbiological studies at some locations in the country.

Date of Sowing

Lentils are planted from October to November depending on the agroecological conditions and cropping pattern. The first to the second week of November was found to be the optimum time for planting lentil in the *Terai* (Neupane *et al.* 1979). Delay in sowing after the third week of November resulted in a drastic reduction in grain yield. Studies conducted at Lumle (1650 m asl) have indicated that the third to the fourth week of September was the optimum time for planting in a maize/lentil system (LAC 1984). At Rampur, in inner *Terai* conditions, planting in the fourth week of October resulted in the highest grain yield and was at par with the second week of November planting. A drastic reduction in yield was noticed when sowing was delayed beyond the second week of November (Table 1). Lentils are grown, to a large extent, as a relay crop with paddy, wherein lentil seeds are broadcast on a standing crop of paddy after the drainage of excess water. Studies conducted at Khumaltar (1350 m asl) indicated that the optimum time for relay planting lentil was 15-20 days prior to the harvesting of paddy (NGLRP 1990). This practice is beneficial where labor is limited at the time of paddy harvest, or the field cannot be prepared readily because of excessive moisture.

Seeding Rate

Farmers usually use low seeding rates, which often result in poor and sparse plant populations. Based on earlier studies, a seed rate of 40 kg/ha was recommended to farmers (AID 1978). Studies conducted at Parwanipur showed no difference between 20, 40 or 80 kg/ha of seed rates in grain yield of lentil (Neupane *et al.* 1979). There was no effect of 40, 60 or 80 kg/ha seed rates at Rampur (Table 1). Hence it would be worthwhile to test seed rates lower than the presently recommended rate of 40 kg/ha.

Intercropping Studies

Lentils are often grown mixed with wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), linseed (*Linum usitatissimum*) and mustard (*Brassica campestris* var. *toria*). Various studies were conducted to evaluate the existing farmer practices and to develop better ones.

Devkota (1979) reported that under rain-fed conditions the intercropping of lentil and wheat in paired rows was more remunerative than a pure stand of wheat. Pathik and Malla (1981) found that intercropping wheat and lentil in a 1:1 ratio was profitable in terms of land utilization and this combination had a high Land Equivalent Ratio (LER).

Table 1. Effect of sowing date and seed rates on seed yield of lentil at Rampur, 1989.

Treatment	Days to flower	Days to mature	Seed yield (t/ha)
Seeding date			
October 20	94	161	1.31
October 30	85	153	1.33
November 10	86	142	1.18
November 20	81	133	1.12
November 30	80	124	0.92
December 10	72	119	0.72
Mean	83	138	1.09
F Test	**	**	**
LSD (5%)	2.0	3.2	0.20
CV (%)	4.6	6.5	22.7
Seeding rate			
40 kg/ha	83	139	1.05
60 kg/ha	84	139	1.06
80 kg/ha	83	138	1.17
Mean	83	138	1.09
F Test	NS	NS	NS
CV (%)	5.1	4.0	25

** $P > 0.01$.

Also, intercropping of wheat and lentil (1:1) was better under rain-fed upland conditions, but lentil was more compatible with mustard (DOAG 1988). Lentil yields were reduced at various levels by intercropping at Rampur (Table 2). Compared with a sole stand, reductions of 65, 57 and 60% in grain yield of lentil were recorded because of intercropping with wheat, mustard, and linseed respectively. Intercropping lentil in alternate rows with mustard was more compatible than with other crops. The LER was also found to be highest in this treatment.

In the long-term cropping system trial conducted under rain-fed upland conditions at Khumaltar, soybean/lentil produced the second highest net profit in spite of the lowest total grain yield (Table 3). This was due to the high price of both lentil and soybean. Grain yield of lentil was higher in the maize + soybean/lentil pattern and lowest in the maize/finger millet/lentil system. Delay in the harvesting of finger millet did not allow the timely seeding of lentil, resulting in lower yield of lentil in this pattern.

Table 2. Seed yield (t/ha) of lentil and other intercrops in intercropping experiment during 1989 at Rampur.

Crop combination	Wheat	Mustard	Lentil	Linseed	Total yield	LER†
Wheat sole	1.54	-	-	-	1.54	1
Mustard sole	-	0.45	-	-	0.45	1
Lentil sole	-	-	1.17		1.17	1
Linseed sole	-	-	-	0.99	0.99	1
Wheat + Mustard	0.96	0.23	-	-	1.19	1.13
Wheat + Lentil	1.18	-	0.40	-	1.58	1.11
Wheat + Linseed	0.82	-	-	0.03	0.85	0.56
Mustard + Linseed	-	0.21	-	0.05	0.26	0.52
Mustard + Lentil	-	0.35	-	0.50	0.85	1.21
Lentil + Linseed	-	-	0.47	0.07	0.54	0.47
Mean	1.13	0.31	0.64	0.29	0.94	
F Test					*	
LSD (5%)					0.44	
CV (%)					30	

† LER = Land Equivalent Ratio.
* P > 0.05.

Weed Control Studies

Lentil competes poorly with many weed species because of its weak stem and slow growth. The major weed species associated with lentil are *Phalaris minor*, *Chenopodium album*, *Vicia hirsuta*, *V. angustifolia*, *Spergula arvensis*, *Lathyrus aphaca*, *Alopecuros* sp., *Lysimachia conjestifolia*, *Drymeria cordata*, *Galensoga parviflora* and *Persicaria capitata* (LAC 1989; Ranjit and Sahu 1989).

Ranjit (1980) reported that Maloran at 2 kg/ha was effective against weeds of lentil both in the mid-hills and *Terai* region. Results of a study conducted at Lumle showed that pre-emergence application of Tolkan at 3 g/L of water increased lentil yield by 96.4% over the weedy check and by 12.8% over the manually weeded plots (LAC 1989). Reduction of the herbicide rate by half increased weed density and as a result no yield benefit could be recorded. Post-emergent application of Tolkan also was reported to be effective against weeds in lentil (LAC 1989). Studies conducted at Rampur revealed that the pre-emergence application of Tolkan at 1 kg/ha was the most effective against weeds, and resulted in yield increases of 26% over the weedy check and 20% over the manually weeded plots (Table 4). The number and dry weight of weeds were significantly reduced by Tolkan.

Table 3. Total seed yields of crops and net profits in the long-term cropping system trial involving lentil at Khumaltar 1987.

Cropping pattern	Mean yield (t/ha)						Annual mean yield (t/ha)	Annual gross profit (Rs/ha)‡	Annual net profit (Rs/ha)
	Maize	Soybean	FM†	Wheat	Lentil	Mustard			
Maize/Wheat	3.850	-	-	1.961	-	-	3.811	20487	5025
Soybean/Wheat	-	2.909	-	2.184	-	-	5.093	31140	16388
Soybean/Lentil	-	3.271	-	-	0.389	-	3.660	29286	17538
Maize+Soybean/Wheat	4.162	1.033	-	1.969	-	-	7.164	29925	13793
Maize+Soybean/Mustard	4.011	1.145	-	-	-	0.287	5.443	30504	17686
Maize+Soybean/Lentil	4.417	1.059	-	-	0.523	-	5.999	28064	14936
Maize/FM/Wheat	3.964	-	0.529	1.615	-	-	6.108	22146	2376
Maize/FM/Lentil	4.532	-	0.613	-	0.191	-	5.336	20304	3518
Maize/FM/Mustard	4.485	-	0.366	-	-	0.213	5.064	22315	5839
Maize/FM/Barley	4.043	-	0.554	-	-	-	6.106	21804	2266
F Test	-	-	-	-	-	-	**	**	**
CV (%)	-	-	-	-	-	-	9.6	10.8	27.7
LSD (5%)	-	-	-	-	-	-	0.773	3942	3942

† FM = Finger millet.
‡ USD 1 = Rs 31.5.
** P > 0.01.

Table 4. Effect of weed control treatments on weed count, dry weight of weeds and seed yield of lentil at Rampur (Ranjit and Sahu 1989).

Treatment	Weed count /0.25 m^2	Dry weed wt. (g/0.25 m^2)	Seed yield (t/ha)
No weeding	175	31.5	1.23
Two weedings†	59	2.7	1.30
Pre-emergent application			
Benthiocarb (2 L/ha)	161	28.7	1.40
Tolkan (1 kg/ha)	55	7.7	1.60
Basalin (2 L/ha)	109	26.0	1.10
Basalin (1 L/ha)	162	37.2	1.00
Lasso (1.5 L/ha)	104	28.5	1.28
Lasso (2 L/ha)	160	39.5	1.10
F test	**	**	**
LSD (5%)	14.2	13.2	0.13
CV (%)	23	35.7	7

† 20 and 40 days after planting.
** P > 0.01.

Microbiological Studies

Limited studies on lentil microbiology conducted in Nepal have indicated the positive effect of *Rhizobium* inoculation in lentils; therefore seed inoculation with *Rhizobium* culture is recommended to the farmers (AID 1978).

Studies conducted at Lumle in a rice/lentil system have clearly indicated that the inoculation of lentil seed with *Rhizobium* gave a 17-84% higher yield over the control (LAC 1989). In the maize/lentil system at Pakhribas (1350 m asl) 13 to 20% more yield was obtained over the control, yet a negative effect of inoculum was observed when it was applied along with compost and/or chemical fertilizer (PAC 1990). A preliminary study on the methods of seed inoculation with *Rhizobium* showed that the sugar-slurry technique was superior to other methods (LAC 1990).

Casual observation and survey of *Rhizobium*-inoculated plots in farmers' fields indicated that lentil exhibits variable effects of inoculation. The absence of nodulation in *Rhizobium*-treated plots was suspected to be due to the loss of viability of inoculum during transportation and handling (LAC 1989).

Conclusion

Lentil is a leading grain legume crop in Nepal. It has the largest area and production of the cultivated grain legumes. However, the productivity of the crop is very low because of the cultivation of low-yielding local cultivars in marginal lands with a suboptimal level of agronomic management. Research results have shown that the third week of September to the second week of November was the best period for sowing lentil depending on agroecological conditions and cropping patterns. Intercropping lentil with wheat or mustard proved profitable. Tolkan 50 WP was found effective against weeds in lentil. However, more research work is needed regarding seeding dates and seed rates for different agroecological regions and cropping patterns. More detailed investigations into biological nitrogen fixation, mineral nutrition and management practices (e.g., irrigation) are needed.

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Section 4. Plant Protection

Plant Protection of Lentil in India

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Abstract

India is the major lentil-growing country in the world, but average production is less than its potential because of several diseases and insect pests. Out of 12 fungal diseases recorded in India, wilt (*Fusarium oxysporum* f.sp. *lentis*), collar rot (*Sclerotium rolfsii*), rust (*Uromyces fabae*) and powdery mildew (*Erysiphe polygoni*) cause considerable damage in different areas. However, none of the viruses and nematodes are important economically. Considerable work has been carried out on the various aspects of lentil diseases. This paper serves as a comprehensive review of the literature in lentil research, with special attention paid to the recognition and control of various biological stresses. Sources of resistance have been reported against wilt and rust, yet there is a need to develop suitable varieties resistant to these diseases. Fungicidal seed treatment has been found effective in checking early stage plant mortality. Effective fungicidal sprays have been reported against rust, but they do not seem practical for use on a crop like lentil. Some of the species of *Trichoderma*, *Streptomyces* and *Bacillus* are reported to control wilt, collar rot and root rot under pot culture conditions; however, their field value for biological control is yet to be established. Among several insect species infesting lentil in the field, the black aphid (*Aphis craccivora*) and the pea pod borer (*Etiella zinckenella*) can pose a significant threat; likewise bruchids can render damage in storage. Attempts have been made to review the research efforts on distribution, biology, ecology, natural enemies and the management practices of these key pests. A review of the literature reveals that there is a need to strengthen the research initiative on resistance to diseases and pests as well as their biological and cultural control. The screening of varieties and germplasm against such stresses as wilt and rust should be conducted under controlled conditions. Likewise, greater documentation on insect pests would assist research efforts, since such information is limited to date.

Introduction

The lentil is an important pulse crop in India, grown in the winter season on 0.8 to 0.9 million hectares. The crop is grown mainly under rain-fed conditions with an average production of only about 467 to 526 kg/ha. The total lentil area in the Indian subcontinent is about 50% of the lentil acreage throughout the world, but the production is only 40%. The major factor contributing to low production is the crop's vulnerability to diseases and insect pests. These biological stresses cause appreciable yield losses, but the plant protection aspect of this crop has received little attention in India. The research conducted in India, on the issue of diseases and insect pests, is reviewed here, with further relevant information given in brief.

Fungal Diseases Infecting Root and Stem

Wilt

In India, lentil wilt was studied in detail by Vasudeva and Srinivasan (1952) in Delhi. At present, it is the main problem in the states of Madhya Pradesh, Uttar Pradesh, Bihar, West Bengal, Assam, Punjab, Haryana, Rajasthan, Himachal Pradesh and others. In some of the fields in Madhya Pradesh, a disease incidence of up to 78% has been observed.

Symptoms

The symptoms are produced at the pre- and post-emergence stages (Vasudeva and Srinivasan 1952; Claudius and Mehrotra 1973; Khare *et al.* 1979). Infected seeds exhibit browning at the micropylar end. Upon germination the radicle develops browning, resulting in the death of the seedlings. Vascular wilt is noticed in plants infected at an advanced stage. The plant growth is checked, leaves become yellow and curled, starting from the lower part of the plant, and the crown droops, followed by death. Roots turn yellowish brown to dark brown without any fungal growth on the surface. In early cases, the tap root is abnormally short and destroyed at the tip. Secondary roots proliferate in a cluster above the affected part if sufficient soil moisture prevails. Walls of the xylem vessels are discolored or brown, while several may contain the fungal hyphae.

Causal organism

Several species of *Fusarium* have been found associated with the wilted lentil plant (Khare *et al.* 1979) but in India *Fusarium orthoceras* App. and Woolen w var. *lentis* Vasudeva and Srinivasan was reported to be the cause of the disease (Vasudeva and Srinivasan 1952). Later, the name of the fungus was suggested as *F. oxysporum* Schlecht. ex Fr. f.sp. *lentis* Vasudeva and Srinivasan by Chattopadhyay and Sengupta (1967). The fungus is specific to lentil but it has great variability. Sharma and Agnihotri (1972) differentiated three isolates of the pathogen from Rajasthan on the basis of their morphology and virulence. In Madhya Pradesh, Claudius and Mehrotra (1973) isolated 14 cultures of the pathogen that differed in their virulence on lentils. Eight isolates of the fungus could be differentiated on the basis of their requirements for nutrition (Kushwaha *et al.* 1974; Khare *et al.* 1975), temperature (Dhingra *et al.* 1974) and sensitivity to fungicides (Agrawal and Khare 1977).

Disease cycle and epidemiology

Fusarium oxysporum f.sp. *lentis* survives in the soil, but also has been found associated with the seeds (Khare *et al.* 1979). The disease is favored in soils with a high proportion of sand, a soil moisture of 25%, a pH of 7.5-8.0 and a temperature range of 17-31°C (Vasudeva and Srinivasan 1952; Saxena and Khare 1988). It does not occur at 75% or more soil moisture. Under Delhi conditions the disease was observed in November but almost ceased in December and January. Fresh cases appeared in February with a maximum occurrence in March. This was reduced again in April with the rise in temperature (Vasudeva and Srinivasan 1952).

Varietal resistance

Efforts have been made to screen lentil varieties and germplasm to identify sources of resistance against the wilt pathogen. Varieties differed considerably in this respect (Khare and Sharma 1969). From 1970 to 1974, 2000 lentil lines were screened at Jabalpur under field and pot culture conditions. Out of these, LWS numbers 4, 6, 10, 14, 15, 20, 23, 24, 25, 26 and 50 were found resistant, with less than 5% wilt (Khare *et al.* 1979). Tiwari and Singh (1980) scored lentil lines against wilt under field conditions and identified 13 lines for use as parents in lentil breeding.

At Pantnagar, LWS 14 and LWS 21 were immune to five strains of the pathogen. Also, substantial resistance was observed in Pant 209, Pant 220, Pant 234, Pant 538, Pusa 3, Pusa 4, JL 80 and UPL 175 (Kannaiyan and Nene 1975a, 1976). In addition, Pusa 3, Pant 234 and JL 80 were found resistant to *Rhizoctonia solani* and *Sclerotium rolfsii*. Pandey *et al.* (1988) screened 49 lentil lines against the wilt complex, of which PL 81-74 and Pant L 234 showed resistance to post-emergence death, but all had high pre-emergence mortality.

Lentil varieties and germplasm have been screened against wilt at different research centers under the All India Coordinated Pulses Improvement Project. At most of the places, wilt-sick plots do not exist, and probably because of variability in the pathogen, disease reaction differed considerably. However, the following showed resistance consistently: lines Pant L 772, Pant L 406, Pant L 639, LP 212, LG 170, LG 171, LG 175, LG 178, LG 224, L 4076, L 4125, L 4162, L 4163, LL 299, LH 82-6, HUL 8 and PDL 1.

Saxena and Khare (1988) reported that varieties with shorter roots, or having fewer secondary roots, showed a low incidence of the disease. Such varieties had compact cork cambium and narrow metaxylem. A large number of varieties should be studied to correlate such characteristics with resistance.

Chemical control

Seed treatment with benomyl at 0.3% is reported to check the disease (Kannaiyan and Nene 1974). MBC, the degradation product of benomyl, was detected in the root and the shoot of lentil up to 45 days after the sowing of treated seed (Kannaiyan *et al.* 1975). Agrawal *et al.* (1975) reported that seed treatment with Thiram + pentachloronitrobenzene (PCNB) or Thiram + Bavistin (1:1) at 2.5 g/kg of seed reduced the disease considerably under field conditions. A reduced disease incidence has been reported by the application of Mn and Zn salts in soil, as a seed pre-soak or a foliar spray (Mehrotra and Claudius 1973). Insecticides like Rogor, Diptrex, Azodrin 5G and

Solives, when applied to the soil as dust at 15-20 kg/ha, reduced the seedling wilt of lentil (Kannaiyan and Nene 1975b).

Cultural control
At Pantnagar, the least wilt was observed in the sowing of 15 December, while the advanced stage wilt was less in the crop sown on 15 November (Kannaiyan and Nene 1975a). At Jabalpur, however, it was noted that delayed sowing reduced plant mortality, but also curtailed the yield greatly (Agrawal *et al.* 1976d). Manipulation of sowing date may prove a good method of lentil wilt control but its efficacy will differ from place to place and season to season.

The cultivation of paddy or sorghum in the rainy season reduced lentil wilt incidence in the succeeding winter (Kannaiyan and Nene 1979), but the disease incidence was increased if the refuse of these crops was incorporated in the soil (Agrawal *et al.* 1976e).

Microbial control
Trichoderma viride Pers. ex Fr., *Streptomyces gorgeroti* and some bacterial species were found antagonistic to *F. oxysporum* f.sp. *lentis* (Mehrotra and Claudius 1972). Similarly, *T. harzianum* Rifai and *T. koningii* Oudemans showed antibiosis and mycoparasitism against the lentil wilt pathogen (Mukhopadhyay *et al.* 1989). These antagonists have shown potential for disease control in the laboratory as well as in pot culture. The possibility of their use on a large scale should be explored by conducting field trials and by standardizing utilization techniques on a large scale.

Collar Rot

Collar rot, in lentils, was described as 'root rot' from Uttar Pradesh, India (Pavgi and Upadhyay 1967). Later, it was named collar rot by Mathur and Deshpande (1968). The disease occurs mainly in India, causing considerable death to seedlings in the early stages of plant growth.

Symptoms
The pathogen infects the collar region of the plant, causing a yellowish brown discoloration and a rotting of tissue. The young seedlings show damping-off symptoms. Plants infected at the advanced stage turn pale gradually, droop and dry. White feathery growth of the fungus, generally associated with dirty white to brown mustard seed-like sclerotia, can be seen on the infected part. Infected plants, under unfavorable conditions, prolong the survival for the disease. Sometimes the fungus may proceed downward causing root rot. Infected plants are easily pulled out from the soil, as the root system is poorly developed and side roots are destroyed.

Causal organism
The disease is caused by *Sclerotium rolfsii* Sacc. which has the perfect stage as *Corticium rolfsii* (Sacc.) Curzi. (Mathur and Deshpande 1968).

Disease cycle and epidemiology

Sclerotium rolfsii survives well in the soil in the presence of sufficient organic matter (Khare *et al.* 1979). The disease is favored by high soil moisture with high temperature and good sunshine after rains. Young seedlings are highly susceptible to the pathogen, and susceptibility decreases with the advancing age of the plant (Agrawal *et al.* 1976a). The disease becomes severe if the stubble of the previous crop (e.g., paddy or sorghum) is left in the field.

Varietal resistance

Khare *et al.* (1979) reported that lentil lines LWS 2, LWS 4, LWS 7, LWS 9, LWS 11, LWS 12, LWS 22, LWS 35, LWS 37, LWS 40, LWS 47, LWS 51, LWS 52, LWS 53, LWS 55, LWS 59, LWS 60, LWS 61, LWS-63, LWS 66 and LWS 74 were resistant to *S. rolfsii* under field as well as artificially inoculated conditions. Resistance has been recorded in Pusa 3, Pant 234 and JL 80 (Kannaiyan and Nene 1976) and in Pusa 1, LP 18 and Pant 638 (Abu Mohammad and Umesh Kumar 1986).

Chemical control

The disease was controlled by seed treatment with Thiram, Captan or Rhizoctol (Khare *et al.* 1974). Later, it was shown that the early stage seedling mortality in lentil can be controlled best by treating the seed with a combination of more than one fungicide, e.g., Thiram + PCNB (1:1) or Thiram + Bavistin (1:1), at 2.5 g/kg seed (Agrawal *et al.* 1975). Mancozeb also has been found effective (Singh *et al.* 1985).

Cultural control

Collar rot in lentils can be reduced greatly by manipulating the sowing date in such a way that the seedling stage does not coincide with high soil moisture and a temperature level above 25°C. Under Jabalpur conditions, 15 October was found to be a suitable sowing date and resulted in low seedling mortality and a high yield (Agrawal *et al.* 1976d). Further delay in sowing reduced the disease incidence greatly but curtailed the yield drastically (Table 1). The disease is reduced considerably by the application of potassium at 60 kg/ha (Prasad and Chaudhary 1984).

Table 1. Effect of sowing dates on the incidence of collar rot (*Sclerotium rolfsii*) and yield of lentil.

Sowing date	Total mortality (%)	Yield/plant (g)	Yield/ plot (g)
15 September	73.2	4.7	43.3
30 September	33.0	2.5	62.4
15 October	7.5	1.7	64.0
30 October	24.0	1.9	52.9
15 November	20.5	1.5	42.9
30 November	6.7	0.6	5.6
CD (5%)	13.87	1.7	35.72

Table 2. Effect of two antagonists (*Trichoderma harzianum* and *Bacillus subtilis*) on mortality of lentil caused by *Sclerotium rolfsii*.

Treatment	Mortality (%) of lentil *T. harzianum*	*B. subtilis*
Control without *S. rolfsii*	13.8	13.8
Control with *S. rolfsii*	78.3	70.7
Antagonist alone with seed	0.0	13.8
Antagonist alone in soil	4.6	4.6
Antagonist with seed and *S. rolfsii* in soil	29.7	19.0
Antagonist and *S. rolfsii* in soil	48.1	24.2
CD (5%)	17.56	26.39

Microbial control

Trichoderma viride, *Streptomyces gorgeroti* and some bacterial species were reported antagonistic to *S. rolfsii*, as isolated from lentil (Mehrotra and Claudius 1972). For example, *Trichoderma harzianum* and *Bacillus subtilis* were found antagonistic to *S. rolfsii*; applying them with seed or soil controlled collar rot in pot culture (Agrawal *et al.* 1977) as shown in Table 2. Similarly, Mukhopadhyay *et al.* (1989) reported the control of collar rot in lentils by using *T. harzianum* or *B. subtilis* applied to seeds with a 2% solution of *gur* (molasses); the collar rot of lentil was reduced by about 80% over that of the control (Khare 1980).

Root Rot

Root rot of lentil is caused by several fungi, making it a complex disease (Khare *et al.* 1979). In India, the disease is caused by *Rhizoctonia solani* Kuhn (Shukla *et al.* 1972) and *Rhizoctonia bataticola* (Taub) Butler (Khare *et al.* 1979). The losses are greater if more than one pathogen is involved simultaneously (Khare 1981).

Symptoms

The plant infected with *R. solani* changes gradually in color from dull green to reddish brown and then to yellow. Leaves wilt from below and the plant becomes dried. When pulled, the diseased plants easily detach at the soil level. Roots are discolored reddish brown and all their tissues except the xylem are infected, disintegrating the cortex and vascular cylinder completely. In the case of *R. bataticola*, the roots turn ashy, showing minute sclerotia in diseased tissues after splitting. Finer roots rot and turn black.

Casual organism

The fungus *R. solani*, isolated from lentil, has been described by Shukla *et al.* (1972). It has hyaline to yellowish brown mycelia with sclerotia up to 2 mm in size, whereas *R. bataticola* produces minute black sclerotia in abundance. Both pathogens are soil-borne, but also are frequently associated with seeds. The disease is favored by high temperature.

Control
Lentil lines Pant L 234, Pusa 3 and JL 80 are reported tolerant to *R. solani* (Kannaiyan and Nene 1976). The disease is checked considerably by seed treatment with PCNB at 2 g/kg seed (Shukla *et al.* 1972) and by the application of potassium at 60 kg/ha (Prasad and Chaudhary 1984). Efforts should be made to identify good sources of resistance against these two dangerous pathogens.

Ozonium Wilt

A minor disease caused by the *Ozonium texanum* Neal and Wester var. *parasiticum thirum* occurs in Bihar, India (Shukla 1982). Infected plants gradually turn yellow from the top and droop. Thick, white mycelial growth develops near the collar region. The epidermis and the cortex beneath the affected region rot and become soft. The vascular tissues are exposed and later disintegrate. Affected plants, when pulled, separate from the collar region leaving behind roots in the soil. The plants may wilt at any stage.

Lentil varieties BR 25, Pusa 1 and LP 350 showed tolerance against the pathogen (11-25% wilt) when tested by artificial inoculation (Abu Mohammad and Umesh Kumar 1986).

Stem Rot or Sclerotial Blight

In India, the disease was reported from Pantnagar (Kannaiyan and Nene 1973). Plants are infected at the collar region, developing water-soaked lesions that turn brown. The pathogen is *Sclerotinia sclerotiorum* (Lib.) de Bary which grows faster under high humidity and when plant growth is excessive, covering stem and leaves. The plant turns yellow and then brown. The affected plant parts show cottony, white, dense fungal growth sometimes associated with irregular, light brown to dark brown sclerotia. Later, the roots, pods and seeds also may be infected.

Infected crop refuse, infected seeds, or the sclerotia mixed with the seed, serve as the source of inoculum for primary infection in the field. Since the disease spreads very fast, it can be controlled effectively by using resistant varieties only. The use of clean seed, crop rotation and burning of the diseased crop residues can help in reducing the disease.

Fungal Diseases Infecting Foliage

Rust

Lentil rust occurs in several countries including India where it has been studied in detail by Prasada and Verma (1948). The disease causes heavy losses whenever favorable conditions prevail, particularly in the states of Uttar Pradesh, Bihar, Punjab, Madhya Pradesh and others. In Madhya Pradesh, it appeared in epidemic form in Narmada Valley (Khare and Agrawal 1978). Yield loss was reported as 11.5 kg/ha with every 1% increase in disease intensity (Singh *et al.* 1986).

Symptoms
Yellowish white pycnidia and aecia develop on the lower surface of leaflets and pods. Later, brown uredial pustules emerge on either surface of leaflets, stem and pods. Pustules are oval to circular, up to 1 mm in size, but they may form big pustules after coalescing with each other. Telia are produced late in the season, mainly on the stem and branches. The plant may dry completely even before seed formation and the affected crop looks damaged by frost (Khare and Agrawal 1978).

Causal organism
The disease is caused by *Uromyces fabae* (Pers) de Bary which is an autoecious fungus infecting lentil, faba bean, sweet pea, *Lathyrus*, etc. Singh and Sokhi (1980) identified six pathotypes on the basis of their differential reactions on varieties of lentil, pea and sweet pea.

Disease cycle and epidemiology
Lentil rust occurs mostly in January-February, in the form of pycnidia and aecia. Aeciospores germinate at 17-22°C and infect other plants, forming either secondary aecia at 17-22°C or uredia at 25°C. Disease development is favored by high humidity and cloudy or drizzly weather, with a temperature of 20-22°C. The disease generally starts from low-lying patches in the field and radiates toward the border (Khare and Agrawal 1978). Uredosori develop late in the season and are rapidly followed by telia. After harvest, aecia and uredia present on the plant die but teliospores resist the heat. Infected inert matter found with the seed, in the form of broken pieces of leaves, stems and pericarps, also acts as the basic inoculum. Teliospores germinate at 17-22°C without a resting period and cause outbreaks of the disease.

Varietal resistance
At Pantnagar, Nene *et al.* (1975) found improved varieties L 9-12, T 36 and Bombay 18 resistant to rust. Germplasm lines LP 846, UPL 172, UPL 175 and BC 10 were immune. Some of the lines (JL 599, JL 632, JL 674 and JL 1005) possessed resistance to wilt as well as to rust. Pandey (1981) reported Pant L 236 as highly resistant and Pant L 406 as resistant to rust. At Jabalpur, Agrawal *et al.* (1976b) found 22 lentil lines of the JL series to be free from the rust, which included JL 599, 632, 674 and 1005. Khare and Agrawal (1978) reported T 36, BR 25, Pusa 10, UPL 175 and 22 other germplasm lines free from rust attack. Mishra *et al.* (1985) found HY 1-1, T 36, NP 47 and 21 other accessions to possess good resistance to rust. In Punjab, Singh and Sandhu (1988) found HPL 5, LL 48, LL 82, LL 133, LL 178 and L 2895 to be resistant to rust under laboratory as well as field conditions. Shukla (1984) screened 251 lentil lines at Kanpur, of which two were immune.

Lentil lines have been scored for rust under the All India Coordinated Pulses Improvement Project at Pantnagar, Dholi, Kanpur, Kumarganj and Sehore, but the disease reaction varied considerably from location to location and year to year. It may be attributed to the possible existence of different races of the pathogen, or escape of the test entry from the disease, as testing at most of the places was done under natural infection. However, Pant L 406, Pant L 639, LL 278, LL 287, L 299, LL 311, LG 171, LG

198, LH 82-6, PDL 1, PDL 4, L 9-12 and HUL 8 have shown good resistance or tolerance at most of the centers for two or more seasons.

Resistance to rust in lentils is reported to be governed by a single dominant gene whereas susceptibility is assigned to a recessive allele (Sinha and Yadav 1989; Singh and Singh 1990).

Chemical control
Seed treatment with Agrosan is reported to eliminate the inoculum from the seed (Prasada and Verma 1948). Being a mercury compound, Agrosan is not compatible with *Rhizobium* sp. Lentil grown from seed treated with Vigil (diclobutazol) is reported to remain free from rust infection for up to 60 days after sowing, while the control crop was infected severely after only 35 days (Singh 1985). Spraying of the crop with Dithane M 45 at 2500 ppm at an interval of 10-12 days from the initiation of the disease controlled the disease effectively, increasing the yield by 81.8% (Agrawal *et al.* 1976c; Singh *et al.* 1985). K. Singh (1984) reported complete control of lentil rust with Wettasul spray. However, the spraying of fungicide on a large scale on a crop such as lentil does not seem practical.

Cultural control
It is possible to clean the seed and to treat with fungicide in order to eliminate the inoculum. Also, it is recommended to burn diseased crop refuse after harvest (Prasada and Verma 1948). In Punjab, the December-sown lentil crop was attacked by rust less than the crop sown in November (Singh and Dhingra 1980).

Powdery Mildew

In India, powdery mildew on lentils was first reported by Sankhla *et al.* (1967) in Rajasthan. It appears almost every year in January-February in Madhya Pradesh. The disease is favored by sunny, clear weather.

Symptoms
Plants are infected at any stage but more severely at flowering. White, powdery, small patches are initiated on the lower leaf surface, but later they become amphigenous, covering most of the foliage. Leaflets become chlorotic, curled, and then fall. A severely infected plant may be killed. Chitle *et al.* (1981) reported the fungus strictly epiphyllous.

Causal organism
The disease is caused by *Erysiphe polygoni* DC (Sankhla *et al.* 1967). According to Bhardwaj and Singh (1984), the *Oidium* state of powdery mildew fungus in lentils resembles that of *Erysiphe pisi*. In the USSR, *Leveillula leguminosarum* f.sp. *lentis* is reported to cause powdery mildew in lentil (Khare *et al.* 1979).

Varietal resistance
Mishra (1973) found lentil lines 10511, 10526, 10528, 10536 and 10537 from Iran to be highly resistant to powdery mildew. At Jabalpur, Pant L 639 and JPL 970 were found

resistant. In the screening tests, conducted under the All India Coordinated Pulses Improvement Project, lentil lines DL 315 at Faizabad and LG 224 at Dholi were found free from the disease. Generally, bold-seeded varieties were more susceptible than small-seeded ones.

Chemical control
Out of 10 acaricides and insecticides, Dinocap, Quinolphos and Triazophos when applied at 0.5 kg ai/ha reduced the disease considerably. The first spray was administered at the initiation of symptoms, followed by two sprays at an interval of 15 days (R.N. Singh 1984).

Ascochyta Blight

The disease occurs mainly in the northern states of India (Khatri and Singh 1975). It appeared in epiphytotic form at Ludhiana during at least three seasons in the last two decades.

Symptoms
Circular, tan to dark brown spots appear on leaves, stem and pods. They are more conspicuous on pods than on leaves. Pycnidia are small, dark brown to black, and formed in concentric rings. Under severe conditions, leaves get blighted and pods remain small with shrivelled seed.

Causal organism
Ascochyta pisi Lib. was reportedly the cause of the disease in India (Khatri and Singh 1975). However, isolates of the fungus from lentil, pea and chickpea have been found highly host specific by Kulshrestha and Vallabhacharyulu (1985) and hence the lentil isolate should be known as *A. lentis* Bond and Vassil. *Ascochyta* sp. has been found associated with lentil seed imported from the USA and Syria (Lambat *et al.* 1985).

Varietal resistance
Out of 947 lentil lines screened against Ascochyta blight, P 1128 was free, while P 465, 467, 654 and 670 had a high degree of resistance (Khatri and Singh 1975). Singh *et al.* (1982) reported LG numbers 169, 170, 172, 173, 174, 186, 191, 192, 204, 209 and 210 resistant consistently for 4 years under field conditions.

Control
Beniwal *et al.* (1989) recommended sun drying the seed to control seed-borne inoculum. The losses due to the disease can be minimized by crop rotation, early seeding, the avoidance of moist weather at harvest and the use of disease-free seed (Nene *et al.* 1988). No work on chemical control has been done in India, but in Canada, a single application of chlorothalonil, Captafol, Folpet, or Metiram at early bloom to pod-set stage controlled the disease, reduced seed infection and increased the yield (Beauchamp *et al.* 1986).

Alternaria Blight

A leaf blight of lentil caused by *Alternaria alternata* (Fr.) Keissler (*A. tenuis*) was reported from West Bengal, India by Sengupta and Das (1964). The disease appeared as small, pale brown spots at tips and margins of leaflets. In severe cases, leaves are blighted and plants succumb to the disease. The pathogen infects chickpea and tomato as well, but at Jabalpur, it was found associated with weak plants after rains, usually as a saprophyte (Khare *et al.* 1979). No control measures are recommended, but *in vitro* the fungus growth is inhibited by Captan and Brestan. Likewise, conidial germination is checked by Dithane M 45 at 1000 ppm (Mishra and Rath 1975).

Downy Mildew

In India, downy mildew of lentil caused by *Peronospora* sp. was reported from Pantnagar (Beniwal and Srivastava 1968) and Jabalpur (Khare *et al.* 1979). The fungus differed morphologically from the *Peronospora lentis* Gaumann previously identified on lentil, and hence, the Indian isolate may be a different species of *Peronospora*. Symptoms appear as pale green to yellow on various lower leaves, indefinite spots on the upper surface, and as greyish downy growth of the pathogen on the lower surface side. Later, fungal growth covers the entire surface and may become amphigenous causing defoliation. In mid-February, stunted bushy plants with smaller leaves were observed as having downy growth and abundant oospores (Beniwal and Srivastava 1968). It emerges at the most critical stage, as it causes blighting of leaves and cessation of apical growth. No work has been undertaken on the control of the disease in India.

Cercospora Leaf Spot

Lentil has been found infected by *Cercospora lensii* at Jabalpur by Sharma *et al.* (1978). It forms water-soaked, central and marginal spots on leaves. No control is recommended as the disease is a minor one.

Viral Diseases

Eleven viruses have been documented (Khare *et al.* 1979) as associated with lentils. Out of these, only three have been reported for lentil in India: the cucumber mosaic virus, the pigeon pea mosaic virus and the tobacco streak virus. However, none of them cause substantial economic losses.

Cucumber Mosaic Virus

This virus was found to occur on lentil and was studied by Rangaraju and Chenulu (1981). The incidence of the virus on different cultivars of lentil varied from 5 to 100%. The symptoms include intervenal chlorosis, growth stunting, the proliferation of axillary shoots and a reduction in leaf size. The causal virus was identified as a strain of CMV on the basis of host range, physical properties, differential host reaction and morphology. No control measures have been worked out in India.

Pigeon Pea Mosaic Virus

The effect of the pigeon pea mosaic virus in lentil has been mentioned by Khare *et al.* (1979). It reduces number, size and weight of fruit and germinability of seeds. It is uncommon.

Tobacco Streak Virus

The lentil has been reported as an experimental host for the Tobacco Streak Virus by Ghanekar and Schwenk (Khare *et al.* 1979)

Nematode Diseases

Several species of nematodes have been found associated with lentil, but only root knot has been recognized as significant for its economic losses. Root knot (*Meloidogyne* sp.) was reported in Madhya Pradesh in 1972 (Khare *et al.* 1979). The affected plants were yellowish and stunted with irregular swellings of the roots. Later, the root knot nematodes on lentil were identified as *Meloidogyne incognita* (Mishra and Gaur 1980) and *Meloidogyne javanica* (Prakash 1981). In India, no work has been reported so far on the control aspect of nematodes on lentil.

In a survey, Mishra and Gaur (1980) found *Heterodera cajani*, *Pratylenchus* sp., *Hoplolaimus* sp., *Helicotylenchus* sp., *Tylenchorhynchus* sp. and *Telotylenchus* sp. associated with lentil. *Rotylenchulus reniformis* and *Tylenchus* sp. have also been observed associated with lentil in India (S.S. Lal, pers. comm.).

Flowering Parasites

The lentil crop was reported as parasitized by *Cuscuta hyalina* Roth. in Bihar, India by Dutta *et al.* (1983). The plants were entwined with slender, golden-colored vines, because of which they became paler and ultimately dried prematurely or produced small seeds. The parasite is leafless and parasitizes the plants by sending haustoria in the stem. No control measures are reported.

Field Insect Pests

The lentil has relatively few insect pests; therefore they generally cause negligible yield loss in India. However, in some locations and seasons, several insects may become serious and require pest management inputs.

Black Aphid, *Aphis craccivora* Koch (Hemiptera: Aphididae)

Of the three aphids recorded on lentils, *A. craccivora* is the most threatening (Lal *et al.* 1980, 1985). Its infestation occurs on lucerne, faba bean, chickpea, clover, lentil, pea and vetches (Hariri 1981) in most legume-growing areas of the world.

Damage
Feeding of aphids depletes assimilates and increases the respiration rate in the plant (van Emden 1973). The lentil crop is vulnerable to pest infestation at the seedling or flowering to podding stages. In severe infestations, leaves and shoots are stunted and deformed. The insect deposits honeydew on the plant upon which a black mold grows.

Biology
Fecundity and development rates vary with host plant, soil fertility, soil moisture and temperature. The multiplication and spread of aphids over large areas is caused by drought. The aphid reproduces viviparously and parthenogenetically. The nymphs undergo four molts before reaching the adult stage. The duration of each instar is usually 1 day, up to 3 days in a few cases. A 1-day-old apterous female begins its brood, reproducing up to a maximum of 12 days. High plant density adversely affects the population build-up in chickpea (Lal *et al.* 1989).

Management
At least 17 predators and 7 parasites have been recorded as natural enemies on *A. craccivora*. A variety of insecticides such as acephate, bromophos, carbaryl, cypermethrin, demeton-methyl, dimethoate, endosulfan, fenvalerate, lindane, malathion, menazone, methomyl, phosdrin, primicarb, pirimiphos-methyl and thiometon have been recommended (COPR 1981; Thakur *et al.* 1986).

Pea Pod Borer, *Etiella zinckenella* (Treit.) (Lepidoptera: Pyralidae)

The pea pod borer is distributed between 46°N and 45°S, occurring in several countries including India. It is a serious pest of common bean, soybean, lima bean, cowpea, pigeon pea, mung bean, pea and lentil (Singh and van Emden 1979; COPR 1981). In India, it has been recorded as a major pest of field pea and lentil (Singh and Dhooria 1971) and damages 5-15% of the lentil pods (DPR 1988). So far this pest is reported to be serious in Punjab and occasionally in Uttar Pradesh.

Damage
Young larvae feed on blossoms and young pods that drop. Older pods show a brown spot where the larva has entered. In the advanced stages of larval development, two to four pods are webbed together. Seeds are partially or entirely eaten, and notable fross and silk is present. The infestation of 12 to 15% in the lentil pods results in an approximate reduction of 11% in grain yield (Singh and Dhooria 1971).

Biology
Singh and Dhooria (1971) reported the bionomics of *E. zinckenella* in detail. In the north of India, five broods occur in a year. A female moth lays an average of 70.4 ± 1.8 eggs.

The egg, larval, pupal and adult stages last for 5, 13, 15 and 5 days respectively. The life cycle is completed in 44 days. The moths are attracted to light.

Management

Out of 809 lines of lentil screened in Punjab, 84 showed consistently less than 10% pod infestation (Kooner *et al.* 1978). In comparison with the check L 9-12, selections P 927 and P 202 showed 80 and 72% lower rate of pest incidence, with 53 and 44% higher yields respectively (Chhabra 1981). Lentil entry LL 56 also had lower pod borer damage in Punjab (DPR 1988). Natural enemies of the pest have been recorded, such as *Bracon piger* Wesm., *B. pectoralis* Wesm. and *Phanerotoma planifrons* in Europe, and *Exeristes roborator* (F.) in Egypt (Hammad 1978).

The use of cypermethrin, endosulfan, methomyl, monocrotophos, permethrin, pirimiphos-methyl, tetrachlorvinphos and trichlorphon has been suggested (COPR 1981).

Storage Insect Pests

Three bruchid species—*Callosobruchus chinensis* (L.), *C. analis* (F.) and *Bruchidius minutus* F.—have been reported to infest lentil seeds in India. *Bruchidius minutus*, being univoltine, is less damaging than the other two, which are multivoltine species. Lentil seeds may be attacked in their pods, in the field and in storage. The eggs are glued by the female to the surface of matured seed or pod or they are laid loosely around pods or seed. The pre-harvest oviposition on the pod becomes an important source of infestation in storage (Pandey *et al.* 1983).

Bruchid-infested lentil seeds lose their food value and germinability. Laboratory studies on the oviposition preference and development of the immature stages of *C. chinensis* in India showed that the number of eggs laid on lentil plants averaged 60 to 65, with an adult emergence of 71 to 73% (Singh *et al.* 1977). Similarly, the loss in weight after 3 months by releasing 50 pulse beetles of *C. chinensis* (2-3 days old in 100 g seed) was 14% (Rajak and Pandey 1965). In addition, lentil has been reported as the preferred host of *C. analis* by Yadav (1985).

It is possible to protect the seed chemically, either by fumigant or by admixture of insecticides like Malathion to the grain (Srivastava and Dadhich 1973). Pirimiphos-methyl, Iodofenphos, Fenitrothion or chlorpyrifosmethyl are also effective. They can be used safely as disinfestation spray on the walls of store, floor and other surfaces at a rate of 1 g ai/m^2 and on the outer surface of sacks at 0.5 g ai/m^2. The use of edible oils at 5-10 ml/kg of seed is highly effective. Similarly, fine powdered clay soils, such as attapulgite and soapstone, can be used effectively in seeds stored for food or feed. The use of moth balls (paradichloro-benzene) also prevents infestation and fumigation with phosphine (aluminium phosphide) or methyl bromide is also effective. However, great care should be taken to ensure the safety of man and animals when fumigants are used (WFP 1983). The dehulled split seeds (*dhal*) are less attacked by bruchids than the whole seeds.

Other Pests

Other minor insect pests reported on lentils in India are: *Lampides boeticus* (L.), *Spodoptera litura* (F.), *S. exigua* (Hb.), *Trichoplusia ni* (Hb.), *Nezara viridula* (L.), *Bruchus lentis* F. (Hariri 1981), *Phytomyza horticola* Gourean, *Ophyomyia phaseoli* (Lal *et al.* 1980), *Helicoverpa armigera* (Hb.) (Garg 1987), *Acyrthosiphon pisum* (Harris) (Lal *et al.* 1985), *Bemisia tabaci* Genn., *Empoasca kerri* Pruthi, *Megalurothrips distalis* (Karny) and *Madurasia obscurella* Jaq. (S.S. Lal, pers. comm.).

Conclusions

The application of fungicides and insecticides has been found effective and recommended in many cases. However, looking to the increasing problem of environmental pollution, we should limit their use to unavoidable circumstances only. At present, the use of chemical sprays, especially fungicides, may not be acceptable to the Indian lentil grower.

There is a need to concentrate efforts for identifying reliable sources of resistance against wilt, rust and powdery mildew as well as insect pests. Resistance has been observed against diseases but in most cases screening has been done under natural infections. There is a need for more systematic screening under artificially inoculated conditions, with a uniform disease grading scale. Variability in most pathogens has been indicated. Efforts should be made to standardize differentials and to identify races or strains, if any.

For the control of root diseases, there seems to be much potential for research on cultural and biological control. Several antagonists have shown promise, but their field value has yet to be established through standardizing techniques for their use on a large scale.

Information on virus and nematode diseases is very meager. The same is true for the field insects on which only a few references are available. Systematic survey work is needed to assess the extent of infestation and the damage being caused by them. Except for one report from Punjab, no work has been reported on host resistance against insect pests.

It is now an appropriate time to consider the establishment of centers of excellence to solve the problems specific to lentil production, to evolve new varieties with multiple disease resistance and to develop and analyze the chemicals commonly effective against diseases and insects.

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Discussion

M.M. Rahman
Do you think that the wash of the plant debris affected with rust can be sprayed on the plants to create disease pressure for screening against rust?

S.C. Agrawal
Normally aecial and uredial stages are killed in the field but teliospores resist the heat. In India, the fresh crop gets infection from teliospores. If stored properly, the telial stage may be tried. I have not yet used it for creating epiphytotics.

I.A. Malik
It has been observed that by growing lentil continously in the same field a marked reduction in the yield occurs without any symptoms of diseases or pests. Is it due to some allelopathic effects? How can we explain such yield reductions?

S.C. Agrawal
I think it may be due to some nutritional (microelement) imbalance in the soil due to growing the same crop continuously. Evidence of phytotoxic metabolites exuded from lentil roots is not available.

M.C. Tyagi
Do we have any report regarding control of diseases by seed treatment with fungicides?

S.C. Agrawal
Application of pesticides in soil is not advisable because of possible pollution problems although pesticides may control root diseases. Control of wilt, collar rot and root rot of lentil occurring at early stages is achieved by seed treatment with benomyl (3 g/kg seed) or Thiram + carbendazim (1:1) (2.5 g/kg of seed). MBC, a degradation product of benomyl, has been detected in plants grown from treated seed up to 45 days after sowing.

B. Sharma
How much reliance can one put on your conclusions about resistance to wilt based on field observation and not under controlled epiphytotic conditions?

S.C. Agrawal
At present we do not have any good wilt-sick plot for lentil. The entries/varieties which I mentioned as resistant have had a consistent resistant reaction for at least three or more seasons at most of the centers. Some of them have been tested under pot culture conditions also. There is little chance of their being susceptible. However, I strongly feel that good wilt-sick plots should be developed at some selected centers for more reliable screening. Variability in the wilt pathogen is indicated, which should also be kept in mind.

M. Abu Bakr
What differentiates the symptoms of Ozonium wilt and Fusarium wilt?

S.C. Agrawal
Ozonium sp. infects the plant at the collar region where white cottony fungus is seen. Epidermis and cortex rot and become soft. Vascular tissues are also involved and yellowing of plant is from the top. With Fusarium wilt no fungal growth is seen on the root surface, but it turns yellowish brown. Yellowing of the plant starts from the lower side. Xylem vessels are discolored brown.

M. Abu Bakr
How many races of *Fusarium* f.sp. *lentis* have so far been identified in this region?

S.C. Agrawal
In Madya Pradesh 14 isolates of *F. oxysporum* f.sp. *lentis* were differentiated at Sagar and 8 at Jabalpur on the basis of their cultural characters, nutritional requirements, etc. In Rajasthan three isolates were differentiated. There is a need to evolve differentials and identify the race differentiation, if any.

M. Ali
Do you have any information on associative effects of crops grown in mixed stands with lentil on the incidence of insect pests and diseases?

S.C. Agrawal
No information is available on effect of intercropping or mixed cropping on lentil diseases or insect pests but lentil wilt is adversely affected if paddy or sorghum is grown in the autumn. However, if paddy or sorghum crop stubbles are left in the soil then collar rot incidence is increased.

P.P. Singh
Has there been any research on effects of root diseases on useful organisms such as *Rhizobium* and vice versa? Can this kind of relationship be useful for controlling disease?

S.C. Agrawal
Infection of lentil roots by most pathogens causes a reduction in nodulation but it is not known whether it is due to interaction of two organisms or injury caused to the root by

the pathogen. Antagonistic organisms like *Trichoderma harzianum*, *T. viride* and *Bacillus subtilis* have been used to control wilt and collar rot diseases under pot culture. They should be exploited for use on a large scale in the field. Soil amendments may help in increasing the population of antagonists in soil.

W. Erskine
What lentil plant protection problems do you expect in the *utera* rice-based system and in the replacement of fallow with lentil in rice/fallow cropping systems?

S.C. Agrawal
In my opinion, paddy fields have poorly aerated soil in which soil pathogens will have little chance to survive. However, diseases like powdery mildew, Alternaria and Stemphylium blight and rust may become serious. Since the paddy stubbles will remain in the field and sowing of lentil will be early in *utera* they may increase the incidence of collar rot. Secured germination may result in high plant population. It may enhance the attack by *Sclerotinia sclerotiorum*.

S. Baldev
What is the reason for no or less incidence of wilt in irrigated fields in genotypes which have some degree of resistance?

S.C. Agrawal
No study has been done on this aspect except that the disease is maximum at 25% soil moisture and reduces significantly with increase in moisture content. It happens in light soil as well as clay soils. Thus it can not be assigned to mechanical injury to roots due to cracks in drying soil which make the entry points for the pathogen. Sandy loam does not crack on drying. Perhaps lentil wilt is the combined effect of the action of pathogen and moisture stress. High water content in the soil may also dilute the toxins produced by the pathogen in the plant. It requires investigation.

S. Baldev
It there any information about water need of susceptible vs. resistant lentil varieties?
S.C. Agrawal
No information is available on water requirements of wilt-resistant and susceptible varieties.

S. Baldev
What is the mode of application of fungicides for the control of wilt?

S.C. Agrawal
Wilt is reported to be controlled by seed treatment and/or soil application of benomyl. Since, the degradation product of benomyl (MBC) is detected in lentil plants up to 40 days after sowing, it probably checks the infection during this period. It also eliminates the pathogen present in the spermosphere zone. However, protection of plant from infection, at an advanced stage, is not possible by seed treatment. Soil application is neither economic nor feasible on a large scale.

Plant Protection of Lentil in Pakistan

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Abstract

Lentil is the second most important pulse crop in Pakistan. Lentil production is often limited by the key diseases Fusarium wilt, rust, Ascochyta blight, Sclerotium collar rot and Rhizoctonia root rot. Screening for resistance to Ascochyta blight and rust is being undertaken within the national breeding program, but resistance to Fusarium wilt is not known. Studies on chemical control have highlighted the value of seed treatment by Benlate and Captan in controlling seedling wilt; Benlate, Dithane M-45 and Ridomil sprays in reducing rust losses; Daconil, Topsin-M and Artracol sprays in reducing Ascochyta losses; Captan and Ridomil as seed treatment for both Sclerotium collar rot and Rhizoctonia root rot. The biological control of Fusarium wilt and root rot with *Trichoderma harzianum* and *Arachniotus* sp. in pots is reported. Among minor diseases in Pakistan, Botrytis gray mold and stem rot are becoming more important in wetter areas.

Introduction

Lentil (*Lens culinaris* Medikus), locally known as *masoor*, is the second most important pulse crop of Pakistan and is cultivated on marginal lands with low fertility. The crop is grown mainly in the *rabi* season, sown in October or early November and harvested in March-April. It is cultivated over an area of 75 500 ha, which constitutes about 6% of the total area under pulses and 0.41% of the total area under all crops. The annual production of the crop is 32 800 tonnes with an average yield of 434 kg/ha (Anonymous 1989). Average crop yield at the national level is very low, about one-half of that in the world; this may be attributed to various agronomic, environmental and pathological factors. The important diseases that affect the production of lentil in Pakistan are Fusarium wilt, Uromyces rust, Ascochyta blight, Sclerotium collar rot and Rhizoctonia root rot. However, the minor diseases like Botrytis gray mold, Sclerotinia stem rot, anthracnose and root knot, depending upon the locality and environmental conditions, may occasionally create an alarming situation (Bashir and Malik 1988). Lentil protection against these diseases had remained a neglected field until the start of the national food legume research program in the early 1980s. Progress since then is summarized below.

Wilt

Lentil wilt, caused by *Fusarium oxysporum* f.sp. *lentis* Snyder and Hansen, is a common disease in most of the lentil-growing areas where temperatures are high. Low fertility and poor sandy soil predispose the plants to wilt. The disease occurs both at seedling and flowering stages. In early sown crops wilting may occur in November, but the disease ceases during the cool months of December and January. In February it starts to reappear and maximum incidence of the disease is observed in March (Bashir and Malik 1988). Nothing is known about the extent of losses caused by lentil wilt in Pakistan. However, the severity of the disease varies from year to year and depends probably upon soil temperature and soil type. Management of the disease is rather difficult and expensive owing to the soil-borne nature of the pathogen. Resistance in lentil cultivars is scarce and there are no organized efforts directed, so far, toward screening lentil germplasm against wilt. There is a need to develop wilt-sick plots to identify resistant sources which could further be exploited for the development of resistant commercial cultivars.

Studies on the chemical control of lentil wilt in Pakistan involved *in vitro* evaluation of various fungicides against mycelial growth and conidial production of the pathogen, and the effect of seed treatment and drench application in the soil on seedling wilt (Khalid 1990). Consequently, it has been found that Benlate, Captan, Dithane M-45 and Liromanzeb were the most effective fungicides, in that order, in inhibiting the growth of *F. oxysporum* f.sp. *lentis* and its conidial production, while Topsin-M, Antracol, Polyram combi and Bavistin were the least effective. Dry and slurry treatment of lentil seed revealed Benlate and Captan to be the most effective, while Dithane M-45 and Liromanzeb appeared to be intermediate in controlling seedling wilt. Benlate and Captan drenches at dosages ranging from 50 to 500 ppm have been found to be effective in controlling the disease.

Since chemical control of the disease is expensive, the possibility for the biological control of lentil wilt by the use of antagonistic microbes has been investigated (Akhtar 1989; Aslam 1989). It was found that the addition of *Arachniotus* sp., *Trichoderma harzianum* and unidentified fungal isolates No. 6 and No. 35 to sterilized soil reduced wilt incidence by 23 to 83%. *Arachniotus* sp. displayed the best performance and reduced disease incidence by 93%, followed by *T. harzianum* which reduced disease incidence by 78%. The addition of 1% organic matter (wheat straw) to the soil enhanced the activity of the antagonists. Complete control of the disease was achieved when *Arachniotus* sp. or *T. harzianum* were used supplemented by chopped wheat straw along with 1% N_2 urea + 1% glucose + 1% K_2SO_4 or 1% N_2 urea + 1% K_2SO_4 + 0.01% $MgSO_4$.

Rust

Lentil rust caused by *Uromyces fabae* (Pers.) de Bary is a common disease in the foothill districts of Pakistan where rainfall is relatively high (Bashir and Malik 1988) but in certain years of high rainfall it may be observed as far in the south as Faisalabad district.

It infects all aboveground parts of the plant and may lead to premature defoliation and death of the affected plants, reduced seed size and heavy yield losses. There are no documented surveys to indicate the magnitude of losses caused by lentil rust. However, the significance of the disease to lentil production was recognized after the mid-1980s and consequently efforts have been directed toward the screening of lentil germplasm against Uromyces rust.

In the 1987/88 crop season, 50 lentil varieties/lines were screened at the Pulses Directorate, Ayub Agricultural Research Institute, Faisalabad, for rust reaction under natural epidemic conditions. Twenty-five entries remained free from disease, perhaps simply by escaping attack (Anonymous 1988a); however, their further response toward rust could not be evaluated because of the rust-free year that followed. In the crop year 1989/90, 86 entries were screened against rust and 2 lines (ILL 354 × M-85-4 and 89511) were found to be resistant, whereas the following were moderately resistant: ILL 4354 × 18-12, ILL 4400 × 18-12-46, ILL 4400 × 18-12-65, 86511, 86592, 86593, 86599, 88505, 88506, 88512, 88516, 88520, 88521, 88522, 88525, 88531, 88532, 88531, 88537, 88546, 89503 and 89518 (Anonymous 1990).

In another disease-screening nursery, the following were found resistant among 308 test lines: AARIL 43, 114, 121, 123, 134, 154, 163, 164, 176, 189, 194, 228, 230, 232, 241, 242, 245, 262, 263, 264, 265, 270, 271, 272, 322 and 323. Another 91 lentil lines were moderately resistant (Anonymous 1990).

Asif (1990) screened 48 lentil lines at the University of Agriculture, Faisalabad where 8 lines were found to be resistant, 10 moderately resistant, 11 moderately susceptible, 11 susceptible and 8 highly susceptible. The resistant lines were AARIL 114, 121, 123, 134, 230, 232, 241 and 270. In addition to germplasm screening, Asif (1990) also evaluated the effect of fungicides on the disease and reported Benlate, Dithane M-45 and Ridomil to be effective in reducing rust incidence.

Blight

Lentil blight caused by *Ascochyta lentis* Bond. and Vasil. was first observed to occur in Pakistan in 1982 on a lentil crop at the National Agricultural Research Center (NARC), Islamabad (Khan *et al.* 1983), while Malik (1983) reported 30-40% damage to the crop by this disease. These earlier reports, besides identifying the symptomatology of the disease, also indicated the seed-borne nature of the pathogen and its role in the survival and carryover of the pathogen from season to season. During the 1984/85 crop season, a severe epiphytotic of the disease was observed at NARC, Islamabad (Iqbal *et al.* 1990a) and in subsequent years the disease spread south as far as Sialkot and Faisalabad districts of the Punjab province. This situation called for the management of the disease and refocused the attention of lentil breeders and pathologists on the screening of lentil germplasm and the identification of fungal toxicants against the disease or its causal agent.

Lentil germplasm screening against blight in Pakistan was simultaneously started at the Pulses Section, NARC, Islamabad and at the University of Agriculture, Faisalabad in the mid-1980s. As germplasm screening requires mass multiplication of the inoculum of *Ascochyta lentis*, a variety of legume meal agar cultures and legume seed cultures have been evaluated for quick mass culturing of the inoculum. Subsequently it was found that among the various legume meal agar media, chickpea seed meal agar and lentil seed meal agar media were the best for luxuriant spore production by *A. lentis*, while among the various legume seed cultures evaluated, chickpea, lentil, faba bean, peas, soybean and cowpea seed were found to be the best substrates for quick mass culturing of the inoculum of *A. lentis*. Culturing the inoculum of *A. lentis* on various legume seeds usually took a much shorter period, 5-8 days, than that taken by the fungus on seed meal agar media, 20-25 days (Anonymous 1987a).

Lentil germplasm screening at NARC, Islamabad against *A. lentis* is practised annually both under natural epiphytotic conditions and in artificially created epidemics in disease-screening nurseries. In these nurseries the test material includes local and exotic lentil germplasm lines received from various institutions within the country as well as from abroad. Thus, out of 154 lentil lines tested during the 1985/86 crop season, 2 lines (L-355 and L-356) were selected as resistant to blight disease. The same year, out of 800 local and exotic lines screened under natural epidemic conditions in the field, 12 lines with the ILL numbers 21, 29, 219, 1683, 1684, 1685, 1686, 1687, 1680, 1682, 1732 and 1733 were selected as resistant. In addition to the above lines, ILL-547a, ILL-548, ILL-582, ILL-3516, ILL-3614, ILL-5709, ILL-6003, ILL-6016, ILL-6024, ILL-6037 and Precoz also were found to be resistant, out of four different lentil screening nurseries of ICARDA, Syria, tested under natural epidemic conditions (Anonymous 1986).

During the 1986/87 crop season, three lentil lines (LP-1, LP-2 and Precoz) were found to be resistant to Ascochyta blight (Anonymous 1987b). The crop season 1987/88 had two blight nurseries, NARC blight nursery and LIABN from ICARDA. Out of 49 entries of the NARC blight nursery L9-12 × 74TA441, 74TA441 × Pant-L.234, FLIP 84-78L, FLIP 84-145 L, L9-12 × Giza 9, FLIP 84-60 L, FLIP 84-147 L, FLIP 84-49 L, FLIP 84-81L, FLIP 85-35L, FLIP 84-83 L, FLIP 85-4L and Jordan local × B-77 were found to be resistant. Out of 31 entries LIABN of ICARDA, ILL 358, LG 41, UJL-81129, Lenka, 78S26038, FLIP 84-44L, FLIP 84-55L, FLIP 84-80L, FLIP 84-95 L, FLIP 88-33 L and Flip 84-12L were resistant lines (Anonymous 1988b). A recent study at NARC has reported 17 resistant and 40 moderately resistant lines out of a germplasm collection of 152 cultivars. The reportedly resistant lines are: Precoz × 830-2, Precoz × L830, Precoz × 74TA9, Precoz × L830-1, Precoz × L 830-2, ILL 5562, ILL 936, FlIP 84-49L, ILL 358, Lenka, 78S26018, 78826052, FLIP 84-43L, FLIP 84-85L, FLIP 84-55L and FLIP 86-12L (Iqbal *et al.* 1990a).

Germplasm screening at the University of Agriculture, Faisalabad identified lentil lines 33121, 33831, ILL-4605, E.4-1, E.8-6, E.8-10, E.11-12, E.11-13 and E.17-1 as resistant to Ascochyta blight in a greenhouse evaluation, while lines 33661, 33704-1, 85S33201, E.2-6, E4-1, E.8-6 and E.11-12 were resistant in the field (Anonymous 1987a). Observations from the lentil blight nursery of the 1990/91 crop season indicated that line 3118 was resistant while 86591 was moderately resistant to the disease (Rehman 1991).

In an *in vitro* study using the poisoned food technique (Bashir *et al.* 1986) at NARC, Islamabad, 12 fungicides were evaluated separately, and in combinations, for their fungitoxic effect on the growth of *A. lentis* at 100 μg/ml dosage rate. They found that mycelia of *A. lentis* were the most sensitive to, and were 100% inhibited by, Tecto-60, Benlate, Calixin M, Captan, Antracol, Topsin M, Vitavax, Calixin M + Benlate and Calixin M + Topsin M. However, spray evaluation of various fungicides at NARC showed Benlate, Tecto-60 and Daconil to be equally effective fungicides for the control of lentil blight (Anonymous 1988b). Ilyas and Khan (1990) at the University of Agriculture, Faisalabad found that the most effective fungicides in inhibiting *in vitro* growth of *A. lentis*, in descending order, were Tilt, Benlate, Topsin-M and Daconil. Tilt completely (100%) inhibited fungus growth at 5 μg/ml while Benlate and Topsin-M completely inhibited growth at a 50 μg/ml dosage rate. The least effective fungicides were Nemispore, Ridomil and Dithane M-45, while Rhizolex, Topas C-50 and Polyram combi displayed intermediate effectiveness. Out of seven fungicides tested as foliar sprays, Daconil, Topsin-M and Antracol gave good control of the disease, with significant increase in yield (Anonymous 1986).

Iqbal *et al.* (1989) while evaluating seven fungicides (Antracol, Benlate, Cobox, Daconil, Dithane M-45, Tecto-60 and Topsin M) as foliar sprays on the susceptible cultivar Masoor-85 found that three sprays of Benlate and Daconil at 0.2% concentration significantly reduced the disease severity. Benlate also proved effective in increasing the yield of lentil by 81%. Studies of the effect of nine fungicides by Rehman (1991) on mycelial growth of *A. lentis* revealed that Score-250 was the most effective in inhibiting the growth of the fungus. Spotless and Topas-100 were comparatively less effective than Score-250. In the greenhouse evaluation, Score-250, Topas C-50 and Spotless were the most effective, while in the field Score-250 and Tilt, at a 0.2% dosage rate, were the most effective fungicides in reducing blight rating. Thus, Score-250 was the most effective fungicide both in the greenhouse and field evaluation.

Sclerotium Collar Rot

Collar rot of lentil caused by *Sclerotium rolfsii* Sacc. was first observed in Pakistan in lentil plots at NARC, Islamabad (Bashir *et al.* 1987). The affected seedlings were wilted and rotted from the collar region downwards. The roots of the plants were associated with white fungal mycelia. When young plants were attacked they died quickly and when older plants were attacked, they gradually turned yellow, wilted and died (Bashir and Malik 1988).

Ali and Ilyas (1989) at the University of Agriculture, Faisalabad carried out some studies on the growth physiology of *S. rolfsii* and found that the fungus grew most (85.5 mm in 144 hours) on potato dextrose agar and produced the maximum number of sclerotia (1000 in 21 days), whereas it grew the least on the water agar medium (15 mm with only 9 sclerotia/petri plate). Richard's agar medium and Basal medium, although less efficient than the potato dextrose agar, also supported the growth of the fungus (64.5 and 74.5 mm respectively); however, the latter was statistically better in supporting growth and sclerotia production (578 sclerotia on Basal medium in comparison with 28 sclerotia on Richard's agar medium). *Sclerotium rolfsii* preferred basic pH and it grew most (83.5 mm in 120 hours) and produced the maximum number of sclerotia (637/petri plate in 21 days) at 7.5 pH. Above and below pH 7.5, the growth and sclerotia production of the fungus decreased significantly. Also, the fungus did not grow at 15 and 20°C even after 120 hours of incubation. It grew at 25°C and above, and 30°C was found to be the optimum for its growth. Above and below 30°C the growth decreased. Continuous light (24 hours a day) was found to be more suitable than continuous darkness or 12 hours light alternating with 12 hours darkness for the growth of *S. rolfsii*. However, the fungus produced the maximum number of sclerotia (804/petri plate), when its culture was exposed to 12 hours light alternating with 12 hours darkness.

The screening of 196 lentil germplasm lines for resistance to collar rot revealed 32 resistant lines such as PAK No. 40622, 40623, 40629, 40634, 40640, 40644, 40652, 40665, 40682, 40692, 40704, 40748, 40754, 40759, 40766, 40771, 40774, 40887, 40795, 40823, and ILL No. 1, 561, 698, 789, 1825, 1830, 2555, 2557, 4876, 5699, 5700 and 5770 (Anonymous 1988b).

An evaluation of various fungicides as seed treatment revealed Captan and Vitavax to be effective against collar rot (Anonymous 1986). Shahid *et al.* (1990), while working on the chemical control of collar rot, made the following observations: Captan and Ridomil were the most effective; Bayleton, Cupravit and Daconil were the least effective; Bavistin and Polyram combi exhibited intermediate effectiveness, in inhibiting the *in vitro* mycelial growth and sclerotial production of *S. rolfsii* when the fungus was grown on lukewarm Waksman's medium amended with the above fungicides at 10, 20, 50 μg/ml dosage rates.

The effect of fungicides on the germination of sclerotia revealed that Benlate and Ridomil were the most effective, Dithane M-45 was the least effective and Captan was intermediate in its effectiveness for the inhibition of sclerotial germination. Suspension of Ridomil and Benlate at 500 μg/ml dosage rate when applied as seed treatment and soil drench gave 100% control of collar rot disease on lentil seedlings.

Rhizoctonia Root Rot

Lentil was first observed to be affected by *Rhizoctonia solani* Kuhn root rot at NARC, Islamabad during the spring of 1988/89 (Iqbal *et al.* 1990b). Foliage of the diseased plants was dull green at first, but later turned pale yellow and/or reddish brown. The lower leaves showed wilting and within a few days the wilting progressed upwards and ultimately the whole plant died. The roots of the affected plants were brown to reddish brown and showed rotting and shredding.

No systematic studies have been done on the prevalence of the disease or losses caused by it in the country. Similarly, nothing is known about the genetic response of the commercial cultivars to root rot disease. However, Khan (1990) conducted some studies on the chemical control of the disease and evaluated the effect of various fungicides on the growth of the fungus as well as the development of the disease. It was reported that *in vitro* growth, sclerotial production and sclerotial germination of *R. solani* were most effectively inhibited by Benlate, Ridomil, Captan and Dithane M-45. The least effective fungicides were Brassicol, Daconil, Bavistin and Polyram combi. Dry or slurry treatment of lentil seed with Ridomil and Benlate, planted after the soil was infested significantly, reduced the incidence of lentil root rot. Similarly, drenching the infested soil with Ridomil and Benlate significantly reduced incidence of the disease.

Studies on the biological control of root rot of lentil have been carried out by Khan (1989) in the Department of Plant Pathology, University of Agriculture, Faisalabad. These studies included the antagonistic effect of soil saprophytes on the *in vitro* growth of *R. solani*, the effect of seed treatment and the application of antagonists and soil supplemented by organic and inorganic substrates on the antagonistic control of the disease. The evaluation of the effect of 10 fungal isolates (three of *Aspergillus* sp., two of *Penicillium* sp., three unidentified isolates, one each of *Arachniotus* sp. and *Trichoderma harzianum*) on the *in vitro* growth of *R. solani* revealed that all the test isolates were antagonistic and, depending upon the isolate, inhibited 14-87% mycelial growth of the pathogenic isolates of *R. solani*. However, *T. harzianum*, *Arachniotus* sp., *Aspergillus* isolate No. 27 and an unidentified isolate No. 35 were the most antagonistic, and these inhibited 87, 58, 41 and 38% growth of the pathogen.

Lentil seed coating with each of these four antagonistic fungi and their sowing in *R. solani*-infested soil revealed that only *T. harzianum* and *Arachniotus* sp. significantly reduced root rot incidence, by 21 and 11%, respectively. However, the direct addition of each of the four antagonists in the form of agar blocks to sterilized pot soil infested with *R. solani* provided 74, 66, 47 and 36% root rot control by *T. harzianum*, *Arachniotus* sp., unidentified isolate No. 35 and *Aspergillus* isolate No. 27, respectively.

A study on the effect of such organic soil amendments as wheat straw, rice husk, maize straw and crushed sugarcane at the rate of 1% of soil weight revealed that wheat straw was the most effective substrate for *T. harzianum* and *Arachniotus* sp. and resulted in 15 and 20% increase in disease control, respectively. Addition of inorganic salts with wheat straw further increased the effectiveness of *T. harzianum* and *Arachniotus* sp. However, 100% control of the root rot was obtained when *T. harzianum* was added to the soil along with chaffed wheat straw amended with urea (1%) + $MgSO_4$ (0.01%) + KH_2PO_4 (0.02%). Similarly, 100% control of the disease was obtained when *Arachniotus* sp. was added to the soil along with chaffed wheat straw amended with urea (1%) + glucose (1%) + $MgSO_4$ (0.01%) + KH_2PO_4 (0.02%).

Minor Diseases

The minor diseases of lentil in Pakistan are Botrytis gray mold (*Botrytis cinerea*), stem rot (*Sclerotinia sclerotiorum*), anthracnose (*Colletotrichum lindemuthianum*) and root-knot nematode (*Meloidogyne incognita*), but Botrytis gray mold and stem rot are becoming more serious in the northern districts of Pakistan where rainfall is relatively higher

(Bashir and Malik 1988). No research work is being conducted on any of these minor diseases. However, at NARC, Islamabad, lentil germplasm is screened against Botrytis gray mold and Sclerotinia stem rot and some sources of resistance have been reported. For example, out of several hundred lines of local and exotic lentil germplasm the following were found to possess resistance to both Botrytis gray mold and Sclerotinia stem rot: ILL 21, ILL 29, ILL 219, ILL 1683, ILL 1684, ILL 1685, ILL 1686, ILL 1687, ILL 1680, ILL 1682, ILL 1732 and ILL 1733 (Anonymous 1986), whereas ILL-5527 × 113458, Laird × Precoz, ILL 5732, ILL 1939, ILL 5585 and LG-16 were resistant to stem rot only (Anonymous 1987).

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Plant Protection of Lentil in Bangladesh

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Abstract

As many as 16 diseases have been recorded on lentil in Bangladesh, of which three diseases have been recognized as the most significant: foot rot (*Sclerotium rolfsii*), rust (*Uromyces fabae*) and Stemphylium blight (*Stemphylium* sp.). It has been reported that seed yield can be reduced 24% by foot rot and 62% by Stemphylium blight. Seed dressing with Baytan 10 DS and Vitavax 200 at 0.25% dry seed were most effective against foot rot, while foliar spray with 0.2% Dithane M-45, wettable sulfur or 0.25% Ferbam were effective against rust disease. Rovral 50 WP as foliar spray at 0.2% effectively controlled Stemphylium blight. Rust can be avoided by early planting (within the first week of November). Five insect pests have been recorded on lentil of which the black aphid (*Aphis craccivora*) is considered to be the most threatening, particularly when sowing is delayed. Spraying of Malathion, Anthio, Rogor or Metasystox at 0.05% can control aphids. Lentil farmers in Bangladesh generally do not use any chemical control measures against pests or diseases although the yield of this crop can be significantly and economically increased with proper plant protection measures.

Introduction

Lentil is the most important pulse crop in Bangladesh because it has the highest consumer preference among all the pulses used in the country. It stands second only to *Lathyrus sativus* in area under cultivation. It is grown from November to March, on high and medium-high land of sandy loam texture. The average yield of lentil in Bangladesh is 763 kg/ha, which fluctuates widely from year to year because of several factors. The widespread occurrence of diseases and pests is considered a major constraint to successful lentil cultivation. Experimental results have shown that diseases can reduce the yield of lentil up to 62%. Efforts have concentrated on the establishment of suitable plant protection measures for increasing or stabilizing the average yield. The present paper reviews the progress achieved so far in the field of disease and pest management of lentil in Bangladesh.

Protection against Diseases

The first comprehensive list on pulse diseases in Bangladesh was published by Ahmed *et al.* (1981) in which only seven diseases were recorded for lentil. In a more detailed list,

Table 1. Lentil diseases recorded in Bangladesh.

Disease	Causal organism	Reference
Rust	*Uromyces fabae*	Talukdar (1974)
Stemphylium blight	*Stemphylium* sp.	Bakr and Zahid (1987)
Foot rot	*Sclerotium rolfsii*	Ishaque and Talukdar (1967)
Wilt	*Fusarium oxysporum*	Fakir *et al.* (1978)
Bushy stunt	*Mycoplasma*	BARI (1981)
Seedling damping-off	*Fusarium* sp., *Pythium* sp.	Fakir (1983)
Cercospora leaf spot	*Cercospora cruenta*	Talukdar (1974)
Leaf spot/leaf blight	*Alternaria* sp.	Ishaque and Talukdar (1967)
Leaf rot	*Choanephora* sp.	Ahmed *et al.* (1981)
Powdery mildew	*Oidium* sp.	Fakir (1983)
Downy mildew	*Peronospora* sp., *P. viciae*	Fakir (1983)
Pod blight	*Alternaria* sp.	Fakir and Rahman (1989)
Wilt	*Fusarium oxysporum*	Fakir *et al.* (1978)
Yellow mosaic	Bean yellow mosaic virus	Islam *et al.* (1970)
Leaf roll	Pea leaf roll virus	Ahmed (1985)
Root knot	*Meloidogyne javanica*, *M. incognita*	Mian (1985)
Nematode diseases	*Giconemoides* sp., *Tylenchus* sp.	Fakir (1983)

Fakir (1983) reported 11 diseases and Ahmed (1985) reported 14 diseases. After exploring all published literature in Bangladesh, the author has found that altogether 16 diseases have been recorded on lentil in Bangladesh, of which 11 diseases were caused by fungi, two each by viruses and nematodes, and one by a mycoplasma (Table 1). Out of these 16 diseases, the following three diseases were considered responsible for major reductions in yield: foot rot caused by *Sclerotium rolfsii*, rust caused by *Uromyces fabae* and Stemphylium blight caused by *Stemphylium* sp. In the following pages these diseases will be discussed in detail.

Foot Rot

Foot rot is generally caused by *Sclerotium (Corticium) rolfsii* Sacc. However, at times, the disease was found to be incited by *Fusarium* sp. also. It is otherwise called collar rot when symptoms are shown on older plants associated with the former pathogen.

The disease occurs in the field as patches of dead plants, most often at the seedling stage. The pathogen attacks the collar region of the plant. The infected plants droop, become chlorotic, quickly die and dry out. The pathogens are soil-borne and sometimes *Fusarium* sp. are seed-borne. The incidence of the disease has been observed to be higher in soil with initially high moisture content.

Management of the disease has been approached from different angles. Seedling mortality was found to be reduced appreciably both in pot culture and in the field, by seed dressing with Panoctin CG/450. Only 1.6% seedling mortality was recorded in the treated plots as opposed to 44.4% seedling mortality in the untreated plots (Fakir and Rahman 1989). In a similar study, Mortuza and Bhuiya (1988) reported pre-sowing seed dressing with Baytan 10DS and Vitavax-200 at 0.25% w/w of dry seed which was very effective in reducing the disease incidence. Baytan reduced the disease incidence up to 74% and Vitavax-200 reduced incidence to 39.8% (Table 2).

Table 2. Effect of fungicides in controlling foot and root rot disease of lentil (Mortuza and Bhuiya 1988).

Treatment	Infection/dead plants (%)			Reduction of disease (%)	Seed yield (t/ha)
	Seedling stage	Vegetative stage	Mature stage		
Calixin	31.6b	16.1b	1.0	7.5	0.3c
Vitavax-200	15.9a	14.5b	1.3	39.8	1.0a
Dithane M-45	28.5b	16.5b	0.6	13.6	0.9b
Baytan 10DS	8.0a	5.5a	0.2	74.0	1.2a
Bavistin	30.9b	16.5b	0.9	8.3	0.9b
Captan	31.1b	14.6b	1.2	11.0	0.9b
Control	30.4b	21.5c	0.8	0	0.8b

Means followed by different letters were significantly different at 5% level of probability.

Attempts have been made to control the disease by the application of different levels of N-P-K fertilizers and supplemental irrigation under field conditions. It was reported that the prevalence of the disease was apparently increased by the application of nitrogenous fertilizers. However, with one or two irrigations, these differences were statistically insignificant (Fakir and Rahman 1989). A similar study, conducted elsewhere in the country, produced identical results (BARI 1989).

Further studies have been conducted to establish the most suitable sowing date for avoiding diseases (BARI 1985; Fakir and Rahman 1989). It was observed that the incidence of the disease declined gradually when sowing was after the first week of November, but the incidence was higher in crops sown at the end of October or at the beginning of November.

It is very difficult to identify sources of absolute resistance against foot rot diseases. However, a few entries have been reported to be moderately resistant against *S. rolfsii* in a sick plot (BARI 1986).

Rust

Lentil rust caused by *Uromyces fabae* is one of the major diseases in Bangladesh. Talukdar (1974) was the first to report the disease in this country. The disease causes variable degrees of damage depending upon the time of onset of the disease, and it varies from year to year according to environmental fluctuations. High humidity, cloudy weather, and slightly above-average night temperatures (20 ± 2°C) are congenial for disease development.

In the field, the disease often emerges in areas with a dense canopy and luxuriant vegetative growth, forming aecial cups on the stem, leaves and pods, upon which uredo and teleuto pustules are gradually formed. In the case of severe infection, the leaves are shed and the plants dry up prematurely. It is not clear, however, which is the primary source of infection. The teleutospores on infected plant debris in the seed seem to act as primary inoculum (Grewal 1988). The probability of the presence of an alternate host also cannot be ignored. The fungus is autoecious and completes its life cycle on lentil plants only.

The disease generally occurs before mid-February in northwestern districts and before the end of January in the southern parts of Bangladesh. The disease can be avoided to a great extent by planting an early maturing cultivar such as L-5 within the first week of November in the north, and in the last week of October in the southern part of the country. Lentil cultivar L-5 matures in 100-110 days. The probable primary source of inoculum can be eliminated by properly cleaning the seed lots that contain any plant debris exhibiting teleutospores.

Earlier reports showed that seed treatment with Captan or Thiram at 2 g/kg dry seed was recommended to eliminate seed-borne inocula (Prasada and Varma 1984). Protective sprays with 250 ppm or 0.2% Dithane M-45 or wettable sulfur or 0.25% Ferbam have been reported to be effective in controlling the disease. Recent studies at BARI reveal that foliar sprays with Calixin-M demonstrated protection. Resistant sources from local and exotic genotypes also have been identified (Bakr 1989).

Stemphylium Blight

Stemphylium blight caused by *Stemphylium* sp. is becoming a serious threat to lentil cultivation. Occurrence of the disease was recorded during 1981 (RARS 1981) and further confirmed by Bakr and Zahid in 1987. Since then the prevalence of the disease is being monitored in farmers' fields. Preliminary studies have indicated that the disease can cause up to 62% yield reduction.

The disease emerges with the appearance of small pin-headed light brown to tan color spots on the leaflets. The spots enlarge rapidly, covering the entire leaf surface within 2-3 days. The foliage and twigs gradually turn dull yellow, giving a blighted appearance to the affected crop. The infected leaves shed severely, leaving only the terminal leaves on the twigs. The twigs bend down, dry up and gradually turn ashy white, but pods remain green. On careful observation white mycelial growth is seen on the infected twigs.

Preliminary studies on predisposing factors of the disease have shown that the pathogen initiates its infection when the ambient night temperature remains above 8°C, the mean day temperature goes above 22°C and the relative humidity inside the canopy goes up to 94%. The pathogen seems to be airborne. No report is available on its seed-borne nature, either externally or internally. The detailed etiology of the disease is yet to be studied.

An attempt was made to identify appropriate control measures of this disease. The application of Rovral 50 WP has been demonstrated to control the disease effectively when sprayed three times at an interval of 7 days starting from the initiation of the disease (Table 3). Also, studies have shown that the incidence of disease is lowered significantly when sowing is delayed beyond the 20th of November, but the yield of the late-sown crop is drastically reduced because of poor growth as well as heavy infection of rust disease.

Screening is underway for local as well as exotic lentil lines by using highly susceptible spreader rows in order to identify sources of resistance. Although sources of absolute resistance against the disease have not yet been found, several genotypes have shown good tolerance repeatedly for three consecutive growing seasons. These lines are L111-58, L107-37, L107-41, L125-14 and L111-71 (Bakr 1989).

Table 3. Effect of some foliar fungicides on the incidence of Stemphylium blight and yield parameters of lentil (Bakr 1989).

Fungicides	Disease score	Twig infect-ion (%)	No. pods/ plant	Seed wt. /plant (g)	Seed yield (t/ha)
Rovral (0.2%)	1.0 d	29.0 c	1263 a	2.5 a	1.54 a
Uniflow sulfur (0.4%)	2.3 c	57.0 bc	966 b	2.2 ab	1.18 c
Antracol (0.2%)	3.3 b	46.5 bc	954 b	1.9 ab	1.38 b
Dithane M-45 (0.2%)	2.5 c	46.8 bc	816 bc	1.7 b	1.39 ab
Control	4.0 a	72.3 a	623 d	1.2 b	1.21 c

Means followed by different letters were significantly different at 5%.

Insect Pests

A large number of insect pests have been reported to cause damage to lentils (Kawar 1979; Hariri 1981; Tahhan and Hariri 1982). Only a few of these have been recorded so far in Bangladesh (Gowda and Kaul 1982; Karim and Rahman 1989). However, all the insects identified in Bangladesh are not considered to be a major threat to lentils in the country. In general, problems due to insect pests are much less commonly encountered than those from diseases. The common insect pests of lentil observed in Bangladesh are discussed below.

Aphids

The aphid *Aphis craccivora* may be considered as the most significant field pest for lentil, although it is not a regular pest of the crop. Generally, infestation occurs in seasons of delayed sowing and is enhanced by prolonged cloudy weather, above-average temperatures and high relative humidity.

The insects attack leaves, buds, flowers and pods. They make colonies on the attacked portions and suck sap from the host. Aphids are efficient vectors of several plant viruses. They are delicate insects and can be controlled by spraying any of the contact chemical insecticides like Malathion, Sumithion, etc.

Pod Borers

Helicoverpa armigera and *Etiella zinckenella* have been reported to occur in lentil fields (Gowda and Kaul 1982), *H. armigera* more often than the latter. The light brown moths start to appear when the normal winter temperatures rise above 10°C during the night. Larvae feed on the leaves and flowers, but they particularly damage the green pods by making bores and eating the young seeds. In mature pods, seeds are partly eaten. Quality of the seed lots is reduced by the presence of partially eaten seeds.

No control measures against the insects have been reported so far from Bangladesh. Malhotra (1989), however, reported that the borers can be controlled by spraying endosulfan at flowering.

Green Stink Bug

The stink bug (*Nezara viridula*) is a highly polyphagous cosmopolitan insect pest. Nymphs as well as adults of this insect suck the sap from the stem, leaves and pods, causing deformation of the plant. However, this is not a serious pest of lentil in Bangladesh.

Cutworms

Cutworms *Agrotis ypsilon* and *Spodoptera exigua* are common soil pests. Caterpillars of the insect cause damage to the leaves and stems. By cutting the stem at base level, they inflict plant loss and thus lower plant stand. Initial attacks can be reduced economically by hand picking and destroying egg and larval masses. Severe stand loss due to cutworms can be prevented by spraying with methyl parathion quinalphos (0.05%) and an application of carbaryl, endosulphan, methyl parathion dust at 25 kg/ha (Gowda and Kaul 1982).

Grain Beetles or Bruchids

Bruchids are the most important storage pest of lentil. They also attack the grain in the field, which may lead to severe damage to a large quantity of the stored seeds, reducing germination and lowering the quality of the seeds. Among the various species of the pest, *Callosobruchus chinensis* has been reported to occur most frequently (Rahman 1989).

To avoid an attack, the seed lot for storage should be dried properly to bring the moisture content down to 9%. The use of a fumigant like phostoxin is a common practice in commercial storage by which 50-100 kg of seed can be fumigated using only one tablet in airtight containers or in store house. Generally, a 72-hour period was found sufficient to properly fumigate the seeds.

Future Research Approaches and Conclusion

Although several plant protection approaches against major diseases and pests have been discussed, there are still information gaps in some fields. There is almost no information on the race situation of *U. fabae* in this region. This information is essential for designing an appropriate breeding program for durable resistance. Alternate hosts of *U. fabae* have not yet been reported in Bangladesh or elsewhere. Similarly, the etiology of Stemphylium blight has also not been fully identified. To formulate an effective disease management package, more information on the epidemiology of Stemphylium blight as well as lentil rust is required.

While it may or may not be cost effective to apply fungicides as foliar spray on a legume crop like lentil, information on seed-dressing chemicals may be more useful for eradication of seed-borne infection. It will also give protection against seedling and root disease like foot rot, collar rot and wilt to finally improve plant stand. Efforts may be directed toward finding need-based fungicides, which should be capable of controlling foliar diseases in a single spray, or at most two, to economize cost of protection against the disease.

Host resistance offers the best means of protection against most of the diseases, but with lentil very little progress has been made in this direction. Efforts in developing multiple and durable disease-resistant cultivars should be given priority. A narrow range of genetic variability is a constraint to developing disease-resistant cultivars. Therefore, the already existing interinstitutional and interorganizational linkage for the exchange of genetic resources should be strengthened. This can be achieved effectively by setting up a regional network of cooperation among lentil scientists.

Very little information is available on the pest situation of lentils in Bangladesh although some general information is available on the protection against similar pests of other legumes. A rigorous survey should be made on the insect pests of lentils and their impact on grain yield. Considering the human health hazard, chemical approaches of pest control should be discouraged. On the other hand, an integrated approach of pest control should be encouraged. Efforts also should be directed toward the identification of cultivars resistant to insect pests.

It is envisaged that some of the protection measures discussed herein are suitable for farm level practice. Therefore, it is necessary to extend this information among the growers in order to minimize the losses caused by pests and diseases.

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Discussion

M.C. Saxena
You mention five sources of resistance to *Stemphylium* in your paper. Are they also resistant to rust? What is their pedigree? Can they be directly used for production in Bangladesh?

M.A. Bakr
Yes, they are also resistant to rust. The strains are L111-58, L107-37, L125-14 and L111-71. No, they are too late in maturity for direct use in Bangladesh conditions.

W. Erskine
For your information, ICARDA is producing a handbook of symptoms of lentil plant protection problems.

M.A. Bakr
I hope this will help in identification of diseases, particularly the wilt complex.

W. Erskine
To date, resistance to rust is holding from Morocco to Pakistan.

M.A. Bakr
We should verify this for the South Asia region.

W. Erskine
How do you distinguish in the field Botrytis and Stemphylium blights, both of which are reported from Bangladesh?

M.A. Bakr
They can be distinguished by the moldy growth on infected parts in Botrytis grey mold, which is not found in Stemphylium blight.

C.S. Saraf
For foot rot diseases, optimum seeding time is 10 November and for Stemphylium blight, optimum sowing time is beyond 20 November. How do you reconcile these?

M.A. Bakr
Although the Stemphylium blight can be escaped by planting after 20 November, the yield is drastically reduced by late sowing owing to less pod-setting as well as infection by rust.

S.C. Agrawal
How did you estimate losses in yield of lentil due to Stemphylium blight?

M.A. Bakr
By weekly spraying of Rovral 50 WP and comparing yields with those of unprotected plots.

B. Baldev
Both early sowing and late sowing favor foot rot. What could be the reasons for this?

M.A. Bakr
Early sown infection is due to high soil moisture and late-sown infection is due to high temperature at the pre-flowering stage.

B. Baldev
Plants shown in your slides appear to be extra tall. Is this normal in Bangladesh? What is the duration of vegetative growth?

M.A. Bakr
Early sown crops, if sown in optimum moisture condition and good soil fertility status, grow up to 50 cm tall, while in late-sown and stress conditions the plant height can come down to 25 cm.

Plant Protection of Lentil in Nepal

P.B. Karki

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Abstract

Lentil is the leading winter grain legume of Nepal. Gray mold, rust, wilt, root rot, nematodes, pod borers, thrips, bruchids and cutworms are reported to be the main biotic constraints to higher lentil production in the country. The screening of lentil germplasm to overcome some of these constraints has been initiated recently. The present status and future prospects of plant protection research of lentil in Nepal are briefly discussed.

Introduction

Lentil is the most important winter legume crop of Nepal. It is generally grown mixed with other winter crops, or relay cropped with rice. Its cultivation is mainly concentrated in the *Terai* foothills and Inner *Terai* regions of Nepal. However, with the development of suitable varieties, and applicable agronomic practices, the crop is gradually spreading to the hilly regions of the country.

Research on lentil, although begun in 1972, became strengthened only after the establishment of the National Grain Legume Research Program (NGLRP) at Rampur in 1985. However, most of the research to date has concentrated on varietal and agronomic aspects. In the past, no serious attempts have been made to initiate plant protection research. This paper reports briefly the present status and future prospects of plant protection research for lentil in Nepal.

Survey

Diseases

The first report of lentil diseases in Nepal was presented by Manandhar (1975). Wilt caused by *Fusarium oxysporum* f.sp. *lentis*, rust caused by *Uromyces fabae* and dry root rot caused by *Macrophomina phaseoli* were the only diseases recorded in Nepal until 1975 (Manandhar 1975). Subsequently, a few more diseases such as nematodes (Manandhar and Amatya 1988), cucumber mosaic virus (NGLRP 1989) and Botrytis gray mold caused by *Botrytis cinerea* (Neupane and Shrestha 1990) were added to the list. Among the four nematodes reported, *Helicotylenchus* and *Tylenchus* were more

Table 1. Diseases associated with lentil in Nepal.

Disease	Causal organism	Reference
Wilt	*Fusarium oxysporum* f.sp. *lentis*	Manandhar (1975)
Rust	*Uromyces fabae*	Manandhar (1975)
Dry root rot	*Macrophomina phaseoli*	Manandhar (1975)
Cucumber mosaic virus	CMV	NGLRP (1989)
Botrytis gray mold	*Botrytis cinerea*	NGLRP (1989)
Nematodes	*Helicotylenchus, Tylenchus, Criconemoides, Aphelenchus*	Manandhar and Amatya (1988)
Collar rot	*Sclerotium rolfsii*	Karki (unpublished)

commonly found than *Criconemoides* and *Aphelenchus* (Manandhar and Amatya 1988). The incidence of collar rot caused by *Sclerotium rolfsii* was widely observed during field trips to different research stations: Nawalpur, Parwanipur, Rampur, Nepalganj and Surkhet (pers. observation). The list of lentil diseases recorded in Nepal is presented in Table 1. Information regarding the extent of losses caused by these disease is unavailable.

Insects

Cutworms (*Agrotis* sp.), defoliating caterpillar (*Spilaretia* sp.), aphids (*Aphis* sp.), pod borers (*Heliothis* sp.) and bruchids (*Bruchus* sp.) were reported in lentil in Nepal (Rachie and Bharati 1985).

The incidence of the above diseases and insects was documented during field trips organized mainly for other purposes. However, an intensive survey over an entire growing season for several years in different parts of the country seems to be vital for the correct listing of diseases and insects. Also, losses due to these factors need to be established in order to priorize future research.

Control Measures

Host Resistance

Lentils are generally grown on marginal lands, with a minimal level of management. The control of diseases and insects through the application of chemicals does not seem to be feasible. Therefore, host plant resistance has been the most widely used method of control. Previously, varieties resistant to the biotic and abiotic stresses were selected directly from the yield trials (NGLRP 1988, 1989, 1990). However, separate nurseries designed for screening against some of the diseases have been started recently.

Wilt/root rot
Screening of lentil for wilt or root rot resistance began in 1989. During the 1989 crop season, a total of 30, 34 and 14 genotypes were screened at Khumaltar (Neupane and Shrestha 1990), Rampur (Karki, unpublished) and Lumle (Kadayat *et al.* 1990) respectively. The tested genotypes exhibited a wide range of variability for resistance to these diseases (Table 2). A number of resistant or tolerant genotypes were identified at all these locations (Table 3).

Table 2. Reaction of lentil genotypes to wilt/root rot at Rampur, Khumaltar and Lumle, 1989/90.

Location	Genotypes tested	Plants affected (%) 0-10	11-20	20-50	Reference
Rampur	34	9	12	13	Karki (unpublished)
Khumaltar	30	6	17	7	Neupane and Shrestha (1990)
Lumle	14	4	4	6	Kadayat *et al.* (1990)

Table 3. Lentil genotypes reported resistant to wilt/root rot at Rampur, Khumaltar and Lumle, 1989/90.

Location	Genotype	Reference
Rampur	Simal, LN 0038, Aarial, LG 198, Raxaul, T31, Pant L 406, LO229-9, ILL 2580	Neupane and Shrestha (1990)
Khumaltar	ILL 6256, ILL 6260, ILL 6316, ILL 6813 ILL 6819, ILL 6820	Neupane and Shrestha (1990)
Lumle	LL 1, ILL 4377, Simrik, 18-10	Kadayat *et al.* (1990)

Confirmation of resistance in these genotypes, in addition to monitoring for the causal pathogen, will be carried out in future. Multilocation testing of the materials will be initiated in order to identify genotypes with broad-based resistance, as well as to monitor the pathogenic variability in the causal organism.

Root-knot nematode
A total of 16 lentil germplasm accessions were screened in a highly nematode-infested plot at Rampur in 1990 (Karki, unpublished). None of the genotypes tested showed a resistant reaction (Table 4). However, genotypes ILL 2578, ILL 4402, Aarial, 87S 9011 and Simal had a gall index ranging from 11 to 30%.

Table 4. Reaction of lentil genotypes to root knot nematode at Rampur 1990 (Karki, unpublished).

Gall index	Genotype
0	None
1-10	None
11-30	Aarial, LO 222-9, ILL 2578, ILL 4402, Simal, 87S 9011
31-50	LG 198, ILL 2580, LN 0038, Pant L 406, Pant L 866, Mahor, 87S 9052
50-100	Raxaul, T31, 87S 9092

Botrytis gray mold
Gray mold caused by *Botrytis cinerea* has been reported as one of the major yield-limiting factors in chickpea production in Nepal (Reddy *et al.* 1988; Karki *et al.* 1989). The disease is also reported in lentil (Neupane and Shrestha 1990) and may pose a serious threat to lentil production in the future. Therefore, with the objective of selecting disease-resistant genotypes, nurseries were set up during the cropping season of 1989 at Khumaltar and Rampur.

The incidence of the disease was high in the nurseries at both locations (Table 5). Out of 70 genotypes screened at Khumaltar, 24 genotypes were found resistant. Similarly, of the 32 genotypes tested at Rampur, the genotypes Aarial, ILL 2580, LG 171, LG 198, LN 0038 and Simrik were rated resistant (Neupane and Shrestha 1990).

Table 5. Reaction of lentil genotypes to gray mold at Khumaltar and Rampur, 1989/90 on a 1-9 scale (1 = resistant, 9 = highly susceptible).

Location	Genotypes tested	Resistant group			Reference
		1-3	4-5	6-9	
Rampur	32	7	16	9	Neupane and Shrestha (1990)
Khumaltar	70	24	29	17	NGLRP (1990)

Chemical Control

In general, no chemicals are used by Nepalese farmers for controlling diseases and insects in standing crops. However, in order to prevent the possibility of the spread of disease through seeds, seed treatment with Thiram or Bavistin (0.2%) is recommended and widely used in research stations. Likewise, the use of Malathion, Celphos and local materials such as neem leaves and ashes is becoming popular to control storage insect pests.

Conclusions

Lentil is affected by a number of diseases and insect pests. Based on various surveys, gray mold, rust, wilt/root rot, nematodes, pod borers, thrips, bruchids and cutworms are identified as the major biotic factors limiting lentil production. However, an intensive survey of the diseases and insects and loss assessments due to these factors needs to be undertaken to priorize future research activities. The use of chemicals for controlling diseases and insects does not seem to be feasible. Varietal screening for resistance to diseases has been established recently and should be strengthened in order to minimize losses due to these factors. An economical, integrated, pest management initiative should be devised for the future.

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Discussion

W. Erskine
Is resistance to aphids (*Aphis craccivora*) known in South Asia?

B. Sharma
Screening of large numbers of germplasm accessions emphasizes host preference rather than antibiosis.

I.S. Singh
Genetic differences in reaction were seen in lentil germplasm in Pantnagar.

M. Rahman
Genetic differences in reaction were seen in lentil germplasm in Bangladesh, but this may only be host preference.

W. Erskine
Please rank the diseases found in Nepal on lentil in order of importance from your experience.

P.B. Karki
Collar rot (*Sclerotium rolfsii*); Botrytis grey mold (*Botrytis* sp.); Wilt/root rot disorder; Rust; Nematode; CMV.

I.S. Singh
Would you kindly specify the reaction of cultivars in Nepal developed in *Terai* of Uttar Pradesh (India) to rust and wilt of lentil?

P.B. Karki
Screening lentil genotypes for resistance to diseases has been recently started. Therefore, at this stage, it is very difficult to give the reaction of cultivars developed in Uttar Pradesh to rust and wilt in Nepal. But, some cultivars from U.P. are widely grown in Nepal which indicates that these cultivars are resistant in Nepal too. Careful observations will be carried out in future.

B. Singh
What is the highest altitude at which lentil is being grown in Nepal? Is there any difference between the lentil types grown at different altitudes?

P.B. Karki
Lentil is grown up to 2000 m elevation, where bold-seeded types are sown.

M.C. Tyagi
The damage caused by aphid (*A. craccivora*) is quite severe in the Northwestern Plains of India. What is its incidence in Nepal?

P.B. Karki
The incidence is severe in some years.

M.C. Saxena
Have you made any observations on the effect of mixed cropping of lentil on the foliar

P.B. Karki
No study has been carried out on the effect of mixed cropping of lentil on the foliar diseases. *Sitona* weevil has not been reported so far on lentil in Nepal.

S.C. Agrawal
In Nepal, you mentioned *Botrytis cinerea* to be serious on lentil. Did you observe its *Sclerotinia* stage on plants?

P.B. Karki
We have not observed the *Sclerotinia* stage of the fungus on plants so far.

Section 5. Post-harvest Processing and Quality

Post-Harvest Processing and Quality of Lentil in Bangladesh

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Abstract

Considerable loss is incurred during post-harvest processing of lentil, which includes threshing, drying, storing, etc. Inadequate drying results in infestation of fungi and insects in storage. Twenty-four species of fungi belonging to 14 genera have been isolated from lentils at the farmers' level of storage. Bruchid (*Callosobruchus chinensis* L.) infested 0.2 to 57.8% of grains stored in different kinds of containers within 8 months. Generally, 60-85% recovery can be obtained in milling. Loss of recovery during milling depends upon the uniformity of seed size and moisture content. Grading of seeds prior to milling minimizes the loss to some extent. Jute bags with a polythene lining are recommended as the best storage containers for farmers in Bangladesh. For quick, off-season drying a blower type dryer, using paddy husk as fuel, has been developed which has the capacity of drying 190 kg in 6 hours. Some research has been conducted to protect seeds from bruchid damage using plant materials, such as the dried and powdered leaves of neem and tamarind, as well as different oils. Such new information and technologies need to be extended and circulated among farmers. Research on chemical pesticides against insect pests and fungal flora in storage continues and socioeconomic aspects have been suggested for future study.

Introduction

Post-harvest processing plays an important role in the production of lentils. The highest returns depend on the successful processing of the crop, which can stabilize the marketing system. The lentils pass through several processes after harvesting until they become ready for consumption. The processes include threshing, cleaning, drying, storing, milling, etc. Each of these steps deserves proper care to reduce post-harvest loss and to maintain the quality of the grain. Very limited research has been focused in this direction. The research project titled Legume Post-harvest Technology was conducted from 1981 to 1984 at the Bangladesh Agricultural Research Institute (BARI). Most of the research findings reported here are from the annual reports of the project, reviewing the research undertaken so far on post-harvest processing. The present paper, however, goes on to present an overview of the status of post-harvest processing of lentil in Bangladesh.

Threshing and Drying

In Bangladesh, lentil harvesting starts at the end of February and continues up to mid-March. Farmers dry and thresh their crop on their threshing yard. Very few large farmers have a *pucca* (cemented farmyard) for drying and threshing. Farmers generally harvest their crop when it is fully mature and leave it in the field for complete drying when the first shower at the end of winter is delayed. In this situation the drying and threshing is easy for farmers. But sometimes, in case of an early shower, farmers are compelled to harvest the crop soon after physiological maturity, when the plants are still green. Ideally, the harvested crop receives liberal sun drying before threshing. This makes threshing less laborious and more cost effective for farmers. Sometimes the grains after threshing are not properly dried. Suboptimal drying causes several problems in storage.

Mechanical Dryer

It was reported that lentils could be stored well when the moisture content was brought down to 9% or less (Rahman 1989). In Bangladesh, sun drying the grain is the only method of drying. To meet emergency needs for grain drying a mechanical dryer was developed using local materials. Paddy husk was used as fuel for generating heat. Its drying capacity was reported to be 190 kg/6 hours and cost for drying was USD 0.13/100 kg. The entire unit required approximately USD 29.50 for installation (BARI 1984).

Storage

Lentil grown in Bangladesh is mostly stored by traders and millers. Most farmers, with their limited storage facilities, store their seed for both sowing and consumption.

Storage by Traders

Traders most commonly store lentils in jute bags which are piled on a cement floor inside their warehouses. The warehouses generally have brick walls and corrugated tin roofs. Sometimes wooden planks are placed underneath the piles of jute bags to elevate the grain from direct contact with the floor. Warehouses are not particularly air-tight, so during the rainy season air with a high relative humidity (90%) enters the store. The grain absorbs moisture from the humid air, raising the seed moisture content to 14%.

Traders report that in this kind of warehouse, lentil in bags could be stored for a maximum of 3 months. After this period, the moisture content is raised above the maximum acceptable level (14%), beyond which the lentils are unstoreable and require further drying.

Storage by Farmers

Farmers in different parts of Bangladesh use various kinds of storage containers. These include earthen containers (*motka* or pot, mud bins, tin containers, kerosene oil tins, cooking-oil tins, biscuit tins), bamboo containers (*doli*, *aury*), metal drums and jute bags (Alam 1971; BARI 1983). The degree of infestation of insects and fungi was studied for the stored grain in different containers, and the most suitable local containers were identified.

Problems in Storage

Farmers store their lentil in different types of containers. They do not take any protective measures except occasional sun drying. At the moment, Bangladesh has a very limited scope for the proper drying of agricultural products during the rainy season. During this time the average relative humidity remains above 90%. These humid conditions are very congenial for the multiplication of various fungi and insect pests. As a result, heavy infestation of fungi and insect pests occurs on stored lentil. This results in serious qualitative losses.

It was further reported that losses in farm level storage are due to storing previously infested and inadequately dried grains, in addition to using improper containers. A majority of the farmers are not capable of procuring appropriate storage containers. They are also not aware of possible protective measures against insect and fungal attack (BARI 1982.)

It was also noted that, although traders stored their procured lentil after adequate drying, there was infestation of fungi and insects. This is because the grains absorbed moisture from the air inside the warehouse, since the store was not airtight.

Prevalence of fungi in stored lentil

Twenty-four species of fungi belonging to 14 genera were identified from the samples of lentil (BARI 1982). The samples were collected from farmers' storage containers in five major lentil-growing areas of Bangladesh. It was reported that association of field fungi like species of *Fusarium*, *Drechslera*, *Cercospora*, *Alternaria*, etc. declined with time in storage, whereas those of storage fungi like *Aspergillus*, *Penicillium*, *Cladosporium*, *Rhizopus*, etc. increased with storage time. Among these fungi *Aspergillus* spp. were most prevalent, while the prevalence of *Botryodiplodia*, *Cercospora*, *Cephalosporium*, *Doratomyces*, *Drechslera*, *Epicoccum*, *Myrothecium*, *Phoma*, *Pestalotia* and *Trichothecium* was very low.

Insect pests of stored lentil

Insects responsible for causing damage to stored pulses belong principally to two species of *Callosobruchus*, namely *C. chinensis* L. and *C. maculatus* Fab. (Begum *et al.* 1985). These insects are commonly called pulse beetles or bruchids. Alam (1971) reported that *C. chinensis* was the most serious pest to lentil, causing enormous damage in storage. In a recent study, however, Rahman (1989) reported that only one species of pulse beetle, *C. chinensis,* occurred on lentil in storage, whereas *C. maculatus* infested pulses other than lentil.

Not much quantitative data are available on the level of bruchid damage to lentil in warehouses and farmers' stores in Bangladesh. Rahman (1971) reported a 12.5% loss of lentil due to pulse beetle in warehouses; 25.2% damage of lentil by *C. chinensis* was reported by Rahman *et al.* (1981). A report on the survey conducted by BARI during 1981/82 and 1982/83 revealed that bruchid infested up to 54.4% of the lentil under the farmers' usual storage conditions (Table 1).

Table 1. Bruchid infestation of lentils stored in various types of containers for different periods (BARI 1984).

Storage container	Extent of infesta-tion (%)	Storage period (months)
Earthen *motka* with mud-sealed lid	2.9	8
Earthen *motka*, unsealed	46.5	8
Metal drum with lid	1.5	8
Jute bag with polythene lining	0.6	8
Jute bag, tightly packed	10.1	6
Earthen pitcher, top-sealed with mud	5.5	2
Earthen pitcher, covered with coconut shell and sealed with cow dung	42.3	8
Earthen pitcher, covered with coconut shell	54.4	8

Methods of Minimizing Losses

Insecticides like deltamethrin at 3 ppm, sevin at 50 ppm and fenitrothion at 30 ppm give effective protection against the adults of *C. chinenis* up to 4, 3 and 2 months, respectively. Sun drying of grain after every 2-3 months to bring the moisture content down to 9% or less is mostly practised by farmers and traders (Rahman 1989). Dried and powdered leaves of neem (*Azadirachta indica*), tamarind (*Tamarindous indica*) and datura (*Datura fastuosa*) when mixed with stored pulses gave good protection against pulse beetle. Also, some edible oils like mustard oil, soybean oil and coconut oil at 10 ml/kg seed were found effective as protectants for up to 5 months of storage (Rahman 1990). Traditional storage containers were evaluated and some modifications were made. It was found that lentils stored in jute bags with polythene lining gave the best protection. Some other storage containers like a metal drum with sand cover, metal pitcher with mud-sealed lid and plastic bags also performed well against insect infestation.

In Bangladesh, lentils are consumed mostly as dehulled grain called *dhal*, so the milling process is prerequisite for cooking. There are no reports about the status of lentil milling in Bangladesh. The author has conducted a sample survey of the mill owners near his research station at Ishurdi, Pabna. The information reported herein is entirely based on that survey, conducted by interviewing the millers using a questionnaire. The millers reported that about 60-85% recovery of *dhal* is generally obtained in their mills, but the data provided by them showed that the recovery of *dhal* from the lower grade grain may come down to 50% (Table 2). The recovery percentage, however, depends upon several factors as follows.

Factors Affecting Recovery Percentage

Seed size and uniformity of grain

The most important factor affecting recovery was the seed size and uniformity of grain. Large and uniform seeds produce a high recovery percentage. A mixture of large and small seeds gave proportionately less recovery. However, the recovery percentage can be improved when the same seed lot is graded into different sizes and then milled.

Moisture content

High moisture content in seed (12% and above, according to the millers) results in splitting of the grains into two halves or more smaller fragments. These fragments sometimes become even smaller and get lost with the husks during winnowing. High moisture content also causes qualitative deterioration of the product.

Grading of Grains and Recovery Percentage

There are usually three to five grades, but frequently the miller uses a 4-grade device (Table 2). Each grade of seed is separated by passing the seeds through the specified sieve. In this way, the larger seeds fall into the better grade. The millers have given an estimate of the percentage of seed quantity in different grades from a seed lot generally available in Bangladesh (Table 2). It was stated that 85% recovery was obtained from the seed of grade I and 50% from the grade IV, while on average they were getting 60% recovery.

Table 2. Percentage of seed obtained by grading a commonly available seed lot in Bangladesh and recovery percentage of seed from each grade.

Grade	Aperture	Seed by weight (%)	Recovery of seed (%)
I	20 x 2.5 mm	25 - 30	85
II	20 x 2.0 mm	30 - 40	70
III	20 x 1.5 mm	15 - 25	60
IV	2 mm (round)	10 - 15	50

Marketing

The marketing of lentil is an important component of post-harvest operations. Efficient marketing ensures the satisfactory transfer of the product from growers to consumers. A study was undertaken at BARI to estimate the total cost of marketing pulses by intermediaries. The total cost included all the cost items incurred by different marketing intermediaries as the lentils pass from primary market to ultimate consumers. Item-wise the cost of marketing is shown in Table 3.

The average total cost of marketing was estimated as USD 2.06/quintal (100 kg), which accounted for 30% of the total cost. The operational charge for milling was around 36% of the total marketing cost incurred by the intermediaries. It was also observed that the transport cost increased as the product moved from small purchaser (called *faria*) to the processors and retailers. The increase in transport cost was attributed to the larger horizon of trading centers from *faria* to big warehouse owners (called *aratdars*) and from *aratdars* to processors (millers).

Table 3. Total cost of marketing of pulses by intermediaries.

	Average cost (Tk†/100 kg)				
Cost item	*Faria*‡	*Aratdar*§	Processor	Total	Percent of total cost
Transport	2.21	10.50	13.64	27.35	39
Loading and unloading	1.28	2.46	2.25	5.99	8
Market toll	2.03	0.24	-	2.27	3
Commission charges	-	0.19	1.34	1.55	2
Personal expenses	3.99	0.46	0.16	4.16	6
Weighing charges	0.13	0.70	0.88	1.71	2
Rent	-	0.13	-	0.13	1
Labor wages	-	-	1.13	1.13	2
Milling	-	-	24.92	24.92	36
Interest on credit	-	-	0.05	0.05	1
Total	10.64	14.68	44.37	69.69	100

† USD 1 = Tk 24.00 during survey.
‡ *Faria* = small purchasers with no storage facility.
§ *Aratdar* = big traders with warehouses.

Future Research Needs and Conclusion

Some information has been generated on the most efficient local seed containers, some chemicals and herbal materials have been found effective against stored grain pests and a low cost dryer has been developed. Proper steps should be taken to have this information disseminated among users. A majority of fungi and storage insects grow at a temperature range of 25-35°C, which is the normal temperature range of storage in Bangladesh except in winter (December-January) and extreme summer months (May-June).

For safe storage two things are needed: creation of oxygen-free or reduced-oxygen atmosphere in storage, and protection of the store from the entrance of moisture from the humid air. To attain the first requirement some research workers have suggested injection of carbon dioxide or nitrogen gas (Henderson 1969; Jay and Pearman 1969). Further research may, therefore, be undertaken to find a suitable method of creating a low-oxygen atmosphere in storage, but to attain this, the second requirement, protection from moisture, is essential. To achieve this, workers may build moisture-protected warehouse structures with a PVC sheet inside. To obtain airtight containers for farmers' use, McFarlane (1970) suggested mature and dry cases of gourd with a surface treatment of either linseed oil or a varnish. Further work on this type of traditional container coated with coal tar or pitch may be undertaken.

Generally, farmers in Bangladesh are unwilling to mix chemical protectants with the grains. Investigation may, therefore, be carried out to find suitable fumigants against fungi as well as insects in the store. Efforts may, however, be directed to refine the herbal materials to make them available in a ready-to-use form. The report on pulse marketing showed that there remains a big gap between the farmgate and the retailers' price; with the farmers deprived of benefit they are therefore shifting toward the cultivation of more remunerative crops. This indicates the need for socioeconomic studies to halt the decline of the lentil area in the future.

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Discussion

J.S. Brar

What is the effect on seed germination when seed of lentil is stored in jute bags with polythene lining?

M.A. Bakr

I do not have the information, but it hardly matters to those farmers who store their grains for consumption.

M.C. Saxena

What proportion of lentil production is used as *dhal* and what proportion as whole seed?

M.A. Bakr

Only 1-2% is consumed as whole seed and almost all the Bangladeshi lentils are consumed as *dhal*.

M.C. Saxena

The *dhal* is used as split *dhal* and whole *dhal*. What proportion of each?

M.A. Bakr

It is used both as split *dhal* and whole *dhal*.

M.C. Saxena

Do the villagers use home level decortication procedures?

M.A. Bakr

Yes, they do. The decorticators are two large stones which are rubbed against each other.

M.C. Saxena

What is the general size of *dhal* mills? How many t/day processing is done?

M.A. Bakr
The quantity of processing is variable; it depends on the size of the mill. It ranges from 1 t to even 10 t/day.

M.C. Saxena
Are there any areas of Bangladesh where the quality of lentil is particularly good?

M.A. Bakr
The seeds of the districts of Rajshali, Pabna, Kustia and Jessore are of good quality.

M.P. Bharati
Please elaborate specifically the traditional (very old) systems used to protect lentil against storage pests.

M.A. Bakr
One of the oldest storage systems is using fine sand on the top of earthen pitchers.

M.P. Bharati
Is there a loss of quality and quantity in lentils to early rains or storms accompanied by hail storms, during the time of harvest? If yes, could you give an estimate.

M.A. Bakr
Yes, there is loss of quality as well as quantity of lentil due to early showers or storm and hail storm, but it is difficult to give quantified data. It is an approximation that during 1990 there was around 20-30% loss of grain yield due to rain accompanied by hail.

M.P. Bharati
What is the marketing channel of lentil in Bangladesh? Are middlemen involved? If yes, how much profit do they make?

M.A. Bakr
The marketing channel in Bangladesh is farmer—*faria* (local purchasers)—*aratdar* (big purchasers)—millers/traders. The profit they make is approximately 30% of the value of the produce.

W. Erskine
In West Asia lentil straw is a highly valued sheep feed that is traded and sometimes even exported. What happens to lentil straw in South Asia and is it traded?

M.A. Bakr
Straw of lentil is used as cattle feed. It is sold locally among the farmers but there is no organized marketing for it.

B. Singh
A mention has been made that coconut oil and soyabean oil are effective protectants for seeds. Do you have some data to support this statement?

M.A. Bakr
Similar reports are also available in Bangladesh, but no quantified information is available.

B. Singh
What precise recommendations for storage are being made to the farmer?

M.A. Bakr
Storage in jute bags lined with polythene is recommended as it gave the best protection against pests. Farmers can also use such sacks for storage.

A.N. Asthana
I understand that the primary infestation by bruchids starts from the field. Is there any method to check this infestation so that the storage losses are minimized?

M.A. Bakr
Reports from Bangladesh suggest that there is very little chance of infestation from the field so it has not so far been taken into consideration.

S.C. Agrawal
Are any data available on milling recovery of *macrospema* type of lentil in comparison with *microspema* type? As far as I know, the seed of *macrospema* is bold but flat.

M.A. Bakr
No, there is not. The recovery which I have mentioned is only for *microspema* seeds of different seed sizes.

W. Erskine
In West Asia, *macrospema* lentil is consumed whole and not split.

M. Ali
Among different edible oils used for treating seeds against stored grain pests, which is most effective? Do you have some research data?

M.A. Bakr
Statement of the research report is that soyabean oil, coconut oil, groundnut oil and also mustard oil were equally effective.

S.S. Lal
Callosobruchus maculatus is not a pest of lentil in India. Please check whether it really occurs in Bangladesh.

M.A. Bakr
I have mentioned in the paper that *C. chinensis* and not *C. maculatus* is the pest of lentil in storage.

S.S. Lal
Mixing of seeds with insecticides is harmful for germination. Do you have information on this point?

M.A. Bakr
I have mentioned Malathion as a seed protectant with almost no residual toxicity.

M.C. Saxena
What is the relative importance of *C. chinensis* vs. *Bruchus lentis* in field infestation of lentil? Any estimate of magnitude of infestation of *C. chinensis* in the field? Are there any genotypes found resistant to *C. chinensis* and *B. lentis*? Is there any intention to increase/start work in this area in the All India Coordinated Pulses Improvement Project (AICPIP)?

S.S. Lal
Only *C. chinensis* is reported to occur in India and not the other species. *Bruchus lentis* does occur in India but not as a serious pest. *C. chinensis* begins its infestation from fields by ovipositing on pods and gets carried to stores where it multiplies, given favorable environments. Field infestation is usually below 1%. Not much work has so far been done on host plant resistance in India but now may begin under AICPIP, considering its importance.

Section 6. International Crop Improvement and Networking

Breeding Lentil at ICARDA for Southern Latitudes

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Abstract

Lentil (*Lens culinaris* Medikus) was domesticated in West Asia and introduced into the Indo-Gangetic plain around 2000 B.C., where it was exposed to new, markedly different environmental conditions. Although half the world area of lentil is found in South Asia, it is based on a narrow genetic base of exclusively *pilosae* lentils with a reduced sensitivity to photoperiod and greater sensitivity to temperature than lentil from West Asia. Major problems with lentil in South Asia are low yield potential and susceptibility to the diseases wilt, rust and Ascochyta blight. The recognized key to increased yield potential is the widening of the genetic base in South Asia. The direct introduction of Mediterranean, medium-duration germplasm is only of value in upland areas surrounding the Indo-Gangetic plain. In contrast, the direct introduction of early maturing germplasm from outside the region, such as Precoz (ILL 4605), has resulted in an injection of genetic diversity into South Asia. ICARDA distributes specific, early flowering, international nurseries and yield trials targeted on South Asia, and widens the genetic base through an extensive program of hybridization and distribution of segregating populations for local testing and selection. This longer-term solution is already producing promising lines, particularly in Pakistan, but it requires close collaboration between programs. Population improvement has been started using cytoplasmic-genetic male sterility. At ICARDA sources of resistance to wilt in both wild and cultivated backgrounds have been found and breeding initiated. Progress with rust resistance is greater, as four national programs have released rust-resistant cultivars following local screening for resistance. Joint research with the program at Islamabad, Pakistan is producing a wide range of Ascochyta blight resistant breeding material.

Introduction

The lentil (*Lens culinaris* Medikus) is an annual diploid (2n = 14) food legume of importance in West Asia, the Indian subcontinent, Southern Europe, North Africa, Ethiopia and the Americas. Its primary gene pool consists of the cultigen (*L. culinaris* ssp. *culinaris*) and the two wild subspecies of *L. culinaris*, namely *L. culinaris* ssp. *orientalis* and *L. culinaris* ssp. *odemensis* (Cohen *et al.* 1984; Ladizinsky *et al.* 1984). The lentil originated in Asia from *L. culinaris* ssp. *orientalis* either in the region between the Hindu Kush and Himalayas (Barulina 1930) or in Turkey (Ladizinsky 1979; Ladizinsky *et al.* 1984). The oldest known lentil remains are dated to 11 000 B.C. from Franchthi Cave in Greece (Hansen and Renfrew 1978), but these were most likely wild material. A summary of the distribution of lentil remains in West Asia may be found in Cubero (1981). The current distribution of *L. culinaris* ssp. *orientalis* and the archaeological evidence (see distribution maps in Cubero 1981) point toward an origin in West Asia. The variability found by Barulina (1930) at the Hindu-Kush junction may best be explained as a gene microcenter (Cubero 1981), as it proved to be a region containing great genetic diversity formed in mountainous areas with a dissected topography and many different environmental niches.

Spread of Lentil into the Indo-Gangetic Plain

The earliest evidence of lentil in the Indo-Gangetic plain is around 2000 B.C. but contacts between Mohenjo-Daro, the Sumerians and Akkadians of Mesopotamia are well documented, and it may have been introduced earlier into the Indus valley (Cubero 1981). De Candolle (1882) wrote "it may be supposed that the lentil was not known in this country (India) before the invasion of the Sanskrit-speaking race."

When lentil was introduced into the Indo-Gangetic plain it was exposed to environmental conditions very different from those where it was domesticated. These contrasting climates are illustrated by climatodiagrams of two representative locations, namely Aleppo, Syria and Kanpur, India (Fig. 1).

A reconstruction of the phenological problems associated with the spread of the crop into the Indo-Gangetic plain was inadvertently made with the introduction of material from West Asia by ICARDA in its early years. West Asian lentils, when sown in India, were mostly coming into flower as the indigenous lentils were maturing (Table 1) (ICARDA 1981, 1982, 1983). Indian lentils are distinct from, for example, Afghan and Irani germplasm (Erskine and Witcombe 1984; Erskine *et al.* 1989; Erskine *et al.* 1990), are exclusively of the *pilosae* type (Barulina 1930) and show limited variation despite the large area under cultivation. This limited variation and the phenological problems prompted the suggestion of a "daylength bottleneck" limiting the flow of lentil germplasm into the Indo-Gangetic plain (Erskine and Hawtin 1983).

It is now known that temperature and photoperiod control time to flower in lentil (Summerfield *et al.* 1985) and that the concept of a daylength bottleneck is an oversimplification. The study of flowering in a broad spectrum of germplasm under a wide range of temperature and photoperiod has indicated that Indian germplasm is both more sensitive to temperature and less sensitive to photoperiod than material from West Asia (Erskine *et al.* 1990). The limited genetic diversity within *pilosae* lentils, and the problems of adaptation of germplasm introduced into India, have a profound bearing on the plant breeding strategies needed today.

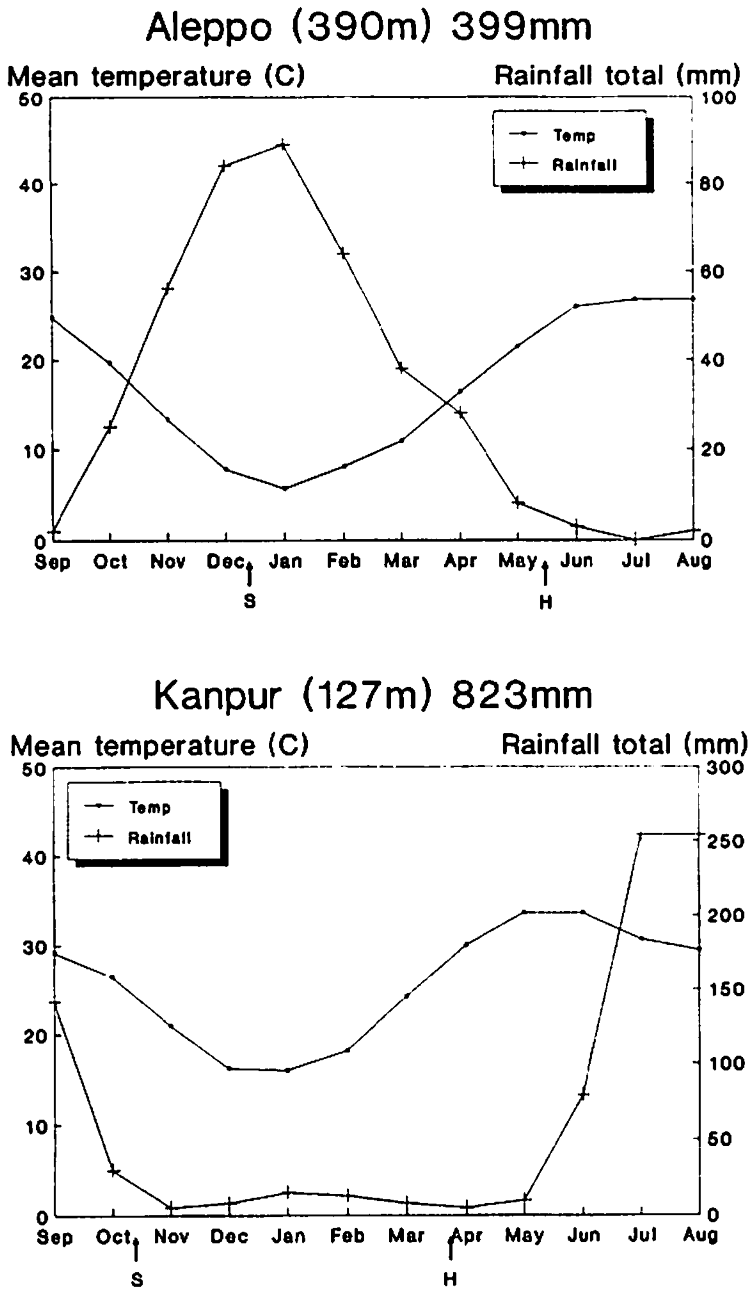

Fig. 1. Climatodiagrams showing monthly mean temperatures (°C) and rainfall totals (mm) in Aleppo and Kanpur, which are representative of the two major agroclimatic regions of lentil production in the developing world. The elevation above sea level (m) and long-term mean annual rainfall totals (mm) are given. Typical dates for sowing (S) and harvest (H) are also shown.

Table 1. Time to flower (days) of germplasm accessions from India and Syria at two locations contrasting in latitude and mean photoperiod prior to flowering.

Accession	Terbol Lebanon 34 °N 12.2 hours	Islamabad Pakistan 33 °N 10.9 hours
ILL 4380 (India)	130	114
ILL 4400 (Syria)	133	132

Problems in South Asian Lentil Addressable by Breeding

The poor yield potential of South Asian lentils is partly responsible for the lower-than-world-average yields of the crop in the region. Additionally, in South Asia the crop loses more yield from disease attack than in other major growing regions. The key diseases are vascular wilt, rust and Ascochyta blight. Whereas many other plant characters, such as biological nitrogen fixation, seed quality and resistance to insects and other parasites, require attention during breeding, the approach taken with these traits is one of maintenance at current levels. ICARDA has focused on the improvement of yield potential, through an increase in biomass, and of resistance to vascular wilt, rust and Ascochyta blight.

Widening the Genetic Base

The key to increasing yield potential in South Asia is through widening the available genetic base. Direct introduction is the easiest means to this end, but we have already discussed the problems with West Asian germplasm. In contrast, the introduction of early flowering germplasm has been more fruitful. For example, Precoz (ILL 4605) was the first early flowering, *macrosperma* line introduced into South Asia. It thrives in the wetter areas of Pakistan such as the National Capital Territory and parts of the North-West Frontier Province. Its early flowering habit synchronizes its flowering with the indigenous germplasm, allowing artificial crossing without the need for extended photoperiod (Tyagi and Sharma 1981). Precoz and/or its derivatives were included in every lentil crossing block in India in 1990. Several other early germplasm accessions introduced into Nepal, such as ILL 4402 and ILL 4404, are in Farmers' Field Trials.

The introduction of germplasm and breeding material from West Asia is, however, important for the upland areas fringing the Indo-Gangetic plain because of the specific needs for cold tolerance and a medium-duration crop. For example, in Baluchistan, Pakistan the medium-maturing selections (ILL 5677 and ILL 5865) are in the pre-release stage, and several promising lines with medium maturity have been selected for the mid-hills in Nepal.

The genetic base may also be widened through hybridization. ICARDA has made a major attempt in this direction by making 50-100 simple crosses per annum with early parents from different origins. There exists a comparative advantage for artificial crossing in West Asia over South Asia because of good synchrony in flowering between parents of diverse origins. The F_1 generation is grown in a high-elevation summer nursery for rapid generation advancement. Some of the crosses are distributed as segregating populations in the International F_3 Nursery and others are sent to specific national programs, particularly to Pakistan and Bangladesh. Selections are made locally for adaptation and disease resistance. As a result of this joint effort, six out of eight test entries in the Pakistan Uniform Variety Trial 1990 were selected by the national program from ICARDA-supplied segregating populations. This material is also fed into the Lentil International Yield Trial-Early and Lentil International Screening Nursery-Early (Table 2). Other promising lines selected by the national programs from these nurseries are mentioned in the breeding chapters of specific countries and will not be covered herein.

Table 2. ICARDA lentil international breeding nursery program showing target regions and type of material for distribution.

Type of nursery	Mediterranean low-medium elevation	Lower latitude	High elevation
Crossing blocks /resistance sources	Tall nursery Large-seeded nursery Small-seeded nursery Wilt nursery	Ascochyta blight nursery Early nursery Rust nursery	Cold tolerant nursery
Segregating populations	F_3 nursery, large-seeded F_3 nursery, small-seeded	F_3 nursery, early	F_3 nursery, cold tolerant
Yield trials	Small-seeded trial Large-seeded trial	Early trial	

A new approach is being initiated to widen the genetic base through hybridization with population improvement. A source of cytoplasmic-genetic male sterility has recently been found at Washington State University, USA (F.J. Muehlbauer, pers. comm.) in a late-maturing background. The best cultivars from South Asia and the Mediterranean region are being crossed with the male sterility to develop a diverse gene pool with adaptation to the Indo-Gangetic plain to share with national programs in the future.

Vascular Wilt

The most serious disease of lentil is vascular wilt, caused by *Fusarium oxysporum* f.sp. *lentis*, which produces major economic losses in parts of South America, the Mediterranean basin and South Asia. A screening method for wilt has been developed (Bayaa and Erskine 1990) and genetic variation in reaction reported (Khare 1981; Bayaa and Erskine 1990). At ICARDA, breeding for resistance to vascular wilt and a study of the inheritance of resistance and linkage to isozyme and Restriction Fragment Length Polymorphism markers has been started recently, the latter in collaboration with Washington State University. Resistance to Fusarium wilt (race 1) in pea is controlled by a locus closely linked to *Est-s*, coding a seed esterase (Hunt and Barnes 1982). In view of the extent of conserved linkage groups between peas and lentil, this possible linkage is worth investigating in lentils. A recent survey of the wilt reaction in 220 wild lentil accessions covering *L. culinaris* sspp. *orientalis* and *odemensis*, *L. nigricans* sspp. *nigricans* and *ervoides* and *Vicia montbretii* (syn. *L. montbretii*) revealed resistance in the *orientalis*, *nigricans* and *ervoides* taxa.

Rust

Rust, caused by *Uromyces fabae*, is the most important foliar disease in lentils. Complete crop loss is possible from an early infestation with the fungus (Khare and Agrawal 1978). Epiphytotics of rust are common in Chile, Ecuador, Ethiopia, India, Morocco and Pakistan.

Field screening has been undertaken at several locations where infection occurs annually, for example, Pantnagar, India and Akaki, Ethiopia. A method to artificially inoculate rust has been described (Kramm and Tay 1984). Genetic differences among genotypes and sources of resistance have been reported by many authors (Khare *et al.* 1979; Reddy and Khare 1984; Shukla 1984; Mishra *et al.* 1985; ICARDA 1988; Singh and Sandhu 1988). Resistance to rust recently has been found to be monogenically inherited with resistance dominant to susceptibility (Sinha and Yadav 1989).

ICARDA is breeding for rust resistance through joint screening with national programs in Ethiopia, Morocco and Pakistan. As a result, national programs have released rust-resistant lines received from ICARDA in Chile, Ecuador, Ethiopia and Morocco (Table 3). An International Nursery of rust-resistant sources was launched in 1990. At ICARDA, linkage of the rust-resistance gene to markers is being sought with Washington State University as the wild species are screened for additional sources of rust resistance.

The major production problem in Bangladesh addressable through breeding is rust. Scientists at Tel Hadya (ICARDA) have been making targeted crosses of rust-resistant sources with the local susceptible cultivar L5 for use in Bangladesh. Selections have now been made in Bangladesh of adapted rust-resistant plants in the F_3 generation from this material.

Table 3. Lentil cultivars released by national programs.

Country	Cultivar
Algeria	ILL 4400
Argentina	Arbolito
Canada	Indianhead
Chile	Centinela
Ecuador	INIAP-406
Egypt	Precoz
Ethiopia	R186, NEL 358
Jordan	Jordan 3
Lebanon	Talya 2
Morocco	ILL 4605
Nepal	Sikhar
Pakistan	Manserha 89
Syria	Idlib 1
Tunisia	Neir, Nefza
Turkey	Firat 87, Erzurum 89, Malazgirt 89, Sazak 91
USA	Crimson

Ascochyta Blight

Ascochyta blight is caused by *Ascochyta lentis* and is economically significant in Argentina, Canada, Ethiopia, India, Pakistan and USSR. Foliar infection has caused yield losses of up to 40% (Gossen and Morrall 1984), but in Canada the economic losses from infected seed are much higher.

Methods of artificial inoculation are known and genotypic differences in foliar reaction following screening for resistance have been reported from Argentina (Mitidieri 1974), Canada (Slinkard *et al.* 1983), India (Khatri and Singh 1975), Pakistan (NARC 1986) and Syria (ICARDA 1984). Preliminary observations at ICARDA of the reaction of wild lentil species to Ascochyta blight have revealed a wide range in resistance. A nursery of Ascochyta-resistant sources has been distributed to national programs in the International Food Legume Testing Program since 1988. Breeding for resistance to Ascochyta blight is being conducted in a joint ICARDA/Pakistan breeding program with the screening undertaken in Islamabad, a 'hot spot' for the disease. As a result the cultivar Manserha 89 has been released with combined resistance to Ascochyta blight and rust in Pakistan. Combined rust and Ascochyta resistance also has been developed in some other lines (Table 4).

Table 4. Reaction of selected lentil lines to Ascochyta blight at NARC, Islamabad, Pakistan and Debre Zeit, Ethiopia and to rust at Debre Zeit and Akaki, Ethiopia on 1-9 scales (1 = free from disease, 9 = completely killed).

		Ascochyta score		Rust score	
Selection	ILL	NARC	D. Zeit	D. Zeit	Akaki
	358	1	5	2	3
78S26052	5604	2	6	1	1
FLIP84-78L	5748	3	5	3	1
FLIP85-33L	5871	1	-	1	-
FLIP86-21L	6007	3	5	1	1
FLIP86-38L	6024	-	5	3	1

Concluding Remarks

The problems with lentils in South Asia, including low yield potential and susceptibility to the diseases of vascular wilt, rust and Ascochyta blight, will be overcome most efficiently through **collaborative** breeding efforts, to benefit from the different relative research advantages of individual programs. For example, ICARDA has an advantage over many national programs in hybridization and in rapid generation advance, while NARC at Islamabad is a hot spot for Ascochyta blight screening and Pantnagar a hot spot for rust screening. The collaborative effort of various specialized programs can most efficiently target and solve common research problems.

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Discussion

P.N. Bahl

You mentioned that history of selection and cultivation might have given rise to specific adaptation resulting in "distinctness" of lentil types grown in Indo-Gangetic Plains in comparison with those cultivated in the Mediterranean region. Can it be presumed that selection forces which were responsible for creating distinct lentil types in different regions were similar to those responsible for evolution of *microsperma* and *macrosperma* types? In other words, is there parallelism between the two situations?

W. Erskine
There is not a clear parallel between the evolution of the distinct *pilosae* lentils of the Indo-Gangetic Plain and the evolution of the *macrosperma* lentils. There are both small-seeded and large-seeded lentils around the Mediterranean in the same region, whereas only *pilosae* lentils are sown in India. *Pilosae* lentils evolved in response to selection for conditions in a particular area—the Indo-Gangetic Plain—whereas *macrosperma* lentil evolved in the Mediterranean region in response to selection for large seeds.

I.S. Singh
Gene for gene relationship will hold as rust fungus is an obligate parasite. In my view, both host resistance and virulence in the pathogen also need to be simultaneously studied. This must be kept in view in any program aimed at rust resistance!

W. Erskine
I agree.

B. Sharma
What is your expectation from the distant hybridization program involving wild species?

W. Erskine
The wild species may be potential donors of resistance to various biotic and abiotic stresses (rust, vascular wilt, Ascochyta blight and *Orobanche* resistance and tolerance to drought and cold) and also 'yield' genes.

M. Ali
You mentioned an empirical formula to predict days to flower on the basis of temperature and photoperiod. What are the values for *a*, *b* and *c* constants?

W. Erskine
The formula to predict time to flower is explained in Summerfield *et al.* (1985) and Erskine *et al.* (1990). Briefly, the values for *a*, *b*, *c* are values describing 'inherent earliness' (*a*), response to temperature (*b*) and response to photoperiod (*c*) of individual genotypes.

B. Singh
Do you have data supporting the taste preferences for *microsperma* and *macrosperma*?

W. Erskine
We have not found clear differences in taste between lentil lines. In West Asia large seeds are consumed whole in preparations with rice and cracked wheat, whereas small seeds are used in soups.

B. Singh
What row spacing is used in your breeding program?

W. Erskine
We use 37.5 cm between rows with 250 seeds/m^2 plant density. This super-optimum row spacing allows us to use inter-row cultivation for weed control.

A.N. Asthana
It would be better if more collection is made available from Argentina so as to supplement Precoz (ex-Argentina) as a parent in the Indian program.

W. Erskine
We have tried to obtain Argentina germplasm other than Precoz, but it is much the earliest flowering line known in Argentina.

A.N. Asthana
What are the thrust areas of work to increase yield potential?

W. Erskine
For southern latitudes we are trying to increase yield through wide hybridization and broadening the genetic base. For Mediterranean areas we are focusing on increasing biomass, exploiting all available sources of this trait.

M.M. Rahman
What procedures do you follow in screening against rust?

W. Erskine
Screening for rust is done under natural epiphytotic conditions in association with national programs in 'hot spots' such as Merchouch in Morocco and Debre Zeit, Ethiopia. Spreader rows of a susceptible check are sown systematically among the test entries. Artificial inoculation is not usually required.

I.A. Malik
How is the cooking quality determined in lentil at ICARDA?

W. Erskine
We use a thumb-pressing but repeatable technique with plant digestion equipment. It is reported in Erskine, Nakkoul and Williams (1985) Field Crops Research 12:153-161.

S.C. Agrawal
What is the performance of Indian material resistant to diseases, especially wilt and rust, when tested at ICARDA or neighboring areas?

W. Erskine
Indian rust-resistant lines have resistance to rust in Syria. The lines with resistance to wilt tested at Jabalpur range widely in their reaction to vascular wilt in Syria.

S.C. Agrawal
Is the isozyme technique of screening lentil applicable to important diseases like wilt, rust and Ascochyta blight?

W. Erskine
Marker-assisted selection for disease resistance is only feasible after a close linkage between appropriate markers such as isozymes, Restriction Fragment Length Polymorphism and the locus of resistance is established.

M.P. Bharati
Developing a wilt-sick plot to screen against wilt disease can be rather risky because of its spreading effect to other fields. This has happened in many countries including at ICRISAT. Are you aware of this fact and what are your strategies to avoid it happening at ICARDA?

W. Erskine
Vascular wilt is already common at our farm at Tel Hadya, Syria. I do not feel that the establishment of a wilt-sick plot will greatly increase the risk of the disease spreading further.

S.S. Lal
In South Asia, aphids in the field and bruchids in the store are serious problems. To stabilize the yields of lentil there is an urgent need to start a program of resistance breeding against both these pests. What are your plans?

W. Erskine
We have no plans to initiate resistance breeding in Syria to these two important pests of South Asia. We should explore the possibility of a regional initiative in this regard.

J.S. Brar
Since success in artificial crossing in lentil is very poor, and you are making a large number of crosses at ICARDA, what procedure of making crosses do you follow? Is it the conventional procedure or some modified one you are following?

W. Erskine
We make crosses in the plastic house, where temperatures are 12°C at night and 18°C in the day, and also in the field. Success inside is usually three times that in the field. We use a standard emasculation technique.

J.S. Brar
Are any chemicals being used to induce male sterility in lentil flowers to ease the procedure of crossing?

W. Erskine
We have not tried chemical male gametocides on lentil. While such a chemical would be useful in lentil, we are unlikely to find one that will have an effect over the entire flowering period, which in lentil is protracted because of its indeterminate growth habit.

I.S. Singh
With the knowledge of cytoplasmic-genetic male sterility in lentil, is it in your scheme of things, in future, to go for hybrid lentils? Obviously more outcrossing types would be a prerequisite to such a program.

W. Erskine
Hybrid vigor exists in lentil in some cross combinations and we now have a cytoplasmic-genetic male sterility system. However, we have no system of transfering the pollen from male to female parents and the maximum outcrossing rate reported in lentil is only 6%. I find the lack of a delivery system for pollen as the major hurdle in lentil hybrid production, which is, for this reason, not easily forseeable.

The Asian Grain Legumes Network[1]

D.G. Faris

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Abstract

The Asian Grain Legumes Network (AGLN) brings together scientists, administrators and institutions committed to collaboration in solving problems in Asia on chickpea, pigeonpea and groundnut. The network has formal bilateral links between ICRISAT and 11 Asian countries. These links consist of Memoranda of Understanding, work plans tailored to specific country priorities and links between Country-AGLN Coordinators and the AGLN Coordination Unit at ICRISAT. The multilateral links of AGLN join scientists from Asia, ICRISAT and regional and international institutions, through various network activities such as sharing germplasm, information and improved technology. In addition, there is human resource development in-country and at ICRISAT, and working groups to tackle specific high-priority regional problems such as peanut stripe virus and bacterial wilt of groundnut, Botrytis gray mold of chickpea and insect pests. The AGLN also supports special projects such as the Sri Lanka-ICRISAT-ADB Pigeonpea Production Project and the ICRISAT-UNDP Asian Grain Legumes On-farm Research (AGLOR) project. Financial and logistic support comes from AGLN countries, ICRISAT and donor groups. AGLN strengths include its flexibility to meet specific priority problems, its wide range of activities, its focus on a few crops and its direct links among scientists. The AGLN includes all traits generally considered important for a network to succeed. It is hoped that the AGLN experience will provide useful ideas to assist in the planning of other networking activities.

Introduction

There are many types of agricultural research networks (ARNETs), each built to meet the needs and assets of its members (Plucknett *et al.* 1990; Faris 1991). The Asian Grain Legumes Network (AGLN) consists of scientists, administrators and institutions in Asia linked together by a shared commitment to collaboration in solving problems related to chickpea, pigeonpea and groundnut, and the farming systems involving these crops. This paper will describe the AGLN's development, structure, operation and outcome. Again, it is hoped that the information presented in this paper will provide useful ideas for planning the networking activities of lentil scientists.

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[1] ICRISAT Conference Paper no. CP-649 dated 10 April 1991.

Founding

In 1983, a consultative group meeting at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), attended by legume scientists from several Asian countries and representatives from regional donor agencies, identified the major constraints to the production of groundnut, chickpea and pigeonpea in Asia, as well as the priority research needed to overcome those constraints (ICRISAT 1984). With these needs in mind the group endorsed ICRISAT's concept of an Asian Grain Legume Program. At the follow-up review and planning meeting in 1985, ICRISAT's Director General announced the appointment of a coordinator for what has come to be called (since late 1986) the Asian Grain Legumes Network. ICRISAT agreed to supply the AGLN Coordination Unit, or simply the Coordination Unit (CU), to be located at the ICRISAT Center. This meeting also recommended a general plan of action and a list of specific activities to be undertaken by the Coordinator (ICRISAT 1987). The AGLN has been structured, and its major activities have been developed, based on the recommendations of the above two meetings.

Structure

The AGLN is built on the five components of ARNETs: membership, research, coordination, communication and assets (Faris 1991). The AGLN's structure can be divided into bilateral and multilateral elements.

Bilateral Element

The bilateral element is built on strong links between ICRISAT and national program scientists, based on a formal Memorandum of Understanding (MOU) between each AGLN country and ICRISAT (Fig. 1). These MOUs lay out the areas of research collaboration on ICRISAT's mandate crops and such matters as the movement of scientists, the distribution of seed materials and funds, the import of equipment and the release of information and varieties. MOUs have been signed with 11 major AGLN countries: Bangladesh, India, Myanmar, Nepal, Pakistan and Sri Lanka in South Asia; the People's Republic of China, Indonesia, the Philippines, Thailand and Vietnam in East and Southeast Asia. The AGLN also works with other countries of Asia when its assistance is requested.

Collaborative work plans for each country have been developed as part of each MOU. Usually these plans are developed at a review and planning meeting or at other related meetings held in the country concerned. They set out specific commitments by the country and by ICRISAT.

An important part of the bilateral element is the AGLN coordinator in each country who provides the administrative node to link with the CU at ICRISAT. The administrative responsibilities of the country AGLN coordinators are laid out in each work plan tailored

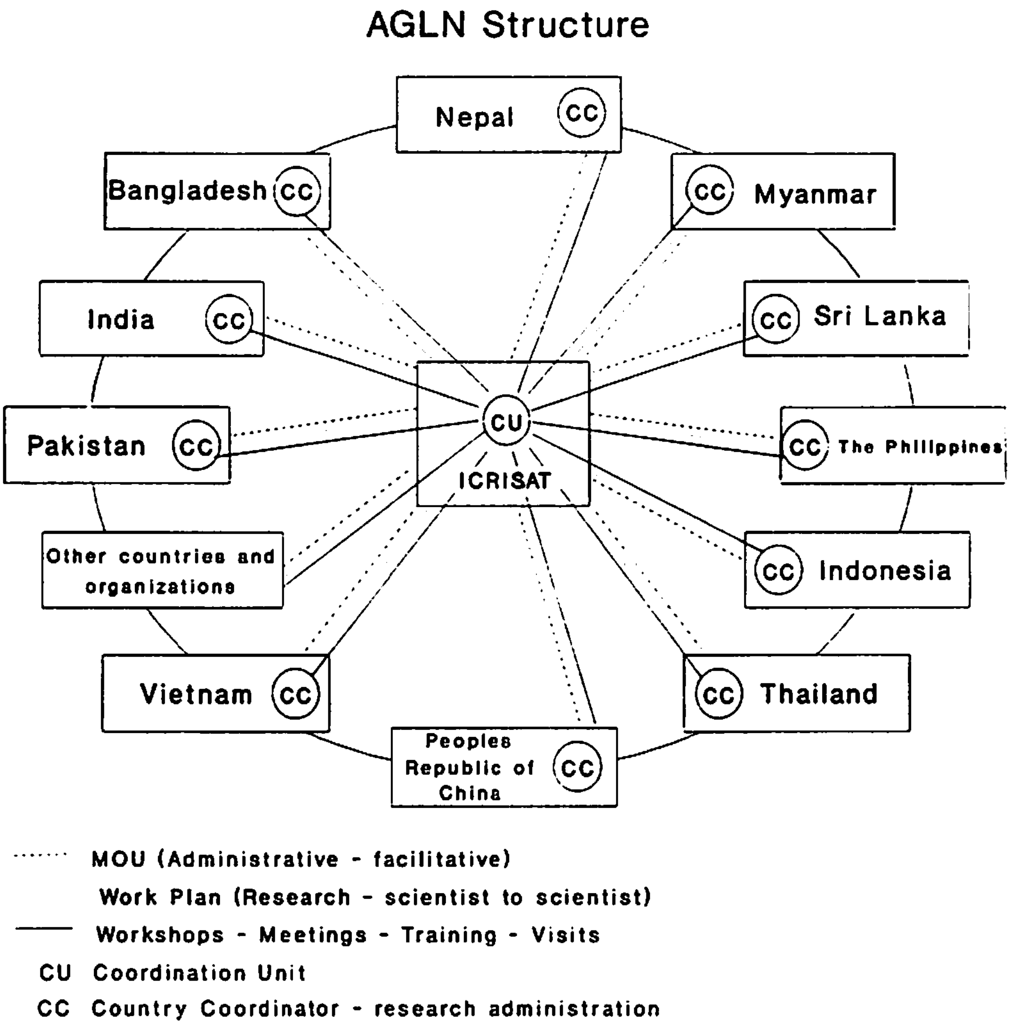

Fig. 1. The structure of the Asian Grain Legumes Network (AGLN), showing its bilateral, multilateral and coordination units.

to each country's administrative setup. The country AGLN coordinators are responsible for activities associated with the AGLN crops in their country. They organize such things as germplasm clearance, research reports, in-country AGLN meetings and the distribution of special funds to support AGLN activities. Thus, in essence, the AGLN has 11 decentralized country AGLN projects or subnetworks in which there is a local and an ICRISAT component (Fig. 1).

An integral part of the AGLN's bilateral element is its interaction with donors and international, regional and mentor institutions. This was a major recommendation of the 1985 meeting (ICRISAT 1987). Contacts and joint activities with these organization have been very fruitful to the AGLN.

Multilateral Element

The multilateral element of the AGLN comes from the many network activities that link network members together (Fig. 1). These activities include the network coordinators' meetings (ICRISAT 1989b, 1991), workshops, monitoring tours, working groups (ICRISAT 1988a), scientists' meetings (ICRISAT 1988a) and multicountry training courses to name a few. Donor, regional and international institute groups are also very much part of the multilateral element of the AGLN. Besides its role in the bilateral element, the CU plays a pivotal role in the multilateral element by helping to organize the above activities.

Coordination Element

The CU at ICRISAT consists of the AGLN Coordinator, a senior scientist and secretarial help. These posts and their logistical back-up are provided to the network by ICRISAT. By coordinating administrative interaction between ICRISAT and each country, the CU facilities direct collaboration between country and ICRISAT scientists, a major function of the CU. The CU also facilitates human resource development activities within the AGLN, which includes training at ICRISAT and in-country.

To carry out these AGLN activities, the CU follows the guidance of network members. The Unit receives this guidance from an Advisory Committee at ICRISAT, from scientists and administrators at the review and work plan meetings in each country, from individual country AGLN coordinators and from meetings of the network coordinators (ICRISAT 1989b, 1991), through workshop recommendations (ICRISAT 1984, 1987).

Activities

The AGLN structure forms the basis of support for a large number of activities and permits the rapid implementation of new activities. A sample of some of the activities follows.

AGLN Directory

Almost 700 scientists have responded to the invitation to become a cooperator in the AGLN. Their names have been entered in a database and the first edition of the directory, giving names and addresses, has been distributed (AGLN 1990). Subsequent editions will list the crop(s) and discipline(s) of each cooperator.

Information Bank

Information from ICRISAT is available to network cooperators through ICRISAT's Information Services, Legume Program and the library. The library operates the Semi-Arid Tropical Crop Information Service (SATCRIS) (ICRISAT 1988b). Also, Information Newsletters are published for each of the three AGLN crops—chickpea, pigeonpea and Arachis—and joint (Commonwealth Agricultural Bureau International) CABI-ICRISAT CAB Prompts Series for chickpea-pigeonpea and for groundnut.

The CU has collected pamphlets, books, reports and maps from each country and these are being catalogued. Unpublished information about each country is also collected by the CU staff. A management information system called AGLNIS (AGLN Information System) is currently being implemented by ICRISAT's Computer Services to allow easy access to this information. Apart from handling information from trip reports, AGLNIS will help in correspondence, as it is linked with the AGLN Directory, in the production of progress reports for distribution to AGLN cooperators and in administering workshops and meetings.

Germplasm and Breeding Material

A major ICRISAT contribution to AGLN is world germplasm collections of chickpea, pigeonpea and groundnut, and improved material of these crops. International trials and nurseries are made available to network cooperators directly through scientists in ICRISAT's Legumes Program, not through the CU. Special attempts are made to visit all trials and to review all results at the annual or biennial AGLN review and planning meetings in each country. The results are published in the various reports distributed by ICRISAT. The CU has also facilitated the movement of the material among scientists in AGLN countries.

Human Resource Development

The Coordination Unit has facilitated and helped to support:

- Trainees in regular ICRISAT Human Resource Development Program (HRDP) courses.
- Special courses such as methods of virus identification, integrated pest management, and legume utilization. Many of these have been made possible by special grants from donors such as the Food and Agriculture Organization (FAO) of the United Nations, the International Development Research Center (IDRC), the Peanut Collaborative Research Support Program (Peanut-CRSP), and the Asian Development Bank (ADB). In-country training courses on chickpea, pigeonpea, groundnut, mung bean and lentil given by local national scientists and scientists from other countries, ICRISAT, Asian Vegetable Research and Development Center (AVRDC), and International Center for Agricultural Research in the Dry Areas (ICARDA). These were financed by the ADB through the AGLN.
- In-country courses on integrated pest management, given in Thailand and Indonesia by local, Australian Center for International Agricultural Research (ACIAR), and ICRISAT staff.
- The agroclimatology workshop with inputs from AGLN countries, the FAO, the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), the International Rice Research Institute (IRRI), the Resource Management Program

(RMP) at ICRISAT, the AGLN itself, and a local geography consultant (Virmani *et al.* 1991). This and similar workshops provide a training component but also enable scientists to use and analyze their own data to put forward a joint publication.

- An in-country training course on virus identification in China. This specialized course was given by ICRISAT, Peanut-CRSP, and local Chinese staff members. The main Chinese faculty member for the course had received his training on this subject at ICRISAT. This course is of special significance as it means that China will be in a good position to screen its groundnut germplasm for seed-borne viruses.

Working Groups

The AGLN structure has helped to support several specialized working groups or subnetworks established to do research on problems identified as being of high priority in groups of AGLN member countries. These working groups have involved specialists from the countries where each specific problem is important, experts from developed country laboratories and appropriate ICRISAT scientists.

The following are examples of working groups:

- The Peanut Stripe Virus Working Group. This group first clarified the nomenclature of this disease. Then, using a Thai scientist in France (where groundnut is not a crop), peanut strains from several countries were characterized, which facilitated the screening of over 9000 germplasm lines in Indonesia. (This disease does not occur in India so could not be screened at ICRISAT.) The group conducted further research on the cultural control of this disease. This working group has been expanded and renamed the Working Group on Asia-Pacific Groundnut Viruses (ICRISAT 1989c).
- The Bacterial Wilt of Groundnut Working Group. This group was recently organized at an ACIAR/ICRISAT collaborative research planning meeting at Genting Highlands, Malaysia, 18-19 March 1990 (Middleton and Hayward 1990). Participants represent countries from Southeast Asia where the disease is important.
- The Botrytis Gray Mold of Chickpea Working Group. The organizational meeting of this group was held 4-7 March 1991 in Bangladesh immediately before this lentil seminar. Present were representatives from Bangladesh, India and Nepal, where this disease is important. The disease is also important in Pakistan, but Pakistan was unable to send a representative.
- The Integrated Pest Management and Insecticide Resistance Management in Asia Grain Legume Crops Working Group. Its organizational meeting is being held at Chiang Mai, Thailand, 19-22 March 1991.
- Ascochyta Blight on Chickpea Working Group. The AGLN will collaborate in this group which is to be organized by scientists at ICARDA (ICRISAT 1990).

Special Projects

The AGLN has become involved in specially funded projects in several AGLN countries. These projects have contained components both for on-farm research and for strengthening in-country back-up research. Examples of these projects include the following:

- The Sri Lanka-ICRISAT-ADB Pigeonpea Production Project that was started because Sri Lanka needs to replace its USD 40 million lentil *dhal* import. Lentil *dhal* is the preferred *dhal* in Sri Lanka but lentil cannot be grown commercially in the country (see H.M. Ariyaratne, this volume). Pigeonpea *dhal* has been found to be a suitable substitute and pigeonpea can be grown if certain problems are overcome. The project deals with the whole sequence from pigeonpea production to its utilization. This project will provide the production technology needed to make pigeonpea *dhal* available at an economic price to consumers in Sri Lanka and to strengthen the research structure to support this technology. Previous attempts to extend pigeonpea production apparently failed because of insect devastation, and lack of a *dhal*-making infrastructure. The steps in this project involve interaction between Sri Lanka and ICRISAT scientists to provide:
  - demonstrations to farmers on growing the crop;
  - an agroeconomic intelligence survey to guide the project;
  - a *dhal*-making infrastructure;
  - on-farm research to determine appropriate technology for growing pigeonpea, especially for insect control, and
  - collaboration between ICRISAT and Sri Lanka pigeonpea scientists to upgrade pigeonpea research in Sri Lanka so it can better identify and answer pressing production problems. This has included placing an ICRISAT scientist in Sri Lanka for extended periods.
- ICRISAT-UNDP (United Nations Development Program) Asian Grain Legumes On-farm Research (AGLOR) Project in Indonesia, Nepal, Sri Lanka, and Vietnam has identified the need for on-farm research on groundnut in all these countries. These projects are part of the UNDP/FAO/RAS/89/040 project. The on-farm research is based on farmers' needs and problems identified through a rapid rural assessment in each country. This has involved both the research and extension components in each country. It has also included an economic component. This project is just starting.

Other Activities

Other activities that illustrate the AGLN's collaboration with national programs and other organizations include:

- A chickpea scientists' meeting held in 1986 in Pakistan and a groundnut scientists' meeting held in 1988 in Indonesia (ICRISAT 1989a).
- Nepal/IRRI/ICRISAT monitoring tour and workshop on the improvement of chickpea, pigeonpea, and other pulses, held in March 1989.
- Transfer of an ICRISAT chickpea scientist to Nepal for one year and transfer of Nepal chickpea scientist to ICRISAT to analyze and interpret trial results.
- Collaboration with the ACIAR pigeonpea projects in Thailand and Indonesia, and with the ACIAR groundnut project in Indonesia.
- The analysis of pigeonpea production data and the development of a pigeonpea growth model by ACIAR staff working partly at ICRISAT.

- Facilitating the publication of information about the Legumes Germplasm Collection and Lentil Collection in Nepal (Furman *et al.* 1990; Furman and Bharati 1990).
- Association with the initiative to establish a Food Legume Asian Steering Committee (FLASC) to coordinate the activities of all groups in Asia interested in research on food legumes. The FLASC model suggests the possibility of four subnetworks [groundnut, soybean, temperate legumes (including lentil and chickpea) and warm-season legumes (including mung bean and pigeonpea)]. This is presently under consideration by APAARI (Asia-Pacific Association of Agricultural Research Institutions).

Funding

Most support for AGLN activities comes from scientists in AGLN countries who use their existing facilities and resources to carry out AGLN collaborative research. ICRISAT supports the CU, many of the visits of ICRISAT scientists to AGLN countries and the training of scientists from AGLN countries. The value of small external funding is demonstrated by the large number of activities and additional research that have been made possible in the South Asian countries by a grant from ADB. This grant was for the strengthening of legume research programs in Bangladesh, Myanmar, Nepal and Sri Lanka, and has now been expanded to include all 11 countries. Similarly, money made available by the Australian International Development Assistance Bureau (AIDAB) has resulted in several important research activities in Indonesia on peanut stripe virus, and in Thailand on pigeonpea. More recently UNDP has supported the AGLOR project and the ADB the Sri Lanka-ICRISAT-ADB Pigeonpea Production Project. To be successful, future grants need to include substantial support for ICRISAT-AGLN activities and not only to use the CU as a conduit for funneling funds to national programs.

Outcome

The major strength of the AGLN structure is its flexibility to adjust to the priorities of each of its member countries. This is possible because each country has a unique work plan that is based on the needs of that country as identified at in-country review and planning meetings. This allows revision of the crop and research priorities at regular intervals and the identification of special needs. This flexibility is enhanced by direct scientist-to-scientist interaction facilitated by the network.

Another strength of the AGLN is that it encompasses a very wide range of activities including the exchange and development of germplasm material, applied on-farm research, basic research, scientific training, meetings and visits among its members and the supply of information. The working groups have been particularly successful and in the future it is expected that more groups will be established aimed at providing solutions to specific high-priority regional problems.

One strength of the AGLN is its focus on a limited number of crops. Pressure to increase the number of crops in the network has been met by encouraging the formation of other legume networks in Asia and increasing coordination among legume research groups through the FLASC initiative. This present meeting to develop networking for lentil is a good example. AVRDC is considering supporting other networks.

An important feature of the AGLN is that it is structured to encourage and facilitate interchange and research collaboration directly between and among its members. These activities are supported logistically and financially wherever possible. This permits the build-up of groups to effectively tackle problems considered important by network members.

The impact of the AGLN can be seen in the release of varieties in AGLN countries, from germplasm and breeding material exchanged within the network; the strengthening of research on AGLN crops through training and scientist-to-scientist interaction; the provision of answers to larger problems through the working groups, and the development and transfer of technology appropriate for farmers through the on-farm research projects.

The AGLN outcomes broadly fulfill all the traits traditionally identified as being present in successful networks. These traits have been summarized as follows (Faris 1991):

Network component	Trait
Research	A well-defined common theme or strategy An important, widely shared objective or problem An existing or potential source of improved technology (research) A realistic research agenda
Coordination	Strong and effective coordination A steering committee or advisory group
Communication	Education and training Regular meetings (workshops) Information-exchange system Free exchange of results, materials, ideas, and participants
Members	Commitment of funds, resources and staff by NARS Strong self-interest served Capacity to contribute Participants involved in network management
Assets	Flexible outside funding

It is suggested that these traits be kept in mind as the planning for a lentil network emerges. The AGLN will be glad to collaborate with the lentil group in any way that is appropriate.

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Discussion

M. Ali
Does AGLN have any specific program on lentil improvement?

D. G. Faris
No, but it has encouraged the formation of a lentil network along with networks for other countries. The AGLN has also supported the Food Legumes Asian Steering Committee (FLASC) concept for the coordination of networking of all legume research in Asia. This suggestion to support the formation of FLASC has been passed along to APAARI for their support.

C.S. Saraf
What difficulties do you come across in AGLN operation and management?

D. G. Faris
The main difficulties have been to learn and adjust to the administrative structure and procedures in each country for moving germplasm, inviting participants to meetings and providing funds for in-country activities. Many of these problems have been reduced or eliminated through the strong support provided to the country-AGLN coordinators in each country.

M.P. Bharati
How do you measure and what has been the impact of AGLN, since it has been established and operational since 1986?

D.G. Faris
Measurements of impact can only be made if it is clear what is expected. For the AGLN the initial impact has been to bring chickpea, pigeonpea and groundnut scientists together so they can share ideas and conduct collaborative research. The network has participated in directing what collaboration is needed. The AGLN also has provided training. All these activities have made "stronger" scientists and strengthened the NARS. The impact has also been to provide better material and technology which the NARS have used and moved to farmers.

B. Singh
Would you like to include the food legumes of minor importance in the proposed network of food legumes?

D.G. Faris
Each one might be considered as an individual case and where such a legume is of importance or has a good potential to be important in several, then it would be appropriate to consider including it in networking activities.

B. Baldev
In case more funds are available to AGLN, what new activities will the program encourage in future?

D.G. Faris

The on-farm testing of technology to ensure the technology is appropriate to the farmers' needs and capabilities and to increase the impact of new technology by making it available to answer farmers' needs and improve the productivity. Also, support for working groups to answer very important problems in groups of countries in the region. An example is the Working Group on Botrytis Grey Mold of Chickpea.

Recommendations for Regional Research

The meeting identified many problems in lentil production common to different countries of the region. The following regional research program was developed to lift such constraints:

1. Joint collection of lentil landraces, as necessary, and the maintenance of lentil germplasm from different countries at ICARDA for free exchange to different countries.
2. Formation and distribution by ICARDA of a South Asian lentil trial containing 20-30 of the best lines recommended by National ARS (maximum 2 entries/center) in South Asia for distribution to different countries.
3. Exchange of sources of resistance to important biotic stresses (vascular wilt, rust and Ascochyta blight) through formation and distribution by ICARDA of South Asian stress nurseries.
4. Following the identification of 'hot spots' for key diseases—Pantnagar, India and Sialkot, Pakistan for rust; Islamabad, Pakistan and both Gurdaspur and Palampur, India for Ascochyta blight; Sehore, India and Parwanipur, Nepal for vascular wilt (sick plots under development)—exploitation of these sites for disease screening of material from different programs.
5. Distribution by ICARDA of specific, targeted segregating material recombining key traits with local adaptation to programs in the region on an individual request basis.
6. Exploitation by ICARDA of new biotechnological tests to assist lentil breeding and the sharing of useful methodologies and resulting genetic material with NARS in South Asia.
7. Development of regional lentil weed management trials for the two major cropping systems of lowland *utera* or rice-based system and the upland system.
8. Development of regional "need to inoculate" trial for farmers' fields.
9. Need to focus research on improving seedling establishment in lentil, relay-sown into the standing rice crop in the *utera* system common in Bangladesh, India and Nepal.
10. Development of regional trial on the response to foliar application of phosphate in the *utera* system of cultivation.
11. Assistance with disease and pest surveys.
12. Development of methodology for yield loss assessments for use regionally.
13. Monitoring of pathogen variability for key diseases (rust and vascular wilt) through the development of regional host differential sets.
14. Development of methodology for screening for resistance to aphids (*A. craccivora*) for use regionally.
15. As all NARS in South Asia expressed strongly the need to exploit advances in production practices and varietal development on farmers' fields, a regional effort could support such activity, if so requested.
16. Interaction among lentil scientists in South Asia may be improved by meetings to review progress, travelling workshops, working groups and by visits to ICARDA.

17. There is a need for both degree and nondegree training at ICARDA based on the specific needs and requests of NARS in South Asia.
18. There is a need to ensure the flow of information on lentil to regional scientists and to prepare a directory of lentil workers in South Asia.
19. The meeting urges ICARDA to solicit appropriate financial support to undertake this important program.

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