IPM for tropical crops: lentil

Anamika Sharma and Rangaswamy Muniappan*

Address: IPM Innovation Lab, CIRED, Virginia Tech, Blacksburg, VA 24061, USA.

ORCID information: Anamika Sharma (orcid: 0000-0002-7558-3402); Rangaswamy Muniappan (orcid: 0000-0002-2992-2792)

***Correspondence:** Anamika Sharma. Email: anamika@vt.edu

Received: 16 December 2020
Accepted: 9 September 2021

doi: 10.1079/PAVSNNR202116052

The electronic version of this article is the definitive one. It is located here: http://www.cabi.org/cabreviews

(Online ISSN 1749-8848)

Abstract

Lentil is an old-world legume and grown in more than 70 countries. It is a major source of protein in plant-based diets and is often used to fix nitrogen in the soil as a rotational crop, especially with cereal crops. Canada, USA, and Australia are the major exporters of lentil. Around the globe, this crop faces various biotic and abiotic stresses. More than 35 insect pests and the same number of diseases are reported to infest lentil in different parts of the world. While the status of insect pests and diseases varies in different geographical regions, some of them are aphids, armyworm, cutworm, pod borer, Stemphylium blight, fusarium wilt, Alternaria blight, and rust. Cultural management strategies for abiotic and biotic stresses include crop rotation, the timing of seeding, appropriate seed rates, and weed management. Biological control agents are also known for several insect pests. Environmental-friendly options such as biopesticides and microbials (entomopathogenic bacteria, fungi and nematodes, neem products, and *Trichoderma* sp.) can be used as seed treatment and foliar application. Various tolerant and resistant lentil varieties are available around the globe. In the present article, we provide an IPM package for the management of major biotic stresses for lentil crop.

Keywords: *Lens culinaris*, biological control, cultural practices, integrated pest management, IPM technology transfer, package of practices, pest resurgence

Review Methodology: This review discusses major insect pests, diseases of lentil crop, and their management, with the major focus on the tropical region. Authors have created a list of management tactics, including cultural, biological, and conventional methods, and stacked them to develop an IPM package to holistically manage the biotic stresses in lentil crop. Various research and review articles were searched on search engines, such as Google and Google Scholar. Keywords used to search for information included, *L. culinaris*, insect pests and diseases of lentil, biological control, cultural practices, integrated pest management, IPM technology transfer, and IPM package. CABI Web site was often consulted to access the updated information on various insect pests and diseases. Virginia Tech library was extensively used to acquire the literature. Although literature published before 1990 is cited, however, literature published from 1990 to date is the major source of information for this article. More than 100 research articles, reviews, book chapters, and books were screened to synthesize the results.

Introduction

Lentil (*L. culinaris* Medikus; Fabaceae) (commonly known as masur, messer, masser, heramame, adas, mercimek) is indigenous to the Near East and Central Asia and was domesticated around 7000–6000 BC [1]. It is now grown in Australia, Asia (Indian Subcontinent, Middle East, and West Asia), North America, North Africa, and Southern Europe. Canada, Australia, and the USA are the major exporters of lentil [1–3].

It is considered one of the oldest crops to be domesticated in the Old World [1]. *Lens* is a small genus comprised of *L. culinaris* subsp. *culinaris* (and *L. culinaris* subsp. *orientalis*, the putative progenitor of cultivated species) and five related wild taxa (*Lens odemensis*, *Lens ervoides*, *Lens nigricans*, *Lens lamottei*, *Lens tomentosus*). Hence, the genus *Lens* comprises seven taxa in six species. Lentil is an annual, self-pollinated herb of height 15–75 cm tall with erect, semi-erect, or spreading growth habit, and stems are light green and slender [4]. The leaves are

alternate, compound, and pinnate, and upper leaves are converted into tendrils [2, 4]. The primary product of the lentil is the seed and seed size differs according to the cultivars. *L. culinaris* has been divided into two subspecies—macrosperma (seed diameter, 6–9 mm and 1000-seed weight of 25–70 g), which is grown in West Asia, North Africa, and Southern Europe, and microsperma (seed diameter, 2–6 mm and 1000-seed weight up to 25 g), which is grown in South Asia and Sub-Saharan Africa. The macrosperma type has yellow cotyledons (French or European lentil, sold with the seed coat on, with grayish-brown exterior and a creamy yellow interior), whereas the microsperma types have red, orange, or yellow cotyledons (yellow lentil, yellow cotyledons, and olive-green coat with large black pattern and mostly sold in the Middle East and East India; reddish-orange Egyptian or red lentil sold without seed coat in the Indian subcontinent) [1, 2].

Lentil is cultivated on all soil types but grows best in deep sandy loam soils with moderate fertility and soil pH 5.5–7. However, lentil does not tolerate flooded or waterlogged conditions. Since lentils fix nitrogen, it can grow well under low fertilizer input conditions [5]. This crop prefers cool growing conditions, and the young plants are tolerant of spring frosts. Favorable growing conditions for this drought-tolerant crop vary in temperate and subtropical environments; it is typically planted in the spring in cooler climates and the fall or winter in warm climates. In semi-arid parts of the world, it is grown without irrigation and has a slightly lower yield, but good seed quality. At least 650–750 mm of annual rainfall is needed for high yields of good quality seed, but excessive rainfall and humidity negatively impact yield and seed quality. Excessive drought and/or high temperatures during the flowering and pod-fill period also reduce yields [6].

The crop has a high significance in cereal-based systems because of its nitrogen-fixing ability as a rotational crop. Lentils are an excellent source of fiber, protein (22%–35%), amino acid lysine, and the nutrients folate, thiamin, phosphorus, and iron. While it contains fair amounts of minerals, vitamins, and complex carbohydrates, it is low in methionine and cysteine amino acids; hence, when it is consumed with cereals such as wheat and rice, it forms a complete protein. Lentil seed and plant residues are also used for livestock feed [7]. Lentils can be used as a cover crop or green manure in semi-arid areas and have medicinal properties as well [1, 8].

The total time for lentil growth ranges from 80 to 100 days. The crop is harvested once the pods are tough (about 14% moisture is ideal); however, farmers also harvest the pods at a higher moisture rate and then dry the seeds artificially. Due to the presence of a weak stalk, low cut is advisable to minimize losses [5]. Several abiotic and biotic stresses affect lentil quality and yield. The biotic constraints include insect pests (Table 1), diseases (Table 2), and weeds, whereas abiotic stresses include nutrient disorders [deficiency of macronutrients (nitrogen, phosphorous, potassium, calcium, magnesium, sulfur) and micronutrients (iron, zinc, manganese, boron, molybdenum, copper)], nutrient toxicities (salinity, boron), herbicide injury, heat stress, waterlogging, hail injury, and frost injury [2].

Insect pests of lentil

Lentil crop is exposed to a spectrum of insect pests (Table 1). More than 30 insect pests belonging to different feeding guilds have been reported to infest lentil under field and storage conditions. The majority of the insects are reported from Asia [9–11].

- Sap sucking: Aphids [*Aphis craccivora* and *Acyrthosiphon pisum* (Hemiptera:Aphididae)], Green Stink Bug [*Nezara viridula* (Hemiptera: Pentatomidae)], Thrips [*Frankliniella* spp. (Thysanoptera: Thripidae)], Lygus bug [*Lygus hesperus*, *Lygus* spp. (Hemiptera: Miridae)].
- Chewing and biting: Cutworm [*Agrotis ipsilon* (Lepidoptera: Noctuidae)], Armyworm [*Spodoptera exigua* (Lepidoptera: Noctuidae)], Leaf weevils [*Sitona crinitus*, *Sitona macularius* (Coleoptera: Curculionidae)], Bud weevil [*Apion arrogans* (Coleoptera: Curculionidae)], Leaf miner [*Liriomyza cicerina* (Diptera: Agromyzidae)], Grasshoppers.
- Borers: Pod borer [*Helicoverpa armigera* (Lepidoptera: Noctuidae)], Lima bean pod borer [*Etiella zinckenella* (Lepidoptera: Pyralidae)], Pea Moth [(*Cydia nigricana*) (Lepidoptera: Tortricidae)].
- Storage pests: Bruchids [*Bruchus ervi*; *Bruchus lentis* (Coleoptera: Chrysomelidae)], [*Callosobruchus chinensis*, *Callosobruchus maculatus* (Coleoptera: Bruchidae)].

Sap sucking

Among sap-sucking insects, aphids (e.g., *A. craccivora*), thrips (e.g., *Frankliniella* spp.), stink bugs (e.g., *N. viridula*), and lygus bugs (e.g., *L. hesperus*) are the major pests [2, 12]. Aphids suck the sap and colonize in large numbers and secrete honeydew, which induces sooty mold on the plants. They also vector several viruses. *A. craccivora* is a vector of the *Alfalfa virus*, *Cucumber mosaic virus* (CMV), and *Lentil tobacco streak virus*. Yield is drastically reduced if infestations are early and severe. Aphids usually infest lentil at the podding stage, but if they infest at an early stage, then control is necessary [13–15]. Stink bug, *N. viridula* is a polyphagous pest that sucks the sap from leaves, stems, and pods, and thus causes malformation and drying of plants. It causes heavy damage during the reproductive stage of the plant. At least three Lygus species are major pests in lentil production. Lygus bugs pierce tender leaves, stems, buds, petioles, and developing seeds. They cause serious damage to seeds and great economic damage due to chalky spot syndrome, which is characterized by pitted, crater-like depressions in the seed coat with or without a discolored chalky appearance [2, 16–18].

Table 1. Insect pests of lentil and their geographical distribution.

S. No.	Insect pest	Asia	Africa	Europe	N. America	S. America	Australia
	Sap sucking						
1	Black Aphid *Aphis craccivora* (Hemiptera: Aphididae)	P EI	P	P	P	P	P
2	Pea Aphid *Acyrthosiphon pisum* (Hemiptera: Aphididae)	P	P	P EI	P	P	P
3	The Root Aphid (*Smynthurodes betae)* (Hemiptera: Aphididae)	P	A	NK	NK	NK	NK
4	*Macrosiphum creelii* (Hemiptera: Aphididae)	NK	NK	NK	P	NK	NK
5	Green Stink Bug (*Nezara viridula*) (Hemiptera: Miridae)	P	P	P	P	P	P
6	*Balclutha* sp. (Cicadellidae: Deltocephalinae)	P	NK	NK	NK	NK	NK
7	*Empoasca* sp. (Cicadellidae: Typhlocybinae)	P	NK	NK	NK	NK	NK
8	*Cletus signatus* (Hemiptera: Coreidae)	P	NK	NK	NK	NK	NK
9	*Graptostethus servus* (Hemiptera: Lygaeidae)	P	NK	NK	NK	NK	NK
10	*Eusarcocoris ventralis* (Hemiptera: Pentatomidae)	P	NK	NK	NK	NK	NK
11	*Piezodorus rubsofasciatus* (Hemiptera: Pentatomidae)	P	NK	NK	NK	NK	NK
12	Lygus (*Lygus lineolaris)* (Hemiptera: Miridae)	P	NK	P	P	NK	NK
13	Lygus *(Lygus hesperus)* (Hemiptera: Miridae) (Hemiptera: Miridae)	NK	NK	A	P EI	NK	NK
14	Lygus (*Lygus pratensis)* (Hemiptera: Miridae)	P	NK	P	NK	NK	NK
15	Thrips (*Frankliniella occidentalis)* (Thysanoptera: Thripidae)	P	P	P	P	P	P
16	Thrips (*Kakothrips robustus*) (Thysanoptera: Thripidae)	NK	NK	P	NK	NK	NK
17	Thrips (*Thrips angusticeps*) (Thysanoptera: Thripidae)	NK	NK	P EI	NK	NK	NK
18	Whitefly *Bemisia tabaci* (Hemiptera: Aleurodidae)	P	P	P EI	P	P	P
	Chewing and biting						
	Pod borers						
19	Black Cutworm (*Agrotis ipsilon*) (Lepidoptera: Noctuidae)	P	P	P EI	P EI	P	P
20	Armyworms (*Spodoptera exigua)* (Lepidoptera: Noctuidae)	P	P	P	P EI	NK	P
21	*Spodoptera littoralis* (Lepidoptera: Noctuidae)	P	NK	NK	NK	NK	NK
22	*Spodoptera praefica* (Lepidoptera: Noctuidae)	P	NK	NK	P	NK	NK
23	Pod borer (*Helicoverpa armigera)* (Lepidoptera: Noctuidae)	P	P	P	P	P	P
24	*Thysanoplusia oricholcea* (Lepidoptera: Noctuidae)	P	NK	NK	NK	NK	NK
25	*Trichoplusia ni* (Lepidoptera: Noctuidae)	P	NK	NK	NK	NK	NK
26	*Autographa gamma* (Lepidoptera: Noctuidae)	P	NK	NK	NK	NK	NK
27	Lima-bean pod borer (*Etiella zinckenella)* (Lepidoptera: Pyralidae)	P EI	P	P	P	P	P
28	*Etiella behrii* (Lepidoptera: Pyralidae)	P	NK	NK	P	NK	P
29	Pea Moth (*Cydia nigricana*) (Lepidoptera: Tortricidae)	NK	NK	P	P	NK	NK
30	Leaf weevil (*Sitona crinitus*) (Coleoptera: Curculionidae)	P	P	P	NK	NK	NK
31	Leaf weevil *Sitona macularius*) (Coleoptera: Curculionidae)	P	P	P	NK	NK	NK
32	Leaf weevil (*Sitona limosus*) (Coleoptera: Curculionidae)	P	NK	NK	NK	NK	NK
33	*Tychius aorominus quinonepunctatus* (Coleoptera: Curculionidae)	NK	NK	P	NK	NK	NK
34	*Hypera postica* (Coleoptera: Curculionidae)	P	NK	P	P	NK	NK
35	*Altica coerulea* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK
36	*Aulacophora foveicollis* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK
37	*Phyllotreata chotanica* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK
38	*Brumoides suturalis* (Coleoptera: Coccinellidae)	P	NK	NK	NK	NK	NK
39	*Epilachna* spp. (Coleoptera: Coccinellidae)	P	NK	NK	NK	NK	NK
40	Bud Weevil, *Apion arrogans* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK

Continued

Table 1. Continued.

S. No.	Insect pest	Asia	Africa	Europe	N. America	S. America	Australia
41	*Apion ervi* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK
42	*Apion trifolii* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK
43	*Apion pomonae* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK
44	*Apion punctigerum* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK
45	*Apion seniculus* (Coleoptera: Apionidae)	P	NK	P	NK	NK	NK
46	Leaf miners (*Liriomyza cicerina*) (Diptera: Agromyzidae)	P	P	P	NK	NK	NK
47	Leaf miners (*Phytomyza* spp.) (Diptera: Agromyzidae)	P	P	NK	NK	P	NK
48	*Chromatomyia horticola* (Diptera: Agromyzidae)	P	P	P	NK	NK	NK
49	*Ophiomyia phaseoli* (Diptera: Agromyzidae)	P	NK	NK	NK	NK	NK
50	*Contarinia lentis* (Diptera: Cecidomyiinae)	NK	NK	P	NK	NK	NK
51	*Contarinia* spp. (Diptera: Cecidomyiinae)	P	P	P	NK	NK	NK
52	*Melanoplus bivittatus* (Orthoptera: Acrididae)	P	P	NK	P EI	NK	NK
53	*Melanoplus sanguinipes* (Orthoptera: Acrididae)	P	P	NK	P	NK	NK
54	*Melanoplus packardii* (Orthoptera: Acrididae)	P	P	NK	P	NK	NK
55	*Camnula pellucida* (Orthoptera: Acrididae)	P	P	NK	P	NK	NK
	Storage pests						
56	*Bruchus ervi* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	P
57	*Bruchus lentis* (Coleoptera: Chrysomelidae)	P	P	P	NK	NK	NK
58	*Bruchus tristiculurs* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK
59	*Bruchus atomarius* (Coleoptera: Chrysomelidae)	NK	NK	P	NK	NK	NK
60	*Bruchus signaticornis* (Coleoptera: Chrysomelidae)	NK	P	P	P	NK	NK
61	*Bruchidius quinqueguttatus* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK
62	*Callosobruchus chinensis* (Coleoptera: Chrysomelidae)	P EI	P	P	P	P	P
63	*Callosobruchus maculatus* (Coleoptera: Chrysomelidae)	P	P	P	P	P	P
64	*Callosobruchus Analis* (Coleoptera: Chrysomelidae)	P	NK	NK	NK	NK	NK

A—absent; P—present; NK—not known; EI—economically important.

Chewing and biting

Among chewing and biting insects, cutworm (e.g., *A. ipsilon*), pod borers (e.g., *H. armigera*), leaf weevil (e.g., *S. crinitus*), leaf miner (*L. cicerina*), and armyworm (*S. exigua*) are important and are found in all the major lentil-producing countries. Cutworm is polyphagous species and the larvae feed on the leaves, stems, and roots of lentil. The older larvae cut the plant above the root zone. Weeds in and around the crop are the major oviposition sites. The sporadic nature of cutworm populations sometimes prevents the management of this insect pest [2, 17, 19]. Adults of leaf weevils feed on foliage and create circular notches, while larvae feed on root nodules, thus diminishing the nitrogen-fixing capability of root nodules [20]. Leaf miner larvae feed in the leaf mesophyll tissue, forming serpentine mines that later become discolored, and heavy infestation can cause desiccation and premature leaf fall [21].

Borers

Major species of pod borers on lentil are cotton bollworm (*H. armigera*), lima bean pod borer (*E. zinckenella*), pea moth (*C. nigricana*). Pod borers are a major problem in North America and Europe and less of a problem in Asia. The larvae cause damage to the leaves with early instars, scraping the surface of leaflets and feeding on flowers, while older larvae feed on foliage and are more damaging to pods. The adults are active at night and lay hundreds of eggs individually on the underside of leaflets. The last instar drops to the soil to pupate [22–24]. Lima bean pod borer is an occasional pest on lentil. Larvae of this insect feed on the soft green seeds within the pods and destroy the entire pod. Individual seeds typically show holes. Larvae generally feed on maturing pods. Pea moth is widely distributed in colder climatic conditions. The larvae attack the seeds inside the pods, and damage is detected when pods are opened. One larva can consume about six seeds [2, 16, 23].

Storage pests

Several species of Bruchids (e.g., *B. ervi*, *C. chinensis*) are known as storage pests. The adults feed on nectar and pollen and lay eggs on the young pods. Upon hatching, the larvae penetrate the pod and feed on developing seeds. Usually, single larvae feed on a single seed. Larvae eat and create a thin circular exit hole. After pupation, the emerging adult leaves the pod through this exit hole. Adults remain

Table 2. Diseases of lentil and their geographical distribution.

S. no.	Diseases	Asia	Africa	Europe	N. America	S. America	Australia
	Fungal diseases						
1	Damping off (*Pythium* spp.) (Peronosporales: Pythiaceae)	NK	NK	NK	P	NK	NK
2	Damping off (*Fusarium* spp.) (Hypocreales: Nectriaceae)	NK	NK	NK	P	NK	NK
3	Damping off (*Rhizoctonia* spp.) (Cantharellales: Ceratobasidiaceae)	NK	NK	NK	P	NK	NK
4	Pythium seed and seedling rot (*Pythium ultimum)* (Peronosporales: Pythiaceae)	P	P	P	P	P	P
5	Pythium seed and seedling rot *(Pythium irregulare)* (Peronosporales: Pythiaceae)	P	P	P	P	P	P
6	Pythium seed and seedling rot *(Pythium aphanidermatum*) (Peronosporales: Pythiaceae)	P	P	P	P	P	P
7	Fusarium root rot (*Fusarium avenaceum* and other *Fusarium* species) (Hypocreales: Nectriaceae)	P	P	P	P	P	P
8	Rhizoctonia seed, seedling, and root rot (*Rhizoctonia solani*) (Cantharellales: Ceratobasidiaceae)	P	P	P	P	P	P
9	Rhizoctonia seed, seedling, and root rot (*Thanatephorus cucumeris*) (Cantharellales: Ceratobasidiaceae)	P	P	P	P	P	P
10	Aphanomyces root rot (*Aphanomyces euteiches*) (Saprolegniales: Leptolegniaceae)	P		P	P		P
11	Black Streak root rot (*Thielaviopsis basicola*) (Microascales: Ceratocystidaceae)	P	P	P	P	P	P
12	Black root rot (*Fusarium solani*) (Hypocreales: Nectriaceae)	P	NK	NK	NK	NK	NK
13	Collar rot (*Sclerotium rolfsii*) (Atheliales:Atheliaceae)	P	P	P	P	P	P
14	Dry root rot (*Macrophomina phaseolina*) (Botryosphaeriales: Botryosphaeriaceae)	P	P	P	P	P	P
15	Dry root rot (*Rhizoctonia bataticola*) (Cantharellales: Ceratobasidiaceae)	P	NK	NK	NK	NK	NK
16	Leaf rot (*Choanephora* sp.) (Mucorales: Choanephoraceae)	P	P	P	P	P	P
17	White mold/Sclerotinia stem rot (*Sclerotinia sclerotiorum*) (Helotiales: Sclerotiniaceae)	P	P	P	P	P	P
	Disease problems during the growing season						
18	Fusarium wilt (*Fusarium oxysporum* f. sp. *lentis*) (Hypocreales: Nectriaceae)	P	P	P	P	P	NK
20	Fusarium wilt (*F. redolens*) (Hypocreales: Nectriaceae)	P	NK	P	NK	NK	NK
21	Alternaria blight (*Alternaria alternata*; *Alternaria* sp.) (Pleosporales: Pleosporaceae)	P	P	P	P	P	P
22	Anthracnose blight (*Colletotrichum lindemuthianum; Colletotrichum* species) (Glomerellales: Glomerellaceae)	P	P	P	P	P	P
23	Anthracnose blight (*Colletotrichum truncatum*) (Glomerellales: Glomerellaceae)	P EI	P	P	P EI	P	P EI
24	Ascochyta blight (*Ascochyta lentis*) (Pleosporales: Didymellaceae)	P EI	P EI	P EI	P EI	P EI	P EI
25	Stemphylium blight (*Stemphylium botryosum*) (Pleosporales: Pleosporaceae)	P EI	P EI	P EI	P EI	NK	NK
26	Stemphylium blight (*Stemphylium sarciniforme*) (Pleosporales: Pleosporaceae)	P	NK	NK	NK	NK	NK
27	Botrytis gray mold (*Botrytis cinerea*) (Helotiales: Sclerotiniaceae)	P	P	P	P	P	P
28	Botrytis gray mold (*Botrytis fabae*) (Helotiales: Sclerotiniaceae)	P	P	P	P	P	P
29	Downy mildew (*Peronospora lentis*) (Peronosporales: Peronosporaceae)	P	NK	P	P	NK	NK
30	Downy mildew (*Peronospora viciae*) (Peronosporales: Peronosporaceae)	P	NK	NK	NK	NK	NK
31	Powdery mildew (*Erysiphe pisi*) (Erysiphales: Erysiphaceae)	P	P	P	P	P	NK

Continued

Table 2. Continued.

S. no.	Diseases	Asia	Africa	Europe	N. America	S. America	Australia
32	Powdery mildew (*Erysiphe polygoni*) (Erysiphales: Erysiphaceae)	P	P	NK	NK	NK	NK
33	Powdery mildew (*Leveillula taurica*) (Erysiphales: Erysiphaceae)	P	P	P	P	P	P
34	Rust (*Uromyces viciae-fabae*) (Pucciniales: Pucciniaceae)	P	P	P	P	NK	NK
35	Cercospora leaf spot (*Cercospora cruenta*) (Capnodiales: Mycosphaerellaceae)	NK	NK	NK	P	NK	NK
36	Cercospora leaf spot (*Cercospora lentis*) (Capnodiales: Mycosphaerellaceae)	P	NK	NK	NK	NK	NK
37	Cercospora leaf spot (*Cercospora zonata*) (Capnodiales: Mycosphaerellaceae)	P	NK	P	NK	NK	NK
38	Cylindrosporium leaf spot and stem canker (*Cylindrosporium* sp.) (Helotiales: Dermateaceae)	P	NK	NK	NK	NK	NK
39	Helminthosporium leaf spot (*Helminthosporium* sp.) (Pleosporales)	P	NK	NK	NK	NK	NK
40	Phoma leaf spot (*Phoma medicaginis*) (Pleosporales: Didymellaceae)	P	NK	NK	NK	NK	NK
41	Leaf yellowing (*Cladosporium herbarum*) (Capnodiales: Davidiellaceae)	P	NK	P	P	NK	NK
42	Ozonium wilt (*Ozonium texanum* var. *parasiticum*) (Incetae sedis)	P	NK	NK	NK	NK	NK
	Bacterial diseases						
43	Bacterial blight (*Pseudomonas syringae* pv. *syringae*) (Pseudomonadales: Pseudomonadaceae)	P	P	P	P	P	P
44	Bacterial root rot (*Pseudomonas radiciperda*) (Pseudomonadales: Pseudomonadaceae)	P	NK	NK	NK	NK	NK
45	*Erwinia rhapontici* (Enterobacterales: Erwiniaceae)	P	NK	P	P	NK	P
	Virus diseases						
46	*Alfalfa mosaic virus*	P	P	P	P	P	P
47	*Bean Yellow Mosaic Virus*	P	P	P	P	P	P
48	*Cucumber mosaic virus*	P	P	P	P	P	P
49	*Faba bean necrotic yellows virus*	P	P	P	NK	NK	NK
50	Luteoviruses	P	P	P	P	P	P
51	Masterviruses	P	P	NK	NK	NK	P
52	*Pea enation mosaic virus*	P	P	P	P	NK	P
53	*Pea seed-borne mosaic virus*	P	NK	P	P	NK	P
46	*Pea Streak virus*	NK	NK	NK	P	NK	NK
	Nematodes						
47	Cyst nematode (*Heterodera ciceri*) (Tylenchida: Heteroderidae)	P	NK	P	NK	NK	NK
48	Reniform nematode (*Rotylenchulus* sp.) (Tylenchida: Hoplolaimidae)	P	P	NK	NK	P	P
49	Root-Knot nematode (*Meloidogyne* spp.) (Tylenchida: Heteroderidae)	P	P	P	P	NK	NK
50	Root-Lesion nematode (*Pratylenchus* spp.; *Zygotylenchus* spp.) (Tylenchida: Pratylenchidae	P	P	NK	P	P	P
51	Stem and Bulb nematode (*Ditylenchus dipsaci*) (Tylenchida: Anguinidae)	P	P	P	P	P	P

A—absent; P—present; NK—not known; EI—economically important.

in the seeds or hibernate in protected places such as residual crops. Adults of *C. chinensis* and *C. maculatus* can multiply in storage as well, whereas *Bruchus* species do not reproduce in the storage [2, 16, 25, 26].

Diseases of lentil

- Seed, seedling, and root diseases: Black streak root rot (*Thielaviopsis basicola*), dry root rot (*Macrophomina phaseolina*, *Rhizoctonia bataticola*), Black root rot (*Fusarium solani*), Fusarium Wilt (*Fusarium* spp., *F. oxysporum* f. sp. *lentis, F. redolens*), Collar rot (*Sclerotium rolfsii*), Rhizoctonia seed, seedling, and root rot (*Rhizoctonia solani, Thanatephorus cucumeris*) (Table 2).
- Foliar diseases: Alternaria blight (*Alternaria tenuis*), Sclerotinia stem rot (*Sclerotinia sclerotiorum*), Stemphylium blight (*Stemphylium botryosum*), Anthracnose (*Colletotrichum truncatum*), Rust (*Uromyces viciae-fabae*), Ascochyta Blight (*Ascochyta*

lentis), Powdery mildew (*Erysiphae polygoni*), Botrytis Gray mold (*Botrytis cinerea*), Downy mildew (*Peronospora lentis*).

- Viruses: *Alfalfa mosaic virus*, *Cucumber mosaic virus*, *Bean yellow mosaic virus*, *Pea seed-borne mosaic virus, Faba bean nectrotic yellows virus*, Luteoviruses, Masterviruses, *Pea enation mosaic virus*, *Pea Streak virus.*
- Nematodes: Cyst nematode (*Heterodera ciceri*) (Tylenchida: Heteroderidae)], Reniform nematode [*Rotylenchulus reniformis* (Tylenchida: Hoplolaimidae)], Root-Knot nematode [*Meloidogyne* spp. (Tylenchida: Heteroderidae)], Root-Lesion nematode *(Pratylenchus* spp.*; Pratylenchus* spp.; *Zygotylenchus* spp.), Stem and Bulb nematode (*Ditylenchus dipsaci*).

Seedling and root diseases

Fusarium wilt is a major disease and is found on almost all continents. *Fusarium oxysporum* f. sp. *lentis* is a major species that cause damage in all the lentil-growing countries, except Australia. However, *Fusarium redolens* is also reported from Europe and Asia [2, 27–29]. It affects both seedlings and reproductive stages. Wilting of top leaves, plant stunting, shrinking, and curling of leaves reduced root growth, and damaged tap root system are typical symptoms. In Asia, it is reported at the seedling stage. Synergistic interaction between fusarium wilt and root-knot nematode (*Meloidogyne* spp.) is observed in some lentil cultivars; hence, the presence of the nematodes in the field significantly increases wilt incidence [27]. Collar rot causes yellowish-brown discoloration and rotting of the infected region. Dirty white-to-brown sclerotia are visible. This proceeds downward and causes root rot. Rhizoctonia seed, seedling, and root rot, and Black Streak root rot, Pythium seedling and root disease, and black root rot are some of the minor diseases [16, 30, 31].

Foliar diseases

Stemphylium blight is a major problem in Asia and could cause more than 80% of lentil crop loss. The host range of this disease is wide. It causes small, light, beige lesions that can first be found on the upper canopy and then spreads to the lower canopy as well. This causes leaf loss and decreases plant biomass, seed size, yield, and germination rate [32, 33]. Anthracnose causes irregularly shaped, light brown necrotic, tan lesions on lower stems until plants have 8–12 nodes and finally, the plant appears blackish-brown. This is a seed-borne disease and gets transmitted from active plant infections or from spores lying dormant on foliage from past years. High humidity and temperatures are favorable for this disease [34]. Rust is also widespread all over the world and it infects all aboveground plant parts. Yellowish, white pycnidia, and aecial cups, which are single or in groups, are found on leaflets and pods in a circular pattern. When severely infected, complete crop failure occurs, producing small, shriveled seeds. Hot and dry conditions are favorable [25]. Ascochyta blight attacks all aboveground plant parts at every growth stage. It causes severe lesions on leaves, petioles, stems, and pods. When severely infected lesions girdle the stem, it causes the death of all tissues above the lesion. It also causes shriveling, discoloration of seeds, and reduction in seed quality and yield [35].

Botrytis gray mold affects aboveground plant parts including leaves, stems, flowers, pods, and seeds. The outbreak of this disease is reported in all growing regions. A series of cool, wet summers are ideal for its development. The first infection appears on flowers, pods, or lower canopy as dark-green lesions and then turns into pale, tan spots. Severely infected leaves wilt and fall and ultimately plants can die. Infected seeds are shriveled and discolored [36]. Downy mildew infects all the aerial plant parts and causes curled, twisted leaves and dwarfed tips. Cool and humid conditions are favorable. Infected plants remain stunted and form bushy apical growth. Resistant germplasm lines have been identified. Powdery mildew causes small white spots on leaf surfaces, pods, and flowers. When heavily infested, leaves become chlorotic, curled, and necrotic before abscission. This causes a reduction in yield. Cool and dry weather is favorable for this disease and it is prevalent in Asia [16, 37, 38].

Viruses

Alfalfa mosaic virus, *Cucumber mosaic virus, Lentil yellow disease, Bean yellow mosaic virus, Pea seed-borne mosaic virus, Broad bean stain, bean leaf roll virus, Faba bean necrotic yellows virus*, Luteoviruses, Masterviruses, *Lucerne mosaic virus, Pea enation mosaic virus,* and *Pea streak virus* are major virus diseases of lentil. These diseases are mostly transmitted by aphids, leafhoppers, thrips, and weevils [39]. An exclusive list of naturally occurring viruses in lentils is provided by Chen *et al.* [2]. Mostly, these diseases cause chlorosis, leaf malformation, and stunting in plants. Leaflets with *Alfalfa mosaic virus* show a mild mosaic and reddening of leaf margins. This virus is transmitted by several aphid species. *Bean yellow mosaic virus* causes infected leaves that are twisted and curled. Flowering and pod formation is reduced, and small seeds are produced by the infected plants. *Pea seed-borne mosaic virus* causes filiform leaves, indistinct mosaic patterns, mottling, chlorosis, reddening, necrotic lesions, a proliferation of stems, and abortion of pods [16, 17, 39].

Nematodes

Several parasitic nematode species infect the lentil crop (Table 2). Reniform nematode causes patches of stunted chlorotic plants. Infected plants grow less vigorously. The root-knot nematode has a wide host range and causes excessively branched and galled roots. It aids in fusarium

fungus entry into the roots. Root-lesion nematode also causes stunted growth and due to uneven patches gives the appearance of waviness across the field [16, 40, 41].

Weeds

Lentils do not compete well with weeds; therefore, management of weeds before lentil establishment is critical [5, 42]. Other than broadleaf weeds and grasses, parasitic weeds can also be problematic for lentil crop. Parasitic crenate broomrape (*Orobanche crenata*), Egyptian broomrape (*O. aegyptiaca*), and dodder (*Cuscuta campestris*) pose a serious problem in the Middle East [2]. Field preparation, irrigation scheduling, careful harrowing, proper sowing, and crop establishment play an important role in the cultural management of weeds [43, 44].

IPM strategies for lentil crop

Breeding techniques for lentil around the globe target biotic stress (resistance to the black aphid, pod borers, fusarium wilt, root rot, ascochyta blight, rust, stemphylium blight). The International Center for Agricultural Research in the Dry Areas (ICARDA) holds the largest collection of lentil accessions [45]. Wild lentil species are evaluated keeping the major agroecological regions of lentil production in mind. The agroecological regions included are South Asia and East Africa, low-to-medium elevations in the Mediterranean, High elevation (Asia), Central Asia, and the Caucasus, and Latin America [46].

Cultural management includes proper soil preparation, maintaining soil nutrients, crop rotation, selection of certified disease-free seeds, deep plowing, weed-free fields, removal and destruction of crop residue, soil sanitation to maintain problem-free conditions for proper lentil growth, and the management of soil-borne diseases. The use of sticky and pheromone traps to monitor and manage insect pests is also helpful. Timely sowing and change in seeding dates depending on the agroecological regions, climatic conditions, lentil cultivar, and target insect pests and diseases are highly recommended [19, 47]. Resistant varieties are known for aphids, *H. armigera*, *E. zinckenella*, *S. crinitus*, fusarium wilt, ascochyta blight, rust, and stemphylium blight [2, 11], indicating that breeding for inducing plant defense, genetic transformation (to use *Bacillus thuringiensis* gene), and mutation breeding for inducing monogenic resistance to insects in lentil hold potential for managing insect pests in lentil.

Biological management is an important part of the IPM of lentil insect pests. Most of the major insect pests of lentil are polyphagous and also infest other crops. Several commonly found predators, such as syrphid flies, rove beetles, green lacewing, ladybird beetles, and carabid beetles, are known to feed on the majority of the insect pests of lentil. Aphids, armyworms, pod borers, and cutworms have several parasitoids known to occur. A detailed list of all the natural enemies known for lentil insect pests is cited by Chen *et al.* [2], Ujagir and Byrne [11], and Sithanantham *et al.* [48].

Microbials and biopesticides are environmental-friendly options available to manage diseases and insect pests of lentil in all the cultivated regions. Major microbials include entomopathogenic fungus (*Trichoderma* sp., *Beauveria bassiana*, *Metarhizium* sp.), entomopathogenic nematodes (*Steinernema* sp.), entomopathogenic bacteria (*B. thuringiensis*), and entomopathogenic virus (nuclear polyhedrosis viruses). Neem products (*Azadirachta indica*), *Pongamia* sp., citrus oil, and pyrethrins are some of the major biopesticide products easily available around the globe and can help in the conservation of natural enemies as well.

In general, chemicals are not frequently utilized in lentil crop, especially for insect damage. However, chemical control is the most readily available and rapid method to manage insects and diseases. Also, the economic threshold level (ETL) and economic injury level (EIL) for different pests in various agroecological regions are known. Selective pesticides are available to treat target problems in lentil crop and only need-based applications of pesticides enable the conservation of natural enemies in lentil crop. Heavy infestation of aphids, lygus, armyworms, and pod borers usually requires chemical control. Seed treatment helps in virus management and soil and seed-borne diseases, especially in susceptible varieties [2, 19, 25, 43, 47, 49, 50]. More details about IPM strategies for major insect pests, diseases, and weeds are provided in Tables 3 and 4.

Conclusion

Lentil is a cool-season crop and is grown in various agroecological conditions, including cool temperate to subtropical dry conditions. Lentil provides a good yield in tropical conditions. Local environments are important in the evolution of lentil, and matching this crop's phenology to an environment, including climate and soil, is a key part of improving adaptation and increasing lentil yields. Lentil as a crop provides an excellent option for crop rotation in monoculture practices such as in North American agricultural practices and also polyculture agricultural practices in Asian countries. Lentil as a leguminous crop fixes nitrogen and hence functions as a critical crop to be rotated with cereal crops, especially in nitrogen-poor soils. Major constraints for lentil crop are soil preparation, maintaining appropriate fertilizers, management of weeds, insect pests, and diseases. The pest status of the insect pest species and diseases varies across locations and control measures for each species, group of insects, and diseases also depend on farming practices and availability of the resources in the country. General cultural management practices include crop rotation and management of plant canopy. Use of tolerant and resistant varieties and judicial use of biopesticides and chemical pesticides at the flowering and/or podding stage is recommended. Several naturally available microbials are useful to manage diseases

Table 3. IPM strategies for major insect pests, diseases, and weeds of lentil.

	Target	Management	References
1	Aphids	• Monitoring • Aphid-resistant varieties • Biological control: several natural enemies such as predatory coccinellids, lacewings, hoverfly, predatory midges, and braconid wasps are known around the globe • Biopesticides: neem products, pyrethrins • Insecticides	[2,10,14,15]
2	Thrips	• Cultural management: changing planting dates • Biological control: predatory mite, *Amblyseius* spp. • Microbials: entomopathogenic fungus, *Entomophthora* spp. • Insecticides	[2,12]
3	Green stink bug	• Cultural management: soya bean as trap crop, narrow-row planting, early planting • Biological control: parasitoids *Trissolcus basalis*, *Trissolcus megallocephalus*, *Trichopoda pilipes*, *Trichopoda giacomellii*, fire ant *Solenopsis invicta*, and grasshoppers are predators • Microbials: Entomopathogenic fungus, *Beauveria bassiana*, *Metarhizium anisopilae*, *Paecilomyces lilacinus* • Biopesticides: sprays of *Aglaia odorata*, *Annona squamosa*, *A. muricata*, *Melia azedarch*, and *Carica papaya* • Insecticides	[2,10]
4	Lygus	• Cultural management: weed management • Biological control: several parasitoids and predators have been recorded Microbials: Entomopathogenic fungus, *Beauveria bassiana*, *Metarhizium anisopilae*, *Paecilomyces lilacinus, Bacillus thuringiensis*	[2,10,18]
5	Armyworm	• Monitoring: pheromone traps • Biological control: common natural enemies of *S. exigua* in U.S. agricultural crops are braconids (*Chelonus insularis*, *Cotesia marginiventris*, and *Meteorus autographae*) and a tachinid (*Lespsia archippivora*), and in Asia are *Campoletis chlorideae* (Hymenoptera: Ichneumonidae). Predators such as pirate bugs, damsel bugs, and shield bugs attack eggs and larvae. Nuclear polyhedrosis virus (NPV) • Biopesticides: *Beauveria bassiana* and *Nomuraea rileyi* • Insecticides	[2,10,19]
6	Cutworm	• Monitoring: pheromones traps, yellow white traps, and light traps • Biological control: parasitoids, *Trichogramma* spp., *Apanteles marginiventris, Microplitis* sp*., Campoletis flavicincta*, *Hyposoter annulipes, Ophion flavidus*, *Microgaster* sp., *Bracon kitcheneri*, and *Fileanta ruficanda,* tachinid flies, and predators *Broscus punctatus* and *Liogryllus bimaculatus* • Microbials: *Metarhizium anisopliae,* NPV, *Steinernema carpocapsae, Hexamermis arvalis* • Insecticides	[2,10,11]
7	Pod borer	• Monitoring: pheromone traps • Cultural management: time of sowing and spacing • Biological control: dipteran and hymenopteran parasitoids, (*Trichogrammatoidea bactrae-bactrae*, *Macrocentrus ancylovorus, Bracon piger, Apanteles beaussetensis, Bracon pectoralis, Phanerotoma planifrons* and *Cyrtotyx lichtensteini*., lacewings, *H. armigera* Nucleopolyhedrosis Virus (HaNPV)) • Biopesticides: neem products, *Pongamia pinnata* kernel extract • Microbials: entomopathogenic bacterium and fungus (Bt, *Beauveria bassiana, Nomuraea rileyi*), and nematodes • Insecticides	[2,11,22,24]
8	Lima pod borer	• Host plant resistance: short duration genotypes are susceptible compared to medium and long duration genotypes. • Biological control: the parasitoids *Bracon etiellae*, *Bracon pectoralis*, *Phanerotoma planifrons*, and *Pigeria piger* have been reported on larvae but none of them have been evaluated for classical biological control. • Insecticides	[2,10]
9	Pea moth	• Monitoring: pheromone traps • Cultural management: timing of sowing, weed management, short duration genotypes • Biological control: egg parasitoid, *Trichogramma evanescens*	[2,16]
10	Leaf weevil	• Cultural management: crop rotation, weed management, early sowing • Host plant resistance: different *Sitona*-resistant lentil varieties are available in various countries • Insecticides	[2,10]

Continued

Table 3. Continued.

	Target	Management	References
11	Bruchids	• Monitoring: pitfall traps for capturing insects on grain • Cultural management: harvesting crop at physiological maturity, solar treatment, hot air and water treatment, and drying are major cultural management methods, Purdue Improved Crop Storage Bags (PICS) • Biological control: at least 10 species of parasitoids are known to attack different bruchid species • Biopesticides: neem products, Volatile oils of *Cymbopogan nardus*, *C. schoenanthus*, *Clausena anisata, C. citratus,* and *Ocimum basilica*	[2,10]
12	Leaf miner	• Cultural management: early planting • Biological management: six braconids and 12 eulophids parasites are known. • Insecticides	[2,10]
13	Aphanomyces root rot	• Cultural management: selection of pathogen-free field with proper water drainage • Fungicides as seed treatment	[2]
14	Black streak root rot	• Cultural management: rotation with less susceptible crop • Fungicide application is not recommended.	[2]
15	Rhizoctonia seed, seedling, and wet root rot	• Cultural management: crop rotation, disease-free seeds, well-drained soil • Fungicides	
16	Verticillium wilt	• Cultural management: crop rotation, disease-free seeds	
17	Stemphylium blight	• Cultural management: destruction of old infected crop residue, crop rotation • Resistant varieties (Barimasur-4, Barimasur-5, and Barimasur-6 are released in Asia) • Fungicides	[2,17,32]
18	Fusarium wilt	• Cultural management: clean seeds, selection of suitable planting dates • Resistant and early maturing cultivars are available in several countries. • Fungicides	[2,17]
19	Collar rot	• Cultural management: wide row spacing, use of calcium fertilizers, covering of soil with polyethene in summer, organic soil amendments with oat, wheat and maize straw • Microbials: soil/seed application of *Trichoderma harzianum*, *T. viridae*, *Bacillus subtilis*, *Pencillium* spp., and *Gliocladium virens* can be used to manage collar rot • Resistant varieties are available in Asia	[2,16]
20	Rust	• Cultural management: control of volunteer plants over summer, isolation of new season crops, destruction of old lentil stubbles • Monogenic-resistant cultivars are available • Fungicides, seed treatment, and foliar application	[2,17]
21	Botrytis gray mold	• Cultural management: avoid dense canopy, seed sanitation, destruction of infected crop residue, sowing dates, weed control and optimum fertilizer use, particularly avoiding high nitrogen levels • Microbials: bacteria *Pantoea agglomerans, Pseudomonas fluorescens, Penicillium griseofulvum,* and the fungus *Trichoderma* spp. reduce severity of botrytis gray mold • Resistant varieties are less explored. Lentil variety “Nipper” was released in 2006 from the Australian lentil breeding program with resistance to both botrytis gray mold and Ascochyta blight	[2,17,32]
22	Ascochyta blight	• Cultural management: sun drying, hot water treatment, and dry heat treatment of seeds, three-year break between lentil crop • Resistant varieties • Fungicides	[2,17,32]
23	Anthracnose	• Cultural management: use of pathogen free seeds, three-year period without lentil, crop rotation • Tolerant varieties are available in North America. • Fungicides as seed treatment and foliar application	[2,17]
24	Powdery mildew	• Resistant varieties • Fungicides	[2]
25	Sclerotinia stem rot	• Cultural management: in heavily infested fields, long rotations can be helpful, reduced plant density • Some tolerant varieties are known • Fungicide application is not economical	[2,31]
26	Nematodes	• Cultural management: crop rotation, soil solarization, soil amendments such as oil seed cakes • Resistant varieties • Microbials: soil/seed application of *Trichoderma harzianum*, *T. viridae*, *Pasteuria penetrans* • Biopesticides: cakes of *Pongamia glabra*, *Linum usitatissimum*, *Madhuca indica*, and neem	[2,28]

Continued

Table 3. Continued.

	Target	Management	References
27	Virus	• Cultural management: virus free seeds, managing vector insect pests • Resistant varieties • Pesticides	[2]
28	Weeds	• Tillage • Careful harrowing • Use of herbicide-tolerant cultivars • Keep field boundary and bunds free from weeds • The crop field should be weed free initially for 4–5 weeks, followed by timely hoeing and weeding • Inter-culture operation/hoeing should be done twice at 20 and 35 days after sowing using hand-hoe to remove all weeds in between the rows	[25,45]

Table 4. Lentil IPM package.

Crop stage	Management tactic	Purpose
Pre-planting		
Field preparation	Soil sanitation to manage soil-borne diseases and soil-inhabiting insect pests Organic soil amendments and mulching with oat or maize straw can be used Soil-inhabiting fungus *Paecilomyces lilacinus* used with neem cake controls nematode infestation in the field Soil application of neem cake, castor cake, mustard cake, or cotton cake controls nematode infestation Inoculation with *Rhizobium leguminosarum* bacterium Remove alternate host plants and weeds	Management of soil-borne diseases and nematodes
Seed selection	Select pure high-quality certified seeds that are free of disease, weed seeds, and insect damage Select insect/disease-resistant varieties Soil/seed application of *Trichoderma harzianum*, *T. viridae*, *Bacillus subtilis*, *Pencillium* spp., and *Gliocladium virens* can be used to manage collar rot Seed treatment *Trichoderma* sp., *Streptomyces pseudomonas*, and *Bacillus* spp. to manage fusarium wilt/root rot of lentil	Management of seed-borne diseases and seed-inhabiting insects
Sowing	Timely sowing Space between the seedlings be managed as per landscape Wide row spacing to reduce insect pest incidence Changes in planting dates to avoid infection and infestation of some diseases and insect pests	Avoiding seedling diseases and insect infestation
Vegetative growth to maturity	Crop rotation to reduce disease incidence Changes in planting dates to avoid infection and infestation of some diseases and insect pests Weed management in the field Canopy management to reduce disease incidence Foliar application of neem kernel extracts, neem oil, and pyrethrins to control insect pests If pesticide applications are necessary use safe chemical pesticides Soil application of neem cake, castor cake, mustard cake, and cotton cake to control nematode infestation Bacteria *Pantoea agglomerans*, *Pseudomonas fluorescens*, *Penicillium griseofulvum*, and the fungus *Trichoderma* spp. to reduce severity of botrytis gray mold and other soil/seed-borne diseases Use of sticky and pheromone traps to monitor and manage aphids, thrips, pod borers, armyworm	Management of insect pests and diseases to maintain good quality and yield
Harvest	Desiccation or swathing for timely harvest in cold regions Use of taller, non-lodging cultivars that mature evenly and retain their pods and seeds at maturity to allow mechanical harvesting	Maximum yield without losing crop during harvesting
Storage	Dry pods and seeds with less than 12% moisture Store seeds in a cool, dry, airtight place Sundry seeds before storage Use of Purdue improved crop storage bag and other safe bag	Insect and disease-free seeds

and insect pests of lentil without causing harm to humans, the environment, or natural enemies. Several biological control agents are also known for various insect pests.

IPM includes the effective use of various pest control measures to manage pest populations with minimum damage to the environment. IPM approaches should be modified based on agroecological regions. Documentation of crop-loss assessment due to biotic stresses in different agroecological zones and mapping of appropriate sowing time based on specific location is required. Systematic studies on host plant resistance against key endemic pests and the biochemical/biophysical basis for such resistance can make rapid progress in the development of insect-resistant cultivars. Development of multiple resistances and moderate resistance against key pests of the area should be the research priorities. Decent information about natural enemies is available; however, a better understanding of the augmentative release of biological control agents is needed. Identification of other plant-based pesticides will also improve sustainable lentil production.

Acknowledgment

This study was funded by USAID (Lead award number: AID-OAA-L-15-00001; FTFNIPM Cooperative Agreement No: 72036720LA 00001) to the Feed the Future Innovation Lab for Integrated Pest Management (IPM IL) managed by Virginia Tech, Blacksburg, Virginia.

References

1. Sandhu JS, Singh S. History and origin. In: Yadav SS, McNeil D, Stevenson PC, editors. Lentil: an ancient crop for modern times. Dordrecht, The Netherlands: Springer; 2007. p. 331–48.
2. Chen W, Sharma HC, Muehlbauer FJ. Compendium of chickpea and lentil diseases and pests. St. Paul, Minn.: American Phytopathological Society; 2011.
3. Erskine W, Sarker A, Ashraf M. Reconstructing an ancient bottleneck of the movement of the lentil (*Lens culinaris* ssp. *culinaris*) into South Asia. Genetic Resources and Crop Evolution 2010;58:373–81.
4. Muehlbauer FJ, Cubero JI, Summerfield RJ. Lentil (*Lens culinaris* Medic.). In: Summerfield RJ, Roberts EH editors. Grain Legume Crops. London, UK: Collins; 1985. p. 266–311.
5. Oplinger ES, Hardman LL, Kaminski AR, Kelling KA, Doll JD. Lentil. Alternative field crop manual [online]. Madison, WI and St. Paul, MN: University of Wisconsin Cooperative Extension and University of Minnesota Extension Service; 1990. Available from: https://hort.purdue.edu/newcrop/afcm/lentil.html
6. Muehlbauer FJ, Summerfield RJ, Kaiser WJ, Clement SL, Boerboom CM, Welsh-Maddux MM, Short RW. Principles and practice of lentil production. Pullman, WA: USDA-Agricultural Research Service; 2002. Available from: http://www.ars.usda.gov/is/np/lentils/lentils.htm [Accessed: 17 August 2015].
7. Cash D, Lockerman R, Bowman H, Welty L. Growing lentils in Montana. Montana State University extension guide MT199615. Bozeman, MT: Montana State University; 2001.
8. Pavek PLS, McGee R. Plant guide for lentil (*Lens culinaris* Medik.). Pullman, WA: USDA-Natural Resources Conservation Service, Pullman Plant Materials Center; 2016.
9. Lal SS. Insect pest of lentil and their management: review. Agricultural Reviews 1992;13:225–32.
10. Stevenson PC, Dhillon MK, Sharma HC, Bouhssini MEL. Insect pests of lentil and their management. In: Yadav SS, McNeil D, Stevenson PC, editors. Lentil: an ancient crop for modern times. Dordrecht, The Netherlands: Springer; 2007. p. 331–48.
11. Ujagir R, Byrne OM. Insect pests and their management. In: Erskine W, Muehlbauer FJ, Sarker A, Sharma B, editors. The lentil botany, production and uses. London, UK: CAB International; 2009. p. 282–305.
12. Andueza P, Mozos G, de Los PM, Portillo RM. Main pests of lentil in Castilla La Mancha: crop losses and influence on yield parameters. Boletin de Sanidan Vegetal Plagas 2004;30:763–72.
13. Makkouk KM, Kumari SG. Reduction of incidence of three persistently transmitted aphid-borne viruses affecting legume crops by seed treatment with the insecticide imidacloprid (GauchoR). Crop Protection 2001;20:433–37.
14. CABI (Commonwealth Agricultural Bureau International). *Acyrthosiphon pisum.* Distribution maps of plant pests, December 1982, Map 23. Wallingford, UK: Commonwealth Agricultural Bureau International; 1982.
15. CABI (Commonwealth Agricultural Bureau International) *Aphis craccivora*. Distribution maps of plant pests. Map 99. Wallingford, UK: Commonwealth Agricultural Bureau International; 1983.
16. Beniwal SPS, Bayaa B, Weigand S, Makkouk KH, Saxena MC. Field guide to lentil diseases and insect pests. 1993. Available from: http://www.icarda.org/Publications/Field_Guides/Lentil/Lentil.htm.
17. Taylor P, Lindbeck K, Chen W, Ford R. Lentil diseases. In: Yadav SS, McNeil D, Stevenson PC, editors. Lentil: an ancient crop for modern times. Dordrecht, The Netherlands: Springer; 2007. p. 291–313.
18. CABI (Commonwealth Agricultural Bureau International). *Lygus lineolaris*. *Distribution maps of plant pests*. Map 604. Wallingford, Oxfordshire, UK: Commonwealth Agricultural Bureau International; 2000.
19. Clement SL, Wightman JA, Hardie DC, Bailey P, Baker G, McDonald G. Opportunities for integrated management of insect pests of grain legumes. In: Knight R, editor. Linking research and marketing opportunities for pulses in the 21st century. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2000. p. 467–80.
20. Erman M, Yardm EN, Kulaz H. Effect of cultivars and insecticides on sitonid weevil, *Sitona crinitus* (Coleoptera: Curculionidae), and on yield, yield components and nodulation of lentil (*Lens culinaris*). Indian Journal of Agricultural Sciences 2005;75:204–6.
21. Bhatnagar A, Seghal VK. Incidence and seasonal occurrence of insect fauna associated with lentil crop in northern India. Lens Newsletter 1990;17:21–6.

22. Commonwealth Agricultural Bureau International (CABI). Distribution maps of plant pests, no. 15. Wallingford, UK: Commonwealth Agricultural Bureau International; 1993.

23. Jaglan MS, Sucheta, Khokhar KS. Lentil pod borer (*Etiella zinckenella* Treitschke), biology on lentil and pea. Lens Newsletter 1996;23:48–51.

24. Sharma HC. *Heliothis/Helicoverpa* management: emerging trends and strategies for future research. New Delhi, India: Oxford and IBH Publishers; 2005. p. 469.

25. Erskine W, Tufail M, Russell A, Tyagi MC, Rahman MM, Saxena MC. Current and future strategies in breeding lentil for resistance to biotic and abiotic stresses. Euphytica 1994;73:127–35.

26. Bhalla S, Kapur ML, Singh C, Gupta K, Kumar N, Lal B. Interception of bruchids in imported lentil (*Lens* spp.) germplasm. Indian Journal of Agricultural Sciences 2004;74:332–3.

27. Chaudhary RG, Amarjit K. Wilt disease as a cause of shift from lentil cultivation in Sangod Tehsil of Kota, Rajasthan. Indian Journal of Pulses Research 2002;15:193–4.

28. Riccioni L, Haegi A, Valvassori M. First report of vascular wilt caused by *Fusarium redolens* on lentil in Italy. Plant Disease 2008;92:1132.

29. Tiwari N, Ahmed S, Kumar S, Sarker, A. Fusarium wilt: a killer disease of lentil. In: Asku T, editor. Fusarium-plant diseases, pathogen diversity, genetic diversity, resistance and molecular markers. Rijeka, Croatia: IntechOpen; 2018.

30. Sarker A, Erskine W. Lentil production in the traditional lentil world. In: Brouwer JB, editor. Proceedings of lentil focus, Horsham, Victoria, Australia. Sydney: Pulse Australia; 2002. p. 35–40.

31. Akem C, Bellar M, Bayaa B. Comparative growth and pathogenicity of geographical isolates of *Sclerotinia sclerotiorum* on lentil genotypes. The Plant Pathology Journal 2006;5:67–71.

32. Bayaa B, Erskine W. Diseases of lentils. In: Allen DJ, Lenné JM, editors. The pathology of food and pasture legumes. Wallingford, UK: CAB International; 1998. p. 423–71.

33. Mwakutuya E. Epidemiology of Stemphylium blight on lentil (*Lens culinaris*) in Saskatchewan [MSc thesis]. University of Saskatchewan, Saskatoon: Department of Plant Sciences; 2006.

34. Ford R, Banniza S, Photitia W, Taylor PWJ. Morphological and molecular discrimination of *Colletotrichum truncatum* causing anthracnose on lentil in Canada. Australasian Plant Pathology 2004;33:559–69.

35. Pedersen EA, Morrall RAA, McCartney HA, Fitt BDL. Dispersal of conidia of *Ascochyta fabae* f sp. *lentis* from infected lentil plants by simulated wind and rain. Plant Pathology 1994;43:50–5.

36. Davidson JA, Pande S, Bretag TW, Lindbeck KD, Krishna-Kishore G. Biology and control of *Botrytis* spp. in legume crops. In: Elad Y, Williamson B, Tudzynski P, Delen N, editors. Botrytis: biology, pathology and control. Dordrecht, The Netherlands: Kluwer; 2004. p. 295–318.

37. Attanayake RN, Glawe DA, Dugan FM, Chen W. *Erysiphe trifolii* causing powdery mildew of lentil (*Lens culinaris*). Plant Disease 2009;938:797–803.

38. Attanayake RP, Glawe D, McPhee K, Dugan F, Chen W. Taxonomic complexity of powdery mildew pathogens found on lentil and pea in the US Pacific Northwest. Phytopathology 2008;98:S15.

39. Kumari SG, Larsen R, Makkouk KM, Bashir M. Virus diseases and their control. In: Erskine W, Muehlbauer FJ, Sarker A, Sharma B, editors. The lentil botany, production and uses. London, UK: CAB International; 2008. p. 306–25.

40. Agrawal SC, Prasad KVV. Diseases of lentil. Enfield, New Hampshire: Science Publisher Inc.; 2004.

41. Sikora RA, Greco N, Silva JFV. Nematode parasites of food legumes. In: Luc M, Sikora RA, Bridge J, editors. Plant parasitic nematodes in subtropical and tropical agriculture. Wallingford, UK: CAB International; 2005. p. 259–318.

42. Cash D, Lockerman R, Bowman H, Welty L. Growing lentils in Montana. *MontGuide MT199615AG*. Bozeman, Montana, USA: Montana State University Extension Service; 2001.

43. Erskine W, Muehlbauer FJ, Sarker A, Sharma B. The lentil botany, production and uses. London, UK: CAB International; 2009.

44. Preston C. Managing an eternal pest—weeds. In: Brouwer JB editor. Proceedings of lentil focus 2002, Horsham, Victoria, Australia. Sydney: Pulse Australia; 2002. p. 69–73. Available from: admin@pulseaus.com.au

45. Kumar J, Gupta S, Gupta P, Dubey S, Tomar RSS, Kumar S. Breeding strategies to improve lentil for diverse agro-ecological environments. Indian Journal of Genetics 2016;76:530–49.

46. Sarker A, Aydogan A, Chandra S, Kharrat M, Sabaghpour S. Genetic enhancement for yield and yield stability. In: Erskine W, Muehlbauer FJ, Sarker A, Sharma B, editors. The lentil botany, production and uses. London, UK: CAB International; 2009. p. 102–20.

47. Weigand S, Lateef SS, El Din NES, Mahmoud SF, Ahmed K, Ali K. Integrated control of insect pests of cool season food legumes. In: Expanding the production and use of cool season food legumes. Proceedings of the Second International Food Legume Research Conference on Pea, Lentil, Faba Bean, Chickpea, and Grasspea; 12–16 April 1992; Cairo, Egypt. Dordrecht, Netherlands: Kluwer Academic Publishers Group; 1994. p. 679–94.

48. Sithanantham S, Singh SP, Romies J. Biological control of *Helicoverpa*: research status, conservation and opportunities. In: Sharma HC, editor. *Heliothis/Helicoverpa* management: emerging trends and strategies for future research. New Delhi, India: Oxford and IBH Publishing Co. Ltd; 2005. p. 327–69.

49. Chen W, Basandrai AK, Basandrai D, Banniza S, Bayaa B, Buchwaldt L, et al. Diseases and their management. In: Erskine W, Muehlbauer FJ, Sarker A, Sharma B, editors. The lentil botany, production and uses. London, UK: CAB International; 2009. p. 262–81.

50. Sharma OP, Singh SK, Vennila S, Bhagat S, Saini MR, Kumari A, Chattopadhyay C. Field guide of lentil pest and their management. ICAR Technical Bulletin No. 36. 2014. p. 36.