Datasheet

Anguina tritici (bunted wheat)

Index

Summary

Last modified
07 May 2015

Datasheet Type(s)
Pest

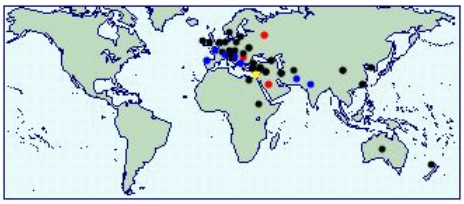
Preferred Scientific Name
Anguina tritici

Preferred Common Name
bunted wheat

Taxonomic Tree
Domain: Eukaryota
Kingdom: Metazoa
Phylum: Nematoda
Family: Anguinidae
Genus: Anguina
Species: Anguina tritici

Host plants
Avena sativa (oats)
Hordeum vulgare (barley)
Secale cereale (rye)
Triticum (wheat)
Triticum aestivum (wheat)
More...

More information



More information

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Pictures

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Picture	Title	Caption	Copyright
	Adult - line drawing	A female wheat seed gall nematode. (After Thorne). Reproduced from Esser RP, O'Bannon JH, Clark RA, 1991. Procedures to detect wheat seed gall nematode (Anguina tritici) should an infestation appear in Florida. Nematology Circular No. 186. Florida, USA: Florida Department of Agriculture and Consumer Services.	R.P. Esser
	Female	Brightfield light micrograph of a female wheat gall nematode, as seen under low power magnification.	J.D. Eisenback/Nemapix Vol. 1
	Symptoms on wheat spikes	Galled and healthy wheat spikes. Three wheat spikes infested with A. tritici on left compared with healthy spike on right.	R.P. Esser
	Infected wheat seed	Healthy wheat seeds (top) and seed galls infected with A. tritici (below).	R.P. Esser
	Galls - line drawing	A. tritici is detected by the presence of brown or black rounded galls among threshed grain.	R.P. Esser

Identity

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Preferred Scientific Name

Anguina tritici (Steinbuch, 1799) Chitwood, 1935

Preferred Common Name

bunted wheat

Other Scientific Names

Anguillula tritici Grube, 1849
Anguillulina tritici (Steinbuch) Gervais & Van Beneden, 1859
Rhabditis tritici Dujardin, 1845
Tylenchus scandens (Schneider) Cobb
Tylenchus tritici (Steinbuch) Bastian, 1865
Vibrio tritici Dujardin, 1845

International Common Names

English: cockle wheat; earcockles; eelworm disease; hard smut; purples; wheat nematode; wheatgall nematode
Spanish: anguillado del trigo; anguilulosis del trigo; falso tizon del trigo

French: anguillule du ble; anguillulose du ble nielle; nielle du ble

Local Common Names

Denmark: hvedeal; hvedegallnematod
Germany: Gichtkoerner des Weizens; Kaulbrand; Radekrankheit des Weizens; radenkrankheit; Weizen-Aelchen
India: tundu
Italy: Anguillula del frumento
Japan: Komugi-tubu-sentyu; Tubu-sentyubyo
Netherlands: Tarweaaltje
Sweden: froegallnematod pa vete
Turkey: bugday gal nematodu

EPPO code

ANGUTR (Anguina tritici)

Taxonomic Tree

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Domain: Eukaryota
Kingdom: Metazoa
Phylum: Nematoda
Family: Anguinidae
Genus: Anguina
Species: Anguina tritici

Description

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Measurements

(After Goodey, 1932):

Females: L = 3-5 mm; a = 25-30; b = 20-25; c = 32-50; V = 90-94.
Males: L = 2-2.5 mm; a = 25-29; b = 12-13; c = 25-28.

Second stage juveniles: L = 0.8-0.95 mm; width = 15-20 µm.

Eggs: 85 x 38 µm (mean).

(After Filipjev and Schuurmans Stekhoven, 1941):

Females: L = 4.1-5.2 mm; a = 21; b = 19; c = 30; V = 88-97; spear = 9-11 µm.
Males: L = 1.9-2.5 mm; a = 30; b = 13; c = 14; spear = 9-11 µm.

First-stage juveniles: L = 0.5-0.6 mm; a = 42; b = 4.5.

Second-stage juveniles: L = 0.8-1.0 mm.

Eggs: 85 x 39 µm (73-140 x 33-63 µm).

(After Swarup and Gupta, 1971):

Eggs (n = 25); L = 75.6 - 102.3 µm (87.1 ± 7.8 µm).

Breadth = 34.9 - 53.5 µm (43.8 ± 5.3 µm).

Second-stage juveniles: (n = 20): L = 0.75-0.79 mm (0.77 mm); a = 47-59 (54); b = 4.0-6.3 (4.5); c = 23-28 (26); stylet = 10 µm.

Third-stage female (n = 4): L = 1.11-1.55 mm (1.26 mm); a = 28-40 (32); b = 9.3-10.2 (9.8); c = 20.0-22.2 (21.1).

Third-stage male (n = 6): L = 1.10-1.23 mm (1.11 mm); a = 26-42 (36); b = 6.4-8.2 (7.6); c = 10.2-13.4.

Fourth-stage female (n=12); L = 1.45-1.92 mm (1.86); a = 21.0-26.5 (22.4); b = 9.6-18.4 (13.2); c = 20.0-35.4 (32.3).

Fourth-stage male (n = 2): L = 1.76, 1.82 mm; a = 25.4, 29.1; b = 7.5, 9.4; c = 15, 20.

Adult female (n=22); L = 2.64-4.36 mm (3.24 ± 0.37 mm); a = 13.2-22.2 (17.98 ± 8.10); b = 9.8-19.40 (13.98 ± 2.50); c = 24-63 (36.4 ± 9.12); V = 70.4-89.8 (80.7 ± 6.84).

Adult male (n = 18); L = 2.04-2.40 mm (2.19 ± 0.32 mm); a = 21.2-30.0 (26.58 ± 2.05); b = 6.30-11.0 (9.29 ± 0.91); c = 17.0-23.8 (19.70 ± 1.55); T = 66.70-81.40 (75.40 ± 3.18).

Other measurement data in Marcinowski (1909) and Byars (1920).

No type specimens extant.

Description

General
Annules very fine, usually visible only in oesophageal region; lateral fields with four or more fine incisures, in adults visible only on young specimens. Lip region low and flattened, slightly offset; lips visible as six raised, radial ridges. Procorpus of oesophagus swollen but constricted at junction with median bulb. Oesophageal glands forming a roughly pyrifom bulb but varying in shape and sometimes showing irregular lobes, not overlapping intestine; cardia small. Tail conoid, tapered to an obtuse or rounded tip.

Chromosomes: 2n = 38.

Female: Body obese, spirally coiled ventrally when relaxed by heat. Isthmus of oesophagus sometimes swollen posteriorly ('storage gland' of Thorne, 1949) then offset from glandular region by a deep constriction. Anterior branch of genital tract greatly developed; ovary usually with two or more flexures, with many oöcytes arranged about a rachis and ending distally in a cap cell (according to Triantaphyllou and Hirschmann (1966) the latter is a terminal epithelial cell). Spermatheca ± pyriform, its broader end separated from oviduct by a sphincter, its narrower end merging into uterus. Posterior genital branch a simple post-vulval sac. Vulval lips prominent. Several eggs may be present in uterus at one time.

Male: Body sometimes curved dorsally when heat relaxed, i.e. ventral surface outermost. Testis with one or two flexures; spermatocytes arranged about a rachis, ending distally in a cap cell. Vas deferens about 200 µm long, separated from testis by a constriction. Spicules paired, stout, arcuate, each having two ventral ridges running from tip to widest part: the head rolled or folded ventrally. Gubernaculum simple, trough-like. Bursa arises just anterior to spicules and ends just short of tail-tip.

Distribution

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There is evidence that this species is becoming extinct or rare in regions where it has been reported in the past. Therefore older records should be treated with caution.

Distribution Table

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The distribution in this summary table is based on all the information available. When several references are cited, they may give conflicting information on the status. Further details may be available for individual references in the Distribution Table Details section which can be selected by going to Generate Report.

Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
ASIA							
Afghanistan	Present					Brown, 1987; CABI/EPPO, 2002; EPPO, 2014	
Azerbaijan	Present					CABI/EPPO, 2002; EPPO, 2014	
China	Present					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
-Anhui	Present					CABI/EPPO, 2002; EPPO, 2014	
-Guizhou	Present					CABI/EPPO, 2002; EPPO, 2014	
-Hebei	Present					CABI/EPPO, 2002; EPPO, 2014	
-Henan	Present					CABI/EPPO, 2002; EPPO, 2014	

Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
-Jiangsu	Present					CABI/EPPO, 2002; EPPO, 2014	
-Shandong	Present					CABI/EPPO, 2002; EPPO, 2014	
-Zhejiang	Present					CABI/EPPO, 2002; EPPO, 2014	
India	Widespread					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
-Bihar	Present					Nath & Patkak, 1993; CABI/EPPO, 2002; EPPO, 2014; Gotke & Swarup, 1988	
-Delhi	Present					CABI/EPPO, 2002; EPPO, 2014; Gotke & Swarup, 1988	
-Haryana	Present					Paruthi & Gupta, 1987; CABI/EPPO, 2002; EPPO, 2014; Gotke & Swarup, 1988	
-Indian Punjab	Present					Sakhuja et al., 1990; CABI/EPPO, 2002; EPPO, 2014	
-Jammu and Kashmir	Present					Kalha et al., 1992; CABI/EPPO, 2002; EPPO, 2014	
-Madhya Pradesh	Widespread					CABI/EPPO, 2002; EPPO, 2014	
-Rajasthan	Present					CABI/EPPO, 2002; EPPO, 2014; Gotke & Swarup, 1988	
-Uttar Pradesh	Present					CABI/EPPO, 2002; EPPO, 2014; Gotke & Swarup, 1988	
Iran	Present					Bamdadian, 1973; CABI/EPPO, 2002; EPPO, 2014	
Iraq	Present					Al-Talib et al., 1986; Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Israel	Present, few occurrences					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
Korea, Republic of	Present					CABI/EPPO, 2002; EPPO, 2014	
Pakistan	Widespread					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
Saudi Arabia	Restricted distribution					CABI/EPPO, 2002; EPPO, 2014	
Syria	Present					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
Taiwan	Present					CABI/EPPO, 2002; EPPO, 2014	
Turkey	Present					Uztuzun, 1970; CABI/EPPO, 2002; EPPO, 2014	
AFRICA							
Egypt	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Ethiopia	Present					Esser et al., 1991; CABI/EPPO, 2002; EPPO, 2014	
NORTH AMERICA							
USA	Absent, formerly present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014; USDA-APHIS, official communication, 2015	Absent, formerly present - based on changes in agricultural practices
-Georgia	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	
-Maryland	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	
-North Carolina	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	
-South Carolina	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	
-Virginia	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	
-West Virginia	Absent, formerly present					Reitz, 1976; CABI/EPPO, 2002; EPPO, 2014	

Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
SOUTH AMERICA							
Brazil	Absent, formerly present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
EUROPE							
Austria	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Bulgaria	Restricted distribution			191*		CABI/EPPO, 2002; EPPO, 2014	
Croatia	Present					CABI/EPPO, 2002; EPPO, 2014	
Cyprus	Present					CABI/EPPO, 2002; EPPO, 2014	
France	Widespread					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
Germany	Present					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
Greece	Widespread					CABI/EPPO, 2002; EPPO, 2014	
Hungary	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Ireland	Present					McKay et al., 1952; CABI/EPPO, 2002; EPPO, 2014	
Italy	Widespread					Byars, 1920; CABI/EPPO, 2002; EPPO, 2014	
Lithuania	Present					Kasimova, 1954; CABI/EPPO, 2002; EPPO, 2014	
Netherlands	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Poland	Present					Suski, 1980; CABI/EPPO, 2002; EPPO, 2014	
Romania	Present					Esser et al., 1991; CABI/EPPO, 2002; EPPO, 2014	
Russian Federation	Restricted distribution					CABI/EPPO, 2002; EPPO, 2014	
-Russian Far East	Present					CABI/EPPO, 2002; EPPO, 2014	
Serbia	Widespread					EPPO, 2014	
Slovenia	Present					Urek & ?irca, 2003	
Spain	Widespread					Benlloch, 1947; CABI/EPPO, 2002; EPPO, 2014	
Sweden	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Switzerland	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
UK	Present					Christie, 1959; CABI/EPPO, 2002; EPPO, 2014	
Ukraine	Present					CABI/EPPO, 2002; EPPO, 2014	
Yugoslavia (Serbia and Montenegro)	Present					CABI/EPPO, 2002	
OCEANIA							
Australia	Present					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	
-Western Australia	Present					Riley & Reardon, 1995; CABI/EPPO, 2002; EPPO, 2014	
New Zealand	Present					Thorne, 1961; CABI/EPPO, 2002; EPPO, 2014	

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Risk of Introduction

RISK CRITERIA CATEGORY

ECONOMIC IMPORTANCE Moderate
DISTRIBUTION Worldwide
SEEDBORNE INCIDENCE Moderate
SEED TRANSMITTED Yes
SEED TREATMENT No

OVERALL RISK Moderate

Notes on phytosanitary risk

A. tritici should be considered a low level risk because it is easy to detect and control and has been eliminated from many grain-growing areas. Selective quarantine should be established in parts of the world where it is not under control.

Hosts/Species Affected

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A. tritici is highly specialized with a narrow host range. Significant multiplication only occurs on wheat or closely related plants. Many common grasses have been exposed to A. tritici; most have been shown to be non-hosts (Leukel, 1957).

Oat and Polypogon monococcum are poor hosts (Southey, 1972). A tritici invades and multiplies in maize tissue, but does not complete its life cycle in this plant (Limber, 1976).

In addition to the hosts listed in the table, Alopecurus monspeliensis and Lolium temulentum (Dahiya and Bhatti, 1980), Holcus lanatus and Phleum pratensis (Filipjev et al., 1959), and Triticum monococcum (Southey, 1972) are also reported as hosts of A. tritici.

Host plants

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Family	Plant name	Context
Poaceae	Avena sativa (oats)	Other
Poaceae	Hordeum vulgare (barley)	Other
Poaceae	Secale cereale (rye)	Main
Poaceae	Triticum (wheat)	Main
Poaceae	Triticum aestivum (wheat)	Main
Poaceae	Triticum dicoccum	Main
Poaceae	Triticum spelta (spelt)	Main
Poaceae	Triticum turgidum (durum wheat)	Other

Growth Stages

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Seedling stage

Symptoms

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The absence of symptoms does not mean absence of A. tritici (Thorne, 1949). Slight elevations occur on the upper leaf surface with indentations on the lower side. Other symptoms include wrinkling, twisting, curling of the margins towards the midrib, distortion, buckling, swelling and bulging. A tight spiral coil evolves, and dwarfing, loss of colour or a mottled, yellowed appearance and stem bending may also occur (Leukel, 1924; Byers, 1920). In severe infection, the entire above-ground plant is distorted to some degree and a disease problem is usually obvious.

Heads (spikes)

Wheat heads are reduced with glumes protruding at an abnormal angle exposing the galls to view. This does not occur in rye heads.

Galls

Young galls are short-thick, smooth, light to dark green, turning brown to black with age, 3.5-4.5 mm long and 2-3 mm wide. Rye galls are small, buff-coloured and longer than wide, 2-4.5 mm long by 1-2.5 mm wide (Leukel, 1924; Byars, 1920).

List of Symptoms/Signs

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Sign	Life Stages	Type
Inflorescence		
galls		
twisting and distortion		
Leaves		
abnormal colours		
abnormal forms		
leaves rolled or folded		
Seeds		
galls		
Stems		
stunting or rosetting		
witches broom		
Whole plant		
dwarfing		

Biology and Ecology

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Habitat

A. tritici thrives in cool conditions in most climates where wheat is grown. The favoured micro-habitat for A. tritici comprises the seed galls where all stages are protected from hostile environmental factors. It also lives in soil, either in or out of galls, and in dry seed storage.

Life Cycle

Several weeks elapse in moist soil before the gall is softened enough to release the juveniles. It takes 2-9 days for juveniles to reach a plant (Leukel, 1924); the first plant encountered is invaded. Horizontal and vertical migration do not exceed 20-30 cm (Leukel, 1957) and 7-19 cm (Limber, 1980), respectively. A film of moisture must be present on the invaded plant to allow nematode movement. Juveniles swim up the stem and enter the leaves or leaf sheath; they then migrate to the growing point where they feed ectoparasitically.

When the floral organs appear, the staminate tissue is invaded followed by the carpellate tissue. Juveniles feed ectoparasitically until floral tissue develops, when gall formation is stimulated. Galls arise from undifferentiated carpellate tissue. Juveniles develop into males or females in the gall (fewer than 25 per gall), and thousands of eggs are deposited. One female can deposit up to 2000 eggs (Southey, 1972). Mature females form tight coils, become quiescent, and die following oviposition. Juveniles entering leaves produce a whitish gall and leaf symptoms.

The entire life cycle of A. tritici is completed in about 113 days; however, the life cycle has been reported to last up to 164 days in India (Swarup and Gupta, 1971). It is not uncommon for juveniles to leave the gall in autumn and seek new plants for overwintering or to overwinter in soil (Maggenti, 1981). Some juveniles leave galls in the autumn and overwinter in the leaf sheaths of host plants (Leukel, 1957). Juveniles enter a state of anhydrobiosis in dry storage. The water content in the nematodes is reduced from the normal level of 45-50% to 5%, lipid droplets become crinkled and indented and the body becomes tightly coiled (Bird and Buttrose, 1974).

The nematodes invade the leaves and leaf sheaths of emergent seedlings and also the developing floral parts. In the final stages of attack, they modify the seed into nematode-infected galls in the floral tissue.

Population Dynamics

Juveniles in the gall range in number from 3600-32 400 in India (Thorne, 1961). The number of females and males in galls ranged from 3-37 and 1 -41, respectively (Christie, 1959).

Economic Threshold Levels

A minimum population of 10 000 juveniles/kg soil is essential for development of ear-cockle. Disease intensity is greatest when nematode galls are placed in soil at a depth of 2-6 cm than when placed deeper (Luc et al., 1990).

Survival

A. tritici has survived up to 35 years in dry storage (Thorne, 1961). Juveniles do not survive more than 1 year in field soil (Norton, 1978). Some juveniles survive in the faeces of rodents, sheep, frogs, salamanders and goldfish (Norton, 1978).

Dissemination

The principal means of dispersion is by wheat seed containing infected galls in commerce and by sowing infected galls in fields. In a survey of grain markets in Haryana, India, 34.17% of wheat samples were found to be contaminated with seed galls caused by A. tritici; the incidence of ear-cockle and tundu disease (caused by association with Rathayibacter tritici) on wheat earheads was 2.85%. Maximum contamination (63.2%) was found in wheat variety C306 and minimum (12.3%) in the dwarf variety WL711 (Paruthi and Bhatti, 1985). The level of R. tritici infection of A. tritici galls has been reported at 20.4% (Paruthi et al., 1989).

Other means of spread include straw from an infected crop, rainfall and flooding, natural migration (20-30 cm), and cow, sheep, sparrow, pigeon and goldfinch manure. A. tritici is also spread by animal feet; farm implements and machines; and by wind (Leukel, 1957).

Nematode/Plant Disease Interactions

Spores of a pathogen, such as Dilophosphora alopecuri, may be carried into the floral tissue on the cuticle of A. tritici. However, in most cases the disease organism is detected inside the gall with A. tritici.

When the entire gall is filled with pathogen spores, the nematodes are eliminated by competition. One disease is traded for another with no real economic gain.

The following diseases are associated with A. tritici: Corynebacterium michiganense pv. tritici [Rathayibacter tritici] on Polypogon monspeliensis (Paruthi et al., 1989); Clavibacter tritici [R. tritici] on barley (Bhatti et al., 1978) and wheat (Swarup and Singh, 1962); and Dilophosphora alopecuri (Poinar, 1983), D. graminus (Filipjev et al., 1959), Neovossia indica [Tilletia indica] (Paruthi and Bhatti, 1980), Sclerophthora macrospora (Paruthi et al., 1992), Tilletia foetida [T. laevis] (Mathur and Misra, 1961), Ustilago nuda [U. segetum var. nuda] (Beniwal et al., 1991), Sitophilus oryzae, Tribolium castaneum and T. confusum on wheat (Nath et al., 1984).

Yellow ear-rot or 'tundu' is a nematode-vectored bacterial disease commonly associated with ear-cockle. The disease is caused by the association of A. tritici with R. tritici.

Notes on Natural Enemies

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There are few reports concerning natural enemies of A. tritici. The nematodes, Arthrobotrys oligospora (Filipjev et al., 1959), Mononchoides fortidens and M. longicaudatus (Bilgrami and Jairajpur, 1989) all reduce numbers of A. tritici. The fungi, Dilophosphora graminis (Filipjev et al., 1959) and Tilletia tritici (Thorne, 1961) cause the nematodes in galls to die as a result of competition rather than by attack.

Natural enemies

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Natural enemy	Type	Life stages	Specificity	References	Biological control in	Biological control on
Arthrobotrys oligospora	Predator	Juveniles				
Catenaria anguillulae	Pathogen					
Dilophosphora graminis		Adults/Eggs/Juveniles				
Mononchoides fortidens	Parasite	Adults/Eggs/Juveniles				
Mononchoides longicaudatus	Parasite	Adults/Eggs/Juveniles				
Tilletia tritici		Adults/Eggs/Juveniles				

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Seedborne Aspects

Incidence

In a survey of grain markets in Haryana, India, 34.17% of wheat samples were found to be contaminated with seed galls caused by A. tritici; the incidence of ear-cockle and tundu disease (caused in association with Rathayibacter tritici) on wheat earheads was 2.85%. Maximum contamination (63.2%) was found in wheat variety C306 and minimum (12.3%) in the dwarf variety WL711 (Paruthi and Bhatti, 1985). The level of R. tritici infection of A. tritici galls has been reported at 20.4% (Paruthi et al., 1989). In surveyed regions in Iran (Ahmadi and Akhiyani, 2001), 21.71% of fields were infested with A. tritici. The mean of infected heads was 5.82% and crop loss was 0.3% of the total yield (1444 tonnes of wheat). The range in size of the nematode galls and the population of A. tritici secondary juveniles in collected wheat samples were determined for each area. The nematode galls ranged from 2.4-5.3 x 1.5-4.2 mm. The maximum and minimum numbers of second stage juveniles were 40250 and 4625, respectively. A survey of head sterility in Syria during the harvest of 1996 included 120 samples representing 30 barley fields in northern Syria (Khatib et al., 2000). Incidence of head sterility varied in the surveyed fields between 9.6 and 57% (average 23.4%). Estimated grain losses ranged from 0.1 to 43.2% (average loss of 11.2%). Preliminary results showed that head sterility prevails in short, normal and tall plants at rather similar levels, i.e. 21.9, 23.3 and 31.1%, respectively. Furthermore, the results showed a correlation between head sterility and the presence of seed gall nematodes.

The life cycle of A. tritici is fully synchronized with the wheat plant. The second-stage larvae take a few days to reach the embryonic growing point of the wheat seed. They continue to increase in numbers at the growing point until 45 days after inoculation. The larvae start penetrating the flower primordia from the 68th day and the developmental stages are discernible from the 70th day onwards. The total life cycle (from second stage to second stage) takes 103 days (Gokte and Swarup, 1987).

The relationship between A. tritici and R. tritici has been shown in inoculation experiments. Symptoms of ear-cockle and tundu were produced by inoculations with nematode seed galls or unsterilized larvae. The bacterial disease, however, did not appear when R. tritici was inoculated alone in the soil or on the wheat growing point (Gupta & Swarup, 1972).

Effect on Seed Quality

Ears of wheat completely infected with tundu (R. tritici) or ear-cockle (A. tritici) showed 100% loss in grain formation. Partially cockled ears resulted in 53.4 and 51.0% grain loss on the basis of number and weight, respectively, whereas ears partially attacked with tundu had grain losses of 68.7 and 77.2%. Other quality characters (colour, appearance and degree of acceptability) of grains obtained from ears partially attacked with tundu were also inferior to those from cockled and healthy ears (Paruthi et al., 1987).

The size of the galls caused by A. tritici on wheat is directly correlated with the number of adult nematodes inside the galls. A maximum of 283 were recorded from a single gall, but the usual number is 10 to 80/gall (Midha and Swarup, 1974).

Seed Transmission

Ear-cockles are the only source of perpetuation of the disease. The principal means of dispersion of the nematode is by wheat seed containing infected galls and by planting infected galls in fields (Luc et al., 1990). Secondary stage juveniles of A. tritici emerge from the galls, penetrate the shoots of the emerging seedling and then migrate upwards between the leaf sheaves. Larvae around the growing point are mechanically carried to the developing ears as culms elongate, where they enter into the flowers (Neergaard, 1977).

In Syria, an experiment was conducted in pots under field conditions to investigate the relationship between inoculum density and infection level of seed-gall nematode and barley yield losses. Inoculation was done at sowing with 125, 250, 500 and 1000 juveniles/100 g soil. A non-inoculated system was used as a control. Two cultivars of the six-rowed barley (Rihan 3 and Furat 1), and two of the two-rowed barley (Tadmor and Zanbaka) were used. The lowest inoculum density of the nematode (125 juveniles/100 g soil) influenced infection level and grain loss. Severity of infection increased with every increase in inoculum density. However, yield reduction slightly increased with increases in inoculum density (26.1, 27.5, 31.6 and 36.8% for 125, 250, 500 and 1000 juveniles/100 g soil), respectively. Results also showed that incidence of infection varied significantly among the cultivars tested, but Rihan 3 was less affected (22.8%) compared to Furat 1, Tadmor and Zanbaka (36.7, 41 and 47.7%, respectively) (Al-Zainab et al., 2001).

Seed Treatment

Chemical

Early investigations of the disinfection of contaminated seed produced varying results. Pennetier (1886), Marcinowski (1910), Byars (1919) and Sommerville (1919) reported that contaminated seed could not be thoroughly disinfested without injuring the wheat seed. Chu (1945) obtained good results with corrosive sublimate.

Physical

Various methods have been used to separate nematode galls from seed lots including fanning, screening and flotation in water. However, none of these methods are as effective as a brine treatment in which sound wheat kernels sink while galls, light kernels and debris float (Suryanarayana and Mukhopadhaya, 1971).

Hot-water treatment of contaminated wheat seed is also effective in the removal of nematode galls from seed lots (Suryanarayana and Mukhopadhaya, 1971). Marcinowski (1910) demonstrated that galls in a seed lot could be destroyed by keeping the mixture in water at 54-56°C for 10-12 minutes. Pre-soaking seeds before the hot-water treatment has also been advocated (Byars, 1919; Chu, 1945).

Jones et al. (1938) developed an indented cylinder machine which separated oval wheat seeds from globular nematode galls; the device was claimed to be 98% effective in removing seed galls. Chu (1945) also designed a machine to separate nematode galls from healthy grain.

Microwave irradiation significantly decreased the mycoflora of soaked (from 8 and 10 seconds onwards) and unsoaked (from 10 and 12 seconds onwards), healthy and cockled seeds, respectively. Mortality of A. tritici juveniles inside soaked and unsoaked cockles was significantly greater from 10 and 14 second-long treatments, respectively. The seed germination decreased (P=0.05) from 16 seconds onwards (Khan and Hayat, 1999).

Seed Health Tests

Visual

Examine seed lots for the presence of nematode galls that are brown-black and lack the brush and embryo marking of normal kernels. They can be distinguished from ergots or sclerotia by the release of motile larvae when wetted (Wiese, 1987).

Plant Trade

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Plant parts liable to carry the pest in trade/transport	Pest stages	Borne internally	Borne externally	Visibility of pest or symptoms
Bulbs, Tubers, Corms, Rhizomes	adults; eggs; juveniles	Yes	Yes	Pest or symptoms not visible to the naked eye but usually visible under light microscope
Flowers, Inflorescences, Cones, Calyx	adults; eggs; juveniles	Yes		Pest or symptoms not visible to the naked eye but usually visible under light microscope
Leaves	adults; eggs; juveniles	Yes	Yes	Pest or symptoms not visible to the naked eye but usually visible under light microscope
Seedlings, Micropropagated plants	adults; eggs; juveniles	Yes	Yes	Pest or symptoms not visible to the naked eye but usually visible under light microscope
Stems (above ground), Shoots, Trunks, Branches	adults; eggs; juveniles	Yes	Yes	Pest or symptoms not visible to the naked eye but usually visible under light microscope
True seeds (inc. grain)	adults; eggs; juveniles	Yes		Pest or symptoms not visible to the naked eye but usually visible under light microscope

Plant parts not known to carry the pest in trade/transport
Bark
Fruits (inc. pods)
Growing medium accompanying plants
Roots
Wood

Impact

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A. tritici has been practically eliminated from grainfields in Europe by using clean seed and crop rotation. Up to 100% losses have been reported in wheat, with wheat grain ears totally infected (Paruthi et al., 1987). Reddy (1983) also reported high losses (90%) in wheat seedlings; and 8.5% of sowed wheat seeds galled, resulting in 69% loss. In China, A. tritici causes an annual market reduction in wheat (Chu, 1945). The conversion of wheat grains to galls caused losses of 6.54 million rupees in India (Sakhuja et al., 1990). Paruthi and Bhatti (1988) reported 23-48% losses and a market price reduction when 5% of wheat seed were galled and flour which contained 2% seed galls was also unacceptable. Losses of 50 and 65% were reported in wheat and rye, respectively (Leukel, 1957), and 52% losses occurred through infestation of the inoculated wheat field market (Paruthi and Bhatti, 1981). These losses were recorded in the absence of control measures, before the introduction of phytosanitary programmes.

Diagnosis

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A. tritici was detected in cereal seed by direct visual inspection as well as wash-filter, freezing-blotter, embryo, seed-gall nematode and growing-on tests (Asaad and Abang, 2009).

Three assay methods are used to detect the presence of A. tritici.

Dissection: a scalpel and tweezers are used to dissect seeds and release nematodes in water.

Salt: this is used to assay dry lots of seed for A. tritici. Seeds are poured into a 20% salt solution, stirred vigorously, and the debris skimmed from the surface and examined under the microscope for galls.

Baerman funnel method: a 9-cm coarse wire screen disc is placed into a 15-cm funnel. Water is added to the funnel just above the support disc and a paper tissue is added to the funnel. The seed subsample is poured to just below the rim of the funnel and water is added until the funnel is full. The funnel is left undisturbed for 24 hours. Water from the funnel is drawn into a 50-ml centrifuge tube and the residue from the tube is pipetted onto a microscope slide after 30 minutes for diagnosis.

Detection and Inspection

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Wheat fields should be inspected for stunted and distorted seedlings. Mature plants should be examined for stunted, irregular spikes with horizontal glumes exposing the galls. Random samples (about 1/2 cup) should be taken from grain in dry storage or vehicles, vessels or aircraft in commerce. Seed lots should be examined for galls or irregular seeds and, if present, they should be included in the 1/2 cup subsamples and their presence noted.

Similarities to Other Species/Conditions

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Symptoms of A. tritici attack are similar to aphid, drought and Hessian fly [Mayetiola destructor] damage. Some plant disease galls resemble nematode galls and may erroneously indicate the presence of A. tritici. Smutted galls crush easily into a black powder, ergot sclerotia (caused by Claviceps purpurea) produce elongated fungal bodies and Clavibacter tritici [Rathayibacter tritici] produces bright yellow, slimy exudations on the spike (Thorne, 1949). Cockle seed is black and hairy.

Prevention and Control

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Introduction

Ear-cockles are the only source for perpetuation of the disease and their removal from contaminated seed lots can completely eradicate the disease (Luc et al., 1990). A. tritici has been eliminated, or reduced to a minimal number of infestations, in Europe and the USA by seed cleaning, crop rotation and fallow (Brown, 1987).

Cultural Control and Sanitary Methods

Seed cleaning:
Salt brine method (Byars, 1920; Leukel, 1957): seed (1 peck per treatment) is poured into a salt solution (8 lbs salt in 5 gallons water) and stirred vigorously. Sound galls sink, and debris and galls float to the surface. The galls and debris are skimmed from the surface and steamed, boiled or chemically treated to kill the nematodes. The salt solution is drained into another container and the cleaned seed is rinsed several times in fresh water to remove salt and then spread in thin layers on a clean surface to dry. The cleaned seed is ready to sow when dry. It is important that the seed is washed two or three times in plain water after brine treatment to remove salt particles which may impair germination.

Crop rotation or fallow
A. tritici cannot survive in soil for more than 1 year if the soil is left fallow or planted to a non-host crop. The pest will be eliminated in more than a year.

Physical Control

Hot-water treatments:
Hot-water treatments may be used to eradicate A. tritici from seed lots (Suryanarayana and Mukhopadhaya, 1971). Marcinowski (1910) demonstrated that nematode galls in a seed lot could be destroyed by keeping the mixture in water at 54-56°C for 10-12 minutes. Pre-soaking the seeds before the hot-water treatment has also been advocated (Byars, 1919; Chu, 1945).

Another hot-water treatment involves pre-soaking the seed at 21-27°C for 2-4 hours, then placing them in water for 30 minutes at 50°C. The seeds

are rinsed in tap water, then spread in thin layers on a clean surface till dry (Byars, 1920; Leukel, 1924).

Mechanical separation:
Jones et al. (1938) developed an indented cylinder machine which separated oval wheat seeds from globular nematode galls; the device was claimed to be 98% effective in removing the seed galls. Chu (1945) also designed a machine to separate nematode galls from healthy grain.

Nematicidal Plants

Nematicidal plants are not as effective as the clean seed or fallow method and offer little hope as an effective method of controlling A. tritici.

Biological Control

There are few reports concerning biological control of A. tritici.

Host-Plant Resistance

A large number of plants have been evaluated for resistance to A. tritici over a period of more than 60 years. A few resistant plants have been found, such as the wheat cultivar Kanred (Leukel, 1924); however, resistance does not appear to be a viable solution to the problem of seed gall nematodes.

Chemical Control

Many chemicals have been used to control A. tritici; they were not highly effective and most are no longer available. Early investigations of the disinfection of contaminated seed produced varying results. Pennetier (1886), Byars (1919), Marcinowski (1910) and Sommerville (1919) reported that contaminated seed could not be thoroughly disinfected without injuring the wheat seed. Chu (1945) obtained good results with corrosive sublimate.

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Distribution Maps

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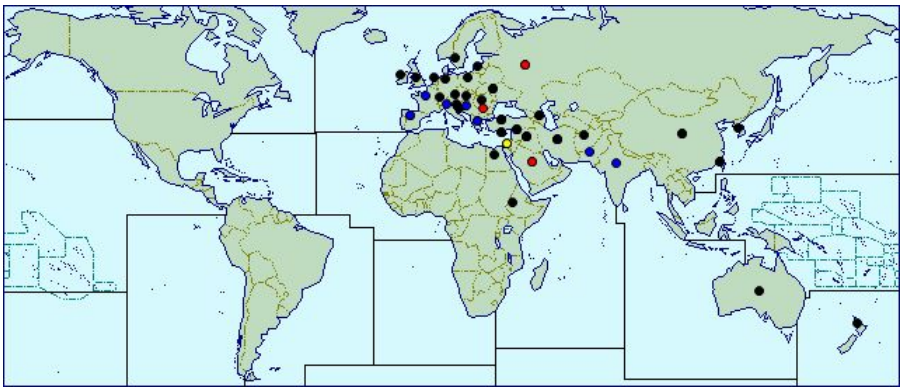

= Present, no further details
= Widespread
= Localised
= Confined and subject to quarantine
= Occasional or few reports

= Evidence of pathogen
= Last reported
= Presence unconfirmed
= See regional map for distribution within the country

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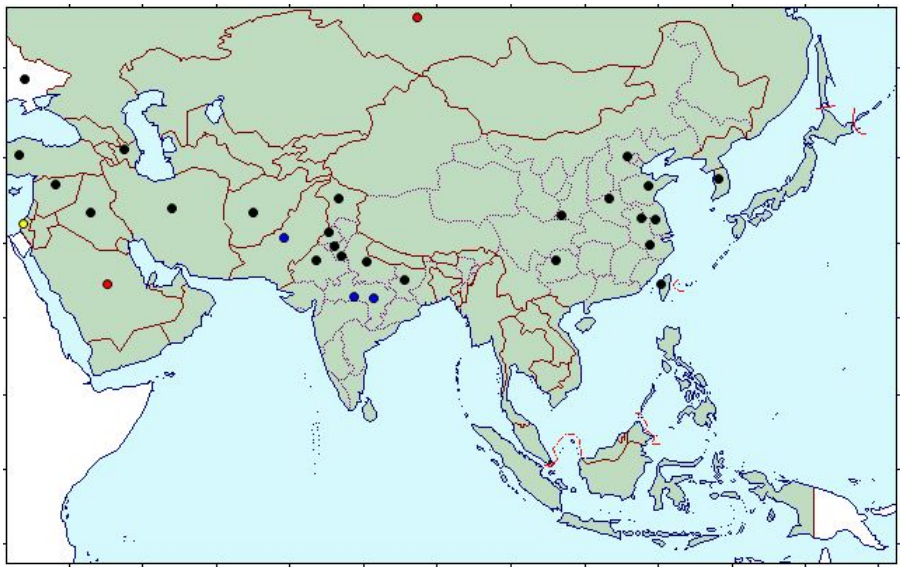

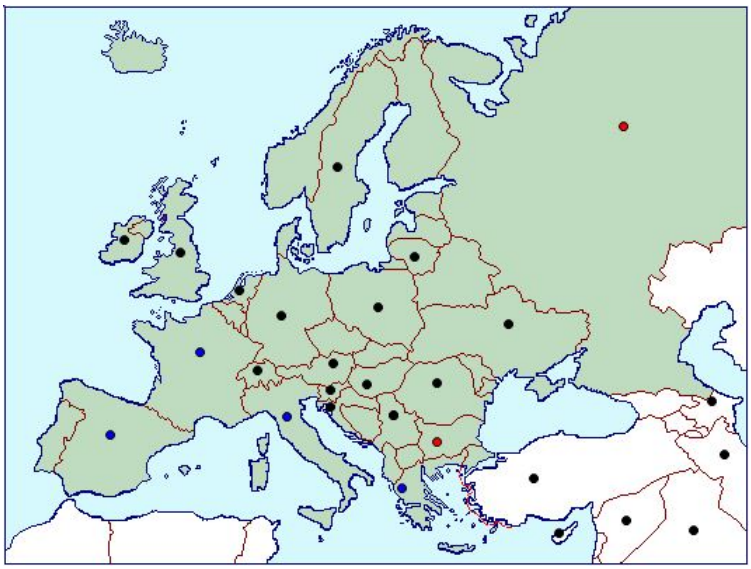

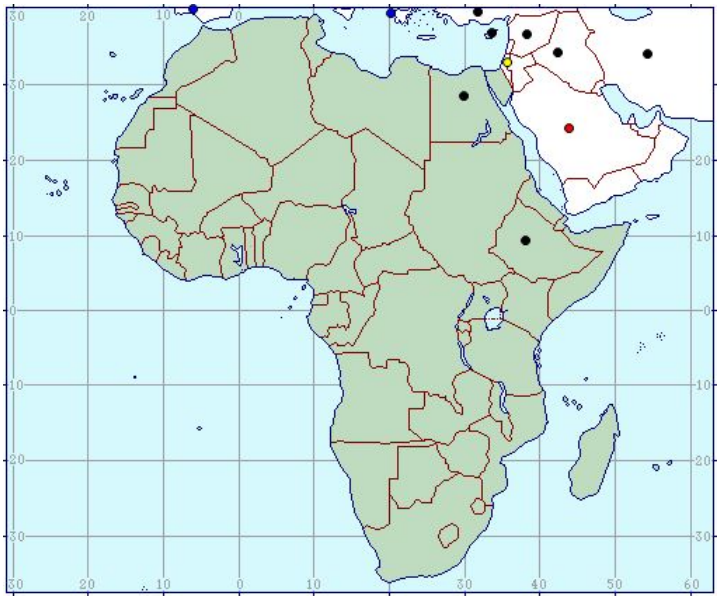


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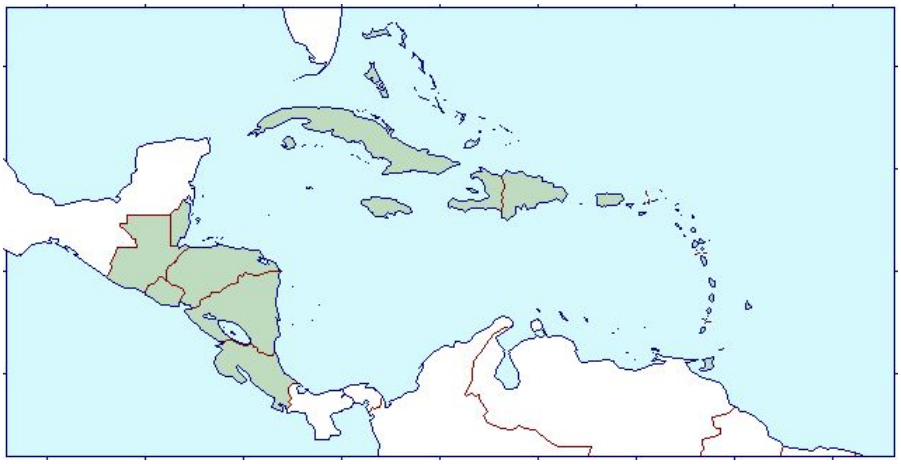


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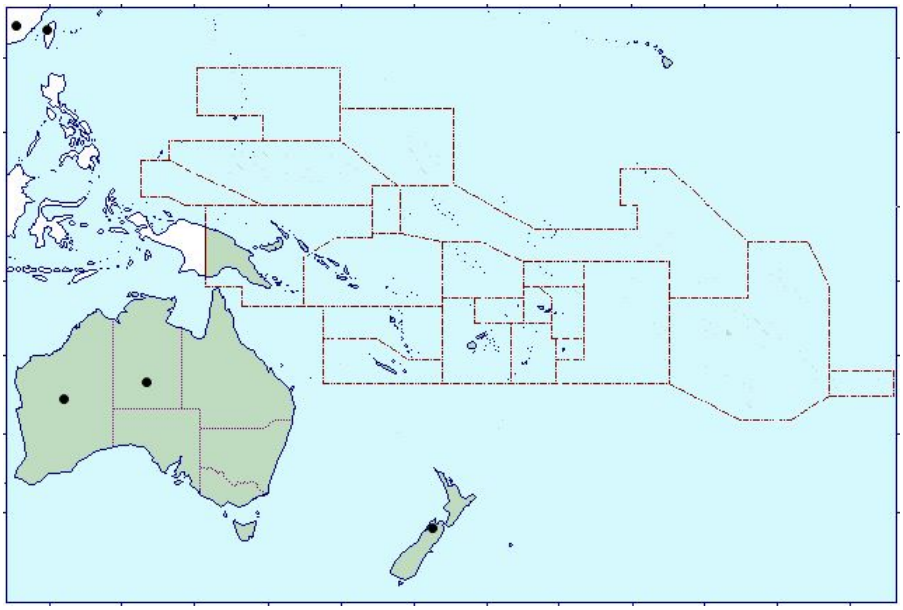

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