Review Article

Status of Wheat Production and Associated Nematode Pests in Pakistan

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Abstract | Plant-parasitic nematodes are potential pests of agricultural crops including wheat and cause quantitative and qualitative loss to crop production worldwide. They cause serious damage to many important agricultural crops and add to the problem of food security worldwide. Wheat (*Triticum aestivum* L.) is the most important economic cereal crop in the world and Pakistan stands in eighth position in global wheat production. The wheat crop is susceptible to several diseases and nematode pests. The most important nematode parasites are cereal cyst nematodes, root-knot nematodes, lesion nematodes, seed-gall nematodes and stem nematodes. In this review article status of global wheat production is presented and its associated parasitic nematodes have been discussed with reference to chronological research data related to Pakistan.

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Introduction

Wheat is the third-largest cereal staple food of the world in terms in global production after maize and rice. Globally its production was over 765 million metric tons in 2019/2020 with an increase of over 30 million tons as compared to the previous marketing year. It is the main food grain source for the majority of the people of the world and an important component of the human diet, particularly in developing countries (https://www.statista.com). It is grown on 20% of the global cultivated land area and is the main food resource for 40% of the world's population (Braun *et al.*, 2010).

Worldwide, wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally (Pathak and Shrivastav, 2015; Ajmal-uddin *et al.*, 2020). Wheat also contributes a number of components which that are beneficial for human health viz., essential amino acids, minerals, and vitamins, beneficial phytochemicals, and dietary fibre (Shewry and Hey, 2015). In Pakistan, wheat is the most important food crop and plays a vital role in the country's food security and economy.

Wheat belongs to the family Triticeae (Hordeae) in the grass family Poaceae (Gramineae). About 95% of the wheat produced is common wheat (*Triticum aestivum* L. emThell.), also known as bread wheat. Wheat is the first important and strategic cereal crop for the majority of the world's population.

Global wheat production

Data on global wheat production during ten years showed that there was a sharp decrease in the production of wheat in the year 2012/13 as compared to the preceding production year. However, there was a gradual increase in production in the next five years, (2013/14-2017/18). Again in the year 2018/19 sharp decrease in production was observed but it increased many folds subsequently in the year 2019/20 (Figure 1) (www.statista.com).

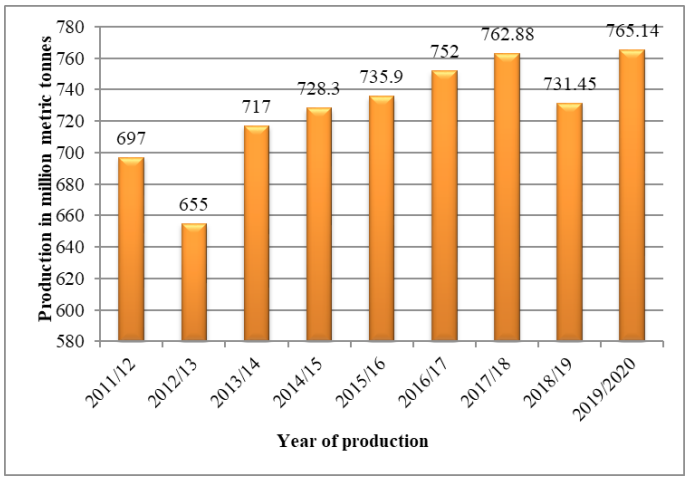

Figure 1: *Global wheat production from the year 2011/2012 to 2019/2020.*
Source: *Statista;* www.statista.com

Leading ten wheat producers worldwide in 2019/2020 (In 1,000 Metric Tons)

Among the 10 global leading wheat-producing countries in 2019/2020 (Figure 2), China is the topmost country by wheat production in the world with 136.0 million metric tons, followed by the European Union which produced about 135.8 million metric tons of wheat. The other top countries in descending order are India, the Russian Federation, the United States of America, Canada, Australia, Pakistan, Ukraine, and Turkey. Pakistan ranked at 8th position in 2020 with 25,700 wheat production in the world (https://www.statista.com/).

Status of wheat production in Pakistan

Agricultural cropping has two seasons in Pakistan: Kharif, the first sowing season starts from April to June and is harvested from October to December. Rice, sugarcane, cotton, maize, moong, mash, bajra and jowar are "Kharif" crops. Rabi, the second sowing season, begins from October to December, and is harvested from April to May. Wheat, gram, lentil (masoor), tobacco, rapeseed, barley, and mustard are "Rabi" crops.

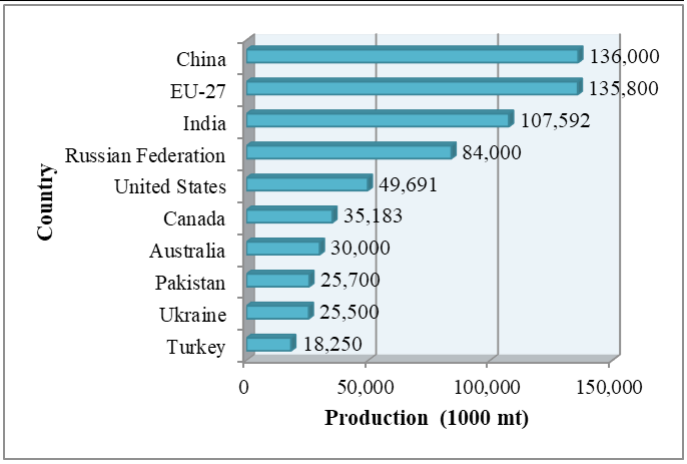

Figure 2: *Ten leading wheat producers worldwide in 2019/2020.*

The important crops (wheat, rice, sugarcane, maize and cotton) account for 21.73 % of the value addition of the agriculture sector and 4.20 % of GDP. The other crops account for 11.53 percent of the value addition of the agriculture sector and 2.23 % of GDP. The production of the wheat crop is given in Table 1 (Source: Pakistan Bureau of Statistics; Pakistan Economic Survey, 2019-20).

Table 1: *Production of wheat crop during 2013-14 to 2019-20.*

Year	Production (000 Tonnes)
2013-14	25,979 (7.3)
2014-15	25,086 (-3.4)
2015-16	25,633 (2.2)
2016-17	26,674 (4.1)
2017-18	25,076 (-6.0)
2018-19	24,349 (-2.9)
2019-20 (P)	24,946 (2.5)

P: Provisional (July-March), Figures in parentheses are growth/decline rates

Source: *Pakistan Bureau of Statistics.*

Wheat production, area, and yield in Pakistan

Wheat accounts for 8.7 percent of value addition in agriculture and 1.7 % of gross domestic product (GDP). Wheat crop production increased by 2.5% to 24.946 million tonnes over last year's (2018-19) production of 24.349 million tonnes. The area under cultivation increased by 1.7 % to 8,825 thousand hectares over last year's (2018-19) area (8,678 thousand hectares). The production increased due to increase in cultivated area, healthy grain formation and better crop yield. The position over the last five years is given in Table 2 and Figure 3 (Pakistan Economic Survey, 2019-20; www.finance.gov.pk).

Table 2: *Wheat production, area, and yield.*

Year	Area		Production		Yield	
	(000 Hec.)	% Change	(000 Tonnes)	% Change	kgs/ hec.	% Change
2015-16	9,224	-	25,633	-	2,779	-
2016-17	8,972	-2.7	26,674	4.12	2,973	7.0
2017-18	8,797	-1.9	25,076	-6.0	2,851	-4.1
2018-19	8,678	-1.4	24,349	-2.9	2,806	-1.6
2019-20 (P)	8,825	1.7	24,946	2.5	2,827	0.7

P: Provisional (July-March)

Source: *Pakistan Bureau of Statistics.*

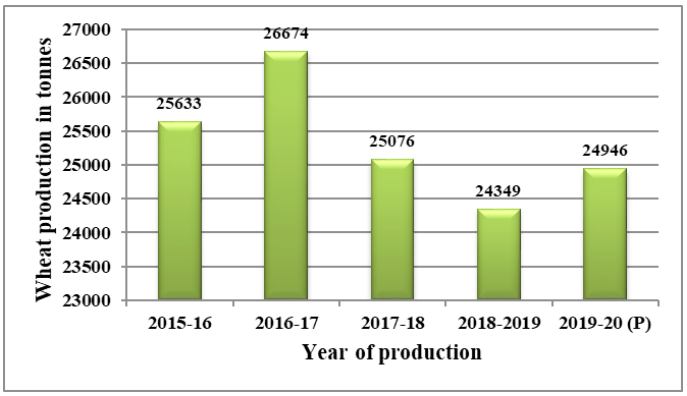

Figure 3: *Wheat production during the year 2015/16 to 2019/2020.*

Province wise production % of wheat

Wheat is grown in all four provinces of Pakistan on a small to large scale. Province wise wheat production is as follows: Punjab produced 76%, Sindh 16%, KP 5% and only 3% wheat was in Balochistan Province (Figure 4) (Sehgal and Robotka, 2020).

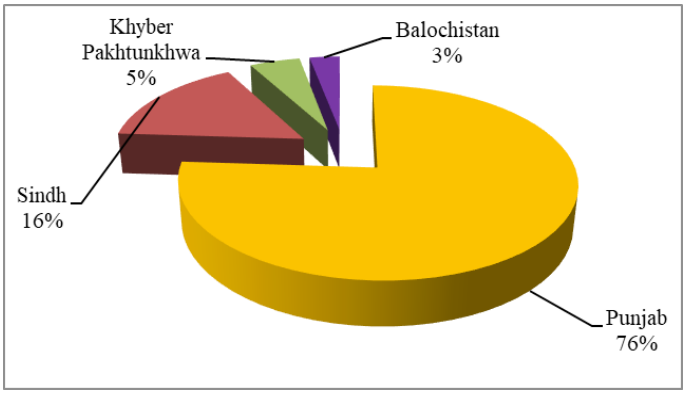

Figure 4: *Wheat production percentages by province.*

Wheat production, yield, and area by province from 2010-11 to 2017-18

Punjab takes first place in wheat production. The maximum wheat production was 20466.30 million tonnes in Punjab and the minimum production was 729.10 million tonnes in Balochistan. Moreover, the Punjab and Balochistan provinces are identified as the highest and lowest wheat producers on average during 2010 to 2018.

Punjab province is the highest producer of wheat. Maximum production (20466.30 million tonnes) was achieved in the year 2016-17 during the period of eight years i.e., 2010-2018 from Punjab; from Sindh 4287.90 was the maximum production in the year 2010-11; KP showed 4287.90 mt productions during the 2015-16 financial years while Balochistan province produced 935.40 mt in 2017-18. However, the overall highest production (26673.60 mt) during 2010-2018 was attained in the 2016-17financial year (Table 3). The same trend was observed in the province-wise average yield of wheat during the eight financial years (2010-2018) as seen in the province-wise production (Table 4). Provincial cultivated area of wheat during the eight financial years (2010-2018) was as follows: The largest area was in Punjab in the year 2014-15, in Sindh during the year 2016-17, in KP in the year 2017-2018 and in Balochistan during the year 2013-14. Overall the largest cultivated area of wheat in Pakistan was during the 2015-2016 financial years (Table 5).

Table 3: *Wheat production by province from 2010-11 to 2017-18.*

Year	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Pakistan
2010-11	19041.00	4287.90	1155.80	729.10	25213.80
2011-12	17738.90	3761.50	1130.30	842.70	23473.40
2012-13	18587.00	3598.70	1257.60	768.10	24211.40
2013-14	19738.90	4002.10	1363.10	875.30	25979.40
2014-15	19281.90	3672.20	1259.90	872.10	25086.10
2015-16	19526.70	3834.60	4287.90	871.30	25633.10
2016-17	20466.30	3910.40	1365.10	931.80	26673.60
2017-18	19178.50	3639.50	1322.70	935.40	25076.10

Source: *Agricultural Statistics of Pakistan (*http://www.amis.pk*).*

Table 4: *Wheat average yields by province from 2010-11 to 2017-18 (Average yield 40 kg per Acre).*

Year	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Pakistan
2010-11	28.79	37.91	16.14	21.64	28.66
2011-12	27.68	36.27	15.68	21.95	27.45
2012-13	28.88	34.40	17.49	21.40	28.28
2013-14	28.94	36.10	17.75	22.17	28.57
2014-15	27.94	33.56	17.40	22.92	27.57
2015-16	28.57	33.60	18.35	23.02	28.12
2016-17	31.09	33.83	18.45	23.92	30.08
2017-18	29.58	33.79	17.76	23.99	28.84

Source: *Agricultural Statistics of Pakistan (*http://www.amis.pk*).*

Table 5: *Wheat area in the province from 2010-11 to 2017-18 ('000' Acres in Area).*

Year	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Pakistan
2010-11	16534.13	2827.93	1790.31	842.15	21994.52
2011-12	16019.89	2592.68	1802.17	959.78	21374.52
2012-13	16090.07	2615.41	1797.23	897.50	21400.22
2013-14	17054.05	2771.59	1919.80	987.20	22732.64
2014-15	17250.75	2735.26	1810.33	951.37	22747.71
2015-16	17084.94	2853.13	1908.43	946.18	22792.69
2016-17	16458.02	2889.95	1850.11	973.86	22171.94
2017-18	16209.92	2692.51	1861.73	974.60	21738.76

Source: *Agricultural Statistics of Pakistan (*http://www.amis.pk*).*

Important nematode pests of wheat

Pests and parasites cause huge economic losses to agricultural crops and threaten global food security. Plant-parasitic nematodes are known to infest almost all cultivated crops, and caused estimated economic losses of over $130 billion worldwide (Chitwood, 2003). The largest damage to crops can be attributed to sedentary endoparasitic nematodes viz., root-knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Globodera* and *Heterodera* spp.) (Blyuss *et al.*, 2019).

In the case of wheat (*Triticum aestivum* L.) the major nematode parasites on a global basis are cereal cyst nematode, primarily *Heterodera avenae* (Peng *et al.*, 2009; Dababat *et al.*, 2015), besides other economically important nematodes including root-lesion nematodes, *Pratylenchus* spp., root-knot nematodes, *Meloidogyne* spp., the ear-cockle nematode or seed gall nematode, *Anguina tritici* (Steinbuch, 1799; Filipjev, 1936) and the stem nematode, *Ditylenchus dipsaci* (Kuhn, 1857; Filipjev, 1936; McDonal and Nicol, 2005).

In Pakistan, one of the earlier records of plant-parasitic nematodes disease on wheat was made by Sattar and Hafeez (1952) who reported *Anguina tritici* from D.G. Khan, Muzaffargarh and Jhung areas of Punjab, Pakistan. Maqbool (1986, 1988b, 1992) gave a comprehensive list of plant-parasitic nematodes with their host association and distribution including wheat crop. Biodiversity of nematode fauna in Pakistan with systematic distribution of nematodes on different crops was given by Maqbool and Shahina (2001) in which more than 74 plant-parasitic nematodes associated with wheat were reported. Later on Shahina and Erum (2007), Erum and Shahina (2010) and Handoo *et al.* (2010) during the nematological survey of wheat crops reported some new species and new record species from wheat in Pakistan. Zarina and Shahina (2012) provided comprehensive bibliographical records on plant Nematology in Pakistan.

Among the nematode fauna of wheat eight new species have so far been described from Pakistan viz., *Scutylenchus quettensis* (Maqbool *et al.*, 1984); *Heterodera pakistanensis* (Maqbool and Shahina, 1986), *Tylenchus bhitai* (Maqbool and Shahina, 1987), *Tylenchorhynchus tritici* (Golden *et al.*, 1987); *Helicotylenchus discocephalus* (Firoza and Maqbool, 1993), *Atetylenchus metaporus* (Erum and Shahina, 2008), *Paurodontella myceliophaga* (Handoo *et al.*, 2010) and *P. balochistanica* (Handoo *et al.*, 2010).

Besides the new nematode species of wheat other plant-parasitic nematodes were recorded with this crop by several scientists from time to time in Pakistan (Akhtar, 1962; Anwer *et al.*, 1991; Erum, 2011; Gul and Saeed, 1990; Khan *et al.*, 2003; Khan, 2011; Solangi *et al.*, 1982; Maqbool and Shahina, 2001; Zarina and Shahina, 2012; Erum *et al.*, 2021). A comprehensive list of new and known plant-parasitic nematodes associated with wheat in Pakistan is incorporated herein (Table 6).

Major nematode pests of wheat

Cereal cyst nematode, *Heterodera* spp.: The cereal cyst nematodes (CCNs) are a group of several closely related species which have been documented to cause economic yield loss in rain-fedwheat production systems in several parts of the world where cereals are produced. These nematodes are obligate sedentary endo-parasites and are among the important pests that limit the production of small grain cereals (Subbotin *et al.*, 2010a; Smiley *et al.*, 2017).

CCNs nematodes alone are estimated to reduce the production of crops by 10% globally (Ali *et al.*, 2019). Economic losses in cereals caused by CCNs were documented and reported in several studies around the world (Dababat and Fourie, 2018; İmren *et al.*, 2019). Among the 80 valid species of the genus *Heterodera* Schmidt, 1871 (Subbotin *et al.*, 2010b; Haque and Khan, 2021), the most common and economically important nematode species found associated with wheat is *Heterodera avenae* Wollenweber, 1924. This species has a worldwide distribution including Pakistan. *Heterodera avenae* has been associated with

molya diseases of wheat and barley in India (Sharma, 2003), and is known to occur in the major wheat-growing areas (Kanwar and Bajaj, 2010), but this disease has not been reported from Pakistan so far.

Table 6: *Plant-parasitic nematodes encountered from wheat in Pakistan.*

***Tylenchus* Bastian, 1865**

**T. Bhitai* Maqbool and Shahina, 1987

T. butteus Thorne and Malek, 1968

T. skarduensis Maqbool and Shahina, 1987

***Filenchus* Andrássy, 1954**

F. cylindricus (Thorne and Malek, 1968) Niblack and Bernard, 1985

F. filiformis (Butschli, 1873) Meyl, 1961

F. vulgaris (Brzeski, 1963) Lownsbery and Lownsbery, 1985

***Aglenchus* Andrássy, 1954**

A. siddiqii Khan, Khan and Bilqees, 1992

***Coslenchus* Siddiqi, 1978**

C. tuberosus (Maqbool, 1983) Mizukubo and Minagawa, 1985

***Boleodorus* Thorne, 1941**

B. neosimilis Geraert, 1971

B. pakistanensis Siddiqi, 1963

B. rafiqi Husain and Khan, 1965

***Basiria* Siddiqi, 1959**

B. graminophila Siddiqi, 1959

B. incita Szczygiel, 1970

***Neopsilenchus* Thorne and Malek, 1968**

N. (N.) minor (Geraert, 1968) Shahina and Maqbool, 1990

***Malenchus* Andrássy, 1968**

M. andrassyi Merny, 1970

M. fusiformis (Thorne and Malek, 1968) Siddqi, 1979

M. labiatus Maqbool and Shahina, 1985

***Ottolenchus* Husain and Khan, 1967**

O. facultativus (Szczygiel, 1970) Brzeski, 1982

O. longicauda Maqbool and Shahina, 1985

***Anguina* Scopoli, 1777**

A. tritici (Steinbuch, 1799) Filipjev, 1936

***Ditylenchus* Filipjev, 1936**

D. dipsaci (Kühn, 1857) Filipjev, 1936

D. emus Khan, Chawla and Prasad, 1969

D. medicaginis Wasilewska, 1965

D. myceliophagus Goodey, 1958

***Hoplolaimus* Von Daday, 1905**

H. californicus Sher, 1963

H. Columbus Sher, 1963

H. dimorphicus Mulk and Jairajpuri, 1976

H. galeatus (Cobb, 1913) Thorne, 1935

H. indicus Sher, 1963

H. seinhorsti Luc, 1958

H. seshadrii Mulk and Jairajpuri, 19762

***Rotylenchus* Filipjev, 1936**

R. robustus (de Man, 1876) Filipjev, 1936

***Helicotylenchus* Steiner, 1945**

H. digonicus Perry in Perry, Darling and Thorne, 1959

H. dihystera (Cobb, 1893) Sher, 1961

**H. discocephalus* Firoza and Maqbool, 1993

H. egyptiensis Tarjan, 1964

H. indicus Siddiqi, 1963

H. macronatus Malik and Jairajpuri, 1975

H. microdorus Prasad, Khan and Chawla, 1965

H. multicinctus (Cobb, 1893) Golden, 1956

H. platyurus Perry in Perry, Darling and Thorne, 1959

***Rotylenchulus* Linford and Oliveira, 1940**

R. reniformis Linford and Oliveira, 1940

***Heterodera* Schmidt, 1871**

H. avenae Wollenweber, 1924

H. mani Mathews, 1971

H. mothi Khan and Husain, 1965

**H. pakistanensis* Maqbool and Shahina, 1986

H. schachtii Schmidt, 1871

H. zeae Koshy, Swarup and Sethi, 1971

***Meloidogyne* Goeldi, 1892**

M. incognita (Kofoid and White, 1919) Chitwood, 1949

M. javanica (Treub, 1885) Chitwood, 1949

***Tylenchorhynchus* Cobb, 1913**

T. annulatus (Cassidy, 1930) Golden, 1971

T. brassicae Siddiqi, 1961

T. clarus Allen, 1955

T. cylindricus Cobb, 1913

T. elegans Siddiqi, 1961

T. mashhoodi Siddiqi and Basir, 1959

T. nudus Allen, 1955

T. straitus Allen, 1955

**T. tritici* Golden, Maqbool and Handoo, 1987

T. tuberosus Zarina and Maqbool, 1994

***Bitylenchus* (Filipjev, 1934) Siddiqi, 1986**

B. maximus (Allen, 1955) Siddiqi, 1986

B. vulgaris (Upadhyay, Swarup and Sethi, 1972) Siddiqi, 1986

***Dolichorhynchus* Mulk and Jairajpuri, 1974**

D. phaseoli (Sethi and Swarup, 1968) Mulk and Jairajpuri, 1974

***Paratrophurus* Arias, 1970**

P. anomalus Kleynhans and Heyns, 1983

***Quinisulcius* Siddiqi, 1971**

Table continue on next page.....

Q. acutoides (Thorne and Malek, 1968) Siddiqi, 1971
Q. curvus (Williams, 1960) Siddiqi, 1970
***Merlinius* Siddiqi, 1970**
M. brevidens (Allen, 1955) Siddiqi, 1970
M. microdorus (Geraert, 1966) Siddiqi, 1970
M. nanus (Allen, 1955) Siddiqi, 1970
***Scutylenchus* Jairajpuri, 1971**
S. koreanus (Choi and Geraert, 1971) Siddiqi, 1979
**S. Quettensis* Maqbool, Ghazala and Fatima, 1984
***Psilenchus* de Man, 1921**
P. hilarulus de Man, 1921
P. hilarus Siddiqi, 1963
P. iranicus Kheiri, 1970
P. pratensis Doucet, 1996
***Atetylenchus* Khan, 1973**
**A. metaporus* Erum and Shahaina, 2008
***Pratylenchus* Filipjev, 1936**
P. brachyurus (Godfrey, 1929) Filipjev and SchuurmansStekhoven, 1941
P. coffeae (Zimmermann, 1898) Filipjev and SchuurmansStekhoven, 1941
P. delatterei Luc, 1958
P. hexincisus Taylor and Jenkins, 1957
P. penetrans (Cobb, 1917) Filipjev and SchuurmansStekhoven, 1941
P. pratensis (de Man, 1880) Filipjev, 1936
P. similis Khan and Singh, 1975
P. thornei Sher and Allen, 1953
P. zeae Graham, 1951
***Hirschmanniella* Luc andGoodey, 1964**
H. gracilis (de Man, 1880) Luc and Goodey, 1964
H. magna Siddiqi, 1966
H. mexicana (Chitwood, 1951) Sher, 1968
H. mucronata (Das, 1960) Luc and Goodey, 1964
H. oryzae (Van Breda de Haan, 1902) Luc and Goodey, 1964
***Radopholus* Thorne, 1949**
R. similis (Cobb, 1893) Thorne, 1949
***Criconemoides* Taylor, 1936**
C. curvatus Raski, 1952
C. sphaerocephalus Taylor, 1936
***Hemicriconemoides* Chitwood and Birchfield, 1957**
H. cocophillus (Loos, 1949) Chitwood and Birchfield, 1957
H. communis Edward and Misra, 1964
H. mangiferae Siddiqi, 1961
***Aulosphora* Siddiqi, 1980**
A. karachiensis Maqbool, Shahina and Zarina, 1986
***Paratylenchus* Micoletzky, 1922**
P. projectus Jenkins, 1956
***Gracilacus* Raski, 1962**
G. musae Shahina and Maqbool, 1993
***Paurodontella* Husain and Khan, 1968**
**P. balochistanica* Handoo, Erum, Nasira and Shahina, 2010
**P. myceliophaga* Handoo, Erum, Nasira and Shahina, 2010
***Aphelenchus* Bastian, 1865**
A. avenae Bastian, 1865
***Aphelenchoides* Fischer, 1894**
A. rutgersi Hooper and Myers, 1971
A. asterocaudatus Das, 1960
***Paraphalenchus* Micoletzky, 1922**
Paraphalenchus spp.
***Xiphinema* Cobb, 1913**
X. americanum Cobb, 1913
X. californicum Lamberti and Bleve-Zacheo, 1979
X. intermedium Lamberti and Bleve-Zacheo, 1979
***Longidorus* (Micoletzky, 1922) Filipjev, 1934**
L. elongatus (de Man, 1876) Thorne and Swanger, 1936
***Paratrichodorus* Siddiqi, 1974**
P. minor (Colbran, 1965) Siddiqi, 1974

* *New species from wheat.*

H. zeae Koshy *et al.* (1971), corn cyst nematodes are another *Heterodera* species considered as one of the most economically important nematodes causing severe losses to maize and other cereals reported from Pakistan, India and other parts of the world (Subbotin *et al.*, 2010b).

Maqbool (1980) reported some cyst nematodes for the first time from wheat and other agricultural crops of Pakistan viz., *H. avenae*, *H. zeae*, *H. mani*, *H. vigni*, *H. mothi*, *H. sacchari* and *H. schachtii*. *H. avenae*, the major pest of wheat was recorded on wheat and maize from Peshawar and Mardan, respectively from Khyber Pakhtunkhwa province (Maqbool, 1980).

H. zeae is the other most economically important species of cyst nematode; this species is the specific pest of maize, but has also been found well distributed in the wheat-growing areas of the country and might possible of the poor wheat growth and production. Other cyst nematode species have been found on wheat viz., *H. mani*, *H. vigni* and *H. mothi* but they have not been shown to be economically important (Maqbool, 1980, 1981). A new cyst nematode species *H. pakistanensis* was described by Maqbool and Shahina (1986) from wheat fields of Sukkur, Sindh Province of Pakistan.

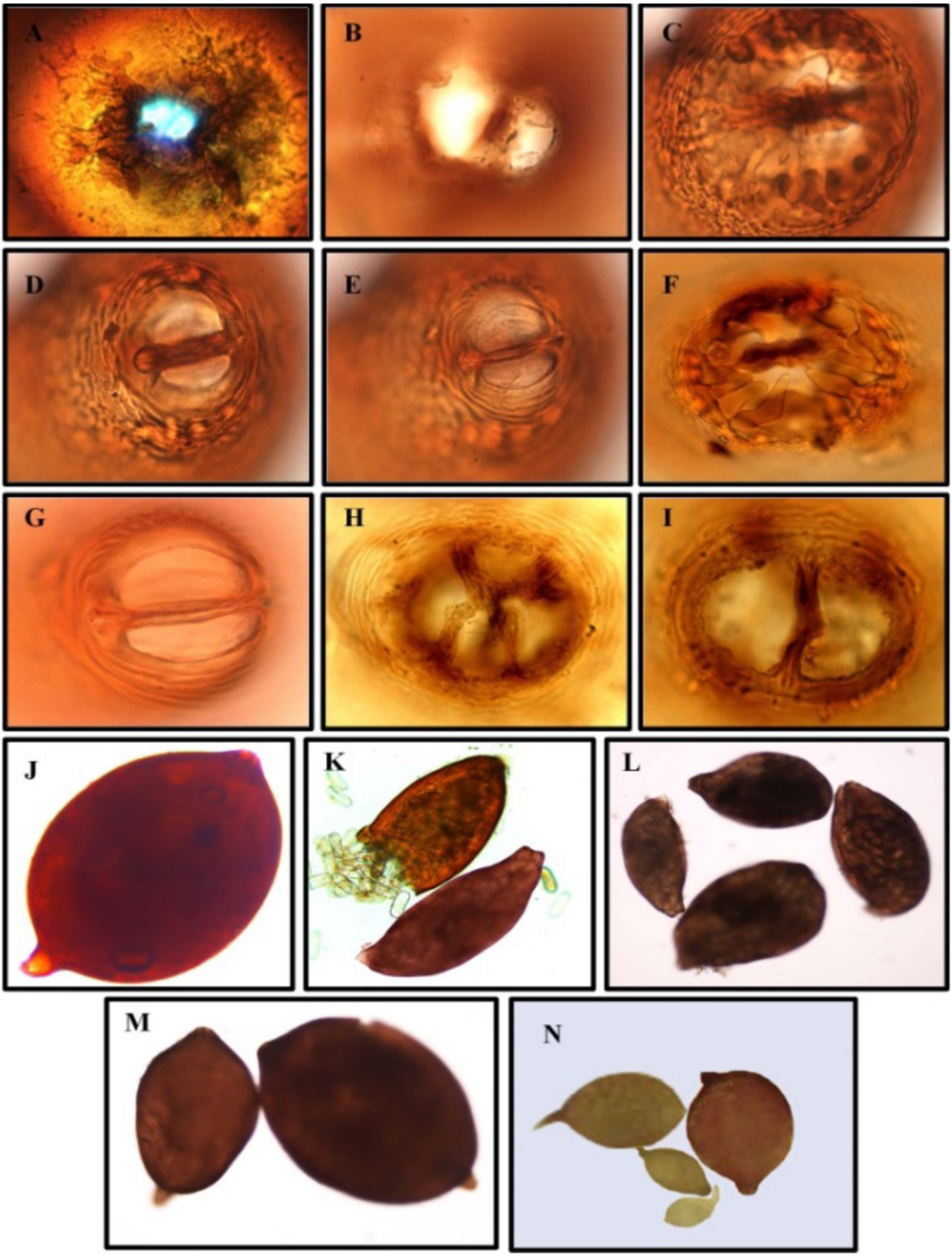

Figure 5: *Cyst nematodes (A-N): Vulval cone: A and B. Heterodera avenae; C and D. H. mothi; E. H. pakistanensis; F and G. H. schachtii; H and I. H. zeae. Female cyst whole body: J. H. avenae; K. H. mothi; L. H. pakistanensis; M. H. schachtii; N. H. zeae.*

H. avenae and *H. zeae* are major pests of wheat and barley in Pakistan. Approximately, 15-20% loss of wheat yield was caused by *H. avenae* in Pakistan (Maqbool, 1988a). Shahina and Maqbool (1990) reported *H. zeae* as a widely distributed species of wheat than other cereal cyst nematodes with a higher incidence in Khyber Pahktunkhwa than in Sind and Punjab provinces.

Shahina and Erum (2007) described the status of cyst nematodes of Pakistan and also reported that *H. zeae* along with *H. mothi* were detected more from wheat fields of Khyber Pakhtunkhwa than Punjab province while *H. avenae* was recorded only from Mirpurkhas, Sindh. *H. avenae* was later on reported from wheat fields of Bahawalpur, Punjab (Erum, 2011).

In another study, *H. avenae* and *H. mani* were reported from district Hunza and district Nager of Gilgit-Baltistan, Pakistan from wheat (Sagir, 2019). *S*everal scientists reported this nematode from time to time (Maqbool and Shahina, 2001; Zarina and Shahina, 2012; Erum *et al*., 2021).

Comparative study of cyst nematodes found from wheat fields of Pakistan

An attempt has been made to include the comparative morphological data of cyst nematode species found in wheat fields of Pakistan along with the key of identification (Erum, 2011). The complementary data will facilitate the correct identification of these cyst nematodes by morphology (Figure 5 and Table 7).

Key to the species of cyst nematode found from wheat fields of Pakistan

- Vulval slit very short (6-12µm). Vulval cone bifenestrate. Vulva denticles present or absent, bullae few to many---Avenae group---2
- Vulval slit very long more than 30µm. Vulval cone ambifenestrate, sometime bifenestrate---3
- Cyst dark brown to black. Vulval slit mean length 9.6µm, second stage larvae stylet knobs shallowly concave anteriorly --- *H. avenae*
- Bullae strong well developed. Vulval cone ambifenestrate---Schachtii group----4
- Bullae absent or few, scattered.Vulval cone ambifenestrate or bifenestrate --- Goettingiana group---5
- Bullae located at two levels, level one below under bridge four fingesr like bullae, level two randomly located long, heavy bullae---*H. zeae*
- Bullae located at one level, typically molar shaped---*H. schachtii*
- Second stage juveniles with three lines in lateral field---6
- Second stage juveniles with four lines in lateral field---7
- Distinct perineal pattern present, cyst elongate, L/W ratio 1.7---*H. mothi*
- Anus with distinct circular pattern. Second stage larvae stylet length 16-19µm, tail length 68-72 µm ---- *H. pakistanensis*

*Seed gall nematode, Anguina tritici (*Steinbuch, 1799*)* Filipjev, 1936

Seed-gall nematode (*Anguina tritici*), also known as ear-cockle, is commonly found on small grain cereals. It is the first known plant-parasitic nematode recorded in scientific literature in 1943 from wheat, and is reported from all wheat growing areas of the world. It has also been recorded from barley from many countries. A single gall may contain over 10,000 dormant juveniles (McDonal and Nicol, 2005). The nematode is one of the most serious pests of wheat in India; also causes yellow ear rot or tundu disease in wheat in association with the bacterium *Clavibacter tritici* (Khan, 2015). In Pakistan ear-cockle is a known pest on wheat and barley and is found in nearly all parts of the country, causing losses of 2-3%. However, in association with the yellow ear rot bacterium, it produces serious yield losses on wheat (Maqbool, 1988a).

Anguina tritici was first recorded from wheat plants from Muzaffarabad, DIG Khan and Jhung, Punjab in Pakistan by Sattar and Hafiz (1952). Shahina et al., (1989) reported that two out of nine wheat varieties showed high resistance against *Anguina tritici*, one variety was least susceptible while six varieties were moderately susceptible to susceptible. Later on, many researchers reported this nematode from time to time (Maqbool and Shahina, 2001; Zarina and Shahina, 2012; Erum et al., 2021).

Root-knot nematodes, Meloidogyne spp.

Root-knot nematodes (RKN) are one of the most important plant parasitic groups that attack almost every crop including cereals worldwide. Mostly they attack cereals and favor light soils and warm temperatures, some species prefer to attack in cool climates while in tropical and subtropical areas three species of RKN viz., *M. incognita*, *M. javanica* and *M. arenaria* are known to attack cereals. Only cereal root-knot nematode *M. nassi* and *M. artiellia* have

Table 7: *Comparative taxonomic data of cyst nematodes (Heterodera spp.) encountered from wheat fields of Pakistan (Measurements are in µm).*

Characters	*H. avenae*	*H. mothi*	*H. pakistanensis*	*H. schachtii*	*H. zeae*
Female					
Length	501-752	417-506	361-554	591-774	434.5-450
Width	352-524	175-321	191-336.5	342.2-501	251-272
Stylet	25-30	17-19.6	20-22	25.2-27.0	22-25
Cyst					
Length	518.2-801.1	440.6-607.5	484-610	608-854	550-653
Width	467-693	212-350	281-442	398-585	350-410.5
Length/width	1.2-1.4	1.5-2.2	1.4-2.3	1.3-1.5	1.4-1.55
Fenestral length	41-45	35.3-52	25-39	30-38	40.2-55.5
Fenestral width	20-25	24-30	15-22	26-31.5	20.2-41
Vulval slit	8.2-14.5	32-41	45-51	-	30.5-48
Male					
Length	1020-1470	935-1052.4	947-1281	805-1243	640.8-997
a	32-56.5	38.6-46	28-37	27-35	18.9-39.9
b	7-10.2	4-5	3.20-4.0	3.5-4.9	3.6-6.6
b'	4-5.9	-	7.5-9.2	8.6-9.9	4.3-5.6
T	38-60	-	-	-	-
Stylet	28.5-33	19-22	21.4-25	25-32	24-28
Spicules	32.5-38	24-28	30-36	32-36.4	24.8-32
Gubernaculum	10.2-13	7-10	8-10.4	9-11	8-11.5
Second stage larvae					
Length	508-587	372-432	412-450	425-502.8	365.5-441
a	15.5-20	20.5-30.5	24-27.9	19.5-23	20-25.57
b	3.0-4.4	2.0-3.5	6-8.8	2.3-3.5	2.51-3.10
c	7.5-10.4	6-8.5	6.3-9.8	9.5-10.6	8.30-10.40
c'	3-4.5	6-7.5	6.2-6.9	4.2-5.5	4.5-5.7
Stylet	24-27.5	16-17.5	16-19	24.0-26.5	19.2-21
Tail length	52.2-68.5	54-72.4	68-72	42-50.5	37.6-48
Hyline tail portion	34-42	25.5-32.2	32-35.5	25-29	16.6-20
D.G.O.	4-5.5	4-6.4	5.6-6.8	3-4	4-5
Lateral lines	4	4	4	4	4
Cyst body shape					
Female body shape	Lemon shaped	Lemon shaped	Lemon shaped	Lemon shaped	Lemon shaped
Cyst wall pattern					
Wall pattern	Zig-zag lines	Zig-zag	Zig-zag, Subcuticu-larpunctation	Zig-zag	Zig-zag
Cyst cone					
Fenestrae	Bifenestrate	Ambifenestrate	Ambifenestrate	Ambifenestrate	Ambifenestrate
Under bridge	Absent	Well developed	Weak, conspicuous	Strongly developed	Well developed
Bullae	Prominen, heavy	Strongly developed, mostly rounded	Absent	Molar shaped, irregularly arranged	2 types:1-4 long fingerlike at the level of under bridge. 2- Small scattered below the level of under-bridge

been shown to cause significant damage to wheat and barley in the subtropics (McDonal and Nicol, 2005). Two species of root-knot nematodes viz., *M. incognita* and *M. javanica* have been reported from wheat in Pakistan (Erum, 2011); other researchers reported prevalence of RKN species in low to moderately high percentages in wheat (Maqbool and Shahina, 2001; Zarina and Shahina, 2012; Erum *et al.*, 2021).

*Stem nematode, Ditylenchus dipsaci (*Kuhn, 1857*)* Filipjev, 1936

Ditylenchus dipsaci is one of the most important species of stem nematodes on cereals including wheat and wide spreads globally. *D. dipsaci* is economically more important on rye and oat than wheat and barley. It was considered an important factor in low wheat yields when associated with *Fusarium* spp. (McDonal and Nicol, 2005). *D. dipsaci* has also been recorded on wheat by researchers in Pakistan (Maqbool and Shahina, 2001; Zarina and Shahina, 2012); however, the economic damage is not so obvious. Erum and Shahina (2010) during the taxonomic studies of plant and soil nematodes associate with wheat reported two new records of stem nematodes viz., *D. emus* (Khan et al. 1969) and *D. medicaginis* (Wasilewska, 1965) from Tandojam, Sindh, Pakistan while *Ditylenchus geraerti* (Paramonov, 1970) Bello and Geraert (1972) was reported as a new record species of wheat from district Hunza, Gilgit-Baltistan, Pakistan (Sagir, 2019).

Root-lesion nematodes, Pratylenchus spp.

Root-lesion nematodes, *Pratylenchus* spp. have been reported from wheat-growing areas of the world, causing damage to the wheat crop. More than eight species of root-lesion nematodes have been recorded on small grains. Among the four species viz., *P. thorei*, *P. neglectus*, *P. crenatus* and *P. penetrans* have worldwide distribution in cereals. *P. thornei* is considered the economically most important species associated with wheat including in Pakistan. Yield loss of 38-85% on what has been reported in Australia, 10-40% in Mexico and 70% in Israel (McDonal and Nicol, 2005; Dababat *et al.*, 2016). High populations of *Pratylenchus* are frequently associated with poorly growing cereals but data on damage are sparsely (Rivoal and Cook, 1993). The other crops of economic importance attacked by this nematode include wheat, maize, cotton, potato, rice, banana, vegetables, ornamentals and fruits (Khan, 2015). From Pakistan 5-6 species of the lesion nematodes have been recorded from wheat by different researchers (Maqbool and Shahina, 2001). Later on *P. delatterei* was encountered as a new record species from wheat plants at Hamdard University, Karachi, Sindh, Pakistan (Erum and Shahina, 2010; Zarina and Shahina, 2012; Erum *et al.*, 2021).

Conclusion and Recommendations

The updated information about the plant parasitic nematodes associated with wheat in Pakistan has been presented. Plant-parasitic nematodes can substantially reduce crop yield. A diverse fauna of plant parasitic nematodes mainly, cyst nematodes have been reported from several prime growing areas of Pakistan.

The use of nematicides has been drastically limited, and farmers have few chemical options. Numerous nematode management tactics have been banned (aldicarb, cadusafos, carbofuran, ethoprofos, chloropicrin, 1,3 dichloropropene, methyl bromide, and others). The use in chemo-irrigation may significantly reduce production costs and do not allow farmers to maintain the profitability of crops and crop quality. It's vital to note that each nematode genera and species has its own resistance in a crop. One of the most environmentally beneficial techniques of nematode management with zero environmental impact is to use natural products. None of the methods is effective by itself in all situations and control is best when measures are combined.

Novelty Statement

In this review article status of global wheat production is presented and its associated parasitic nematodes have been discussed with reference to chronological research data related to Pakistan.

Author's Contribution

Erum Iqbal: Collected the data, part of the manuscript is from the PhD thesis, wrote manuscript.
Firoza Kazi: Wrote the manuscript.
Saboohi Raza: Supervised the work.

Conflict of interest

The authors have declared no conflict of interest.

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