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Incidence and Distribution of Charcoal Rot Disease in Major Sunflower Growing Areas of Khyber Pakhtunkhwa

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ABSTRACT

Background: Charcoal rot is one of the serious threats to sunflowers which causes complete crop loss under epidemic conditions. **Aims:** In the current study, incidence and severity of *Macrophomina phaseolina* (MP) associated with sunflower plantations in Khyber-Pakhtunkhwa (KP) Province of Pakistan was determined through extensive surveys. **Methodology:** For the current study seven districts including Peshawar, Charsadda, Nowshera, Swabi, Bannu, Mardan, and Lakki Marwat were selected and conducted in 2025. Five sites in each district and four fields within each site at a distance of 02 Km apart were surveyed. A zigzag path was followed while surveying each field. The location of each field was marked with Global Positioning System (GPS). **Results:** It has been observed that charcoal rot is present in all surveyed districts of KP province of Pakistan. Disease incidence, when compared across districts, showed that it was the highest in Southern districts (Bannu and Lakki Marwat) than the mid region districts (Swabi and Nowshera). The highest disease incidence was observed in district Bannu (54.7%) and district Lakki Marwat (45.1%). Converesly, the lowest disease incidence was recorded in district Swabi (9.3%). Similarly, disease severity when compared across districts, showed that it was the highest in Southern districts than the mid region districts. The highest severity of the disease was recorded in district Bannu (61.2%), while the lowest disease severity was observed in district Swabi (8.1%). **Conclusion:** Overall, Charcoal rot was found in all sunflower growing areas of KP surveyed during the studies. Disease incidence and severity were higher in southern (Bannu, Lakki Marwat) districts of the province than central districts.

INTRODUCTION

Sunflowers can play a crucial role as compared to other common oil seed crops. Sunflower (*Helianthus annuus* L.) belongs to the family Asteraceae. Helianthus genus contains 65 different species. The basic chromosome number for the Helianthus genus is 17. Diploid, tetraploid and hexaploid species are known. There are only 14 annual species of Helianthus (Andrew *et al*., 2013). Sunflower is an annual herb, with a rough, hairy stem, 3 to 12 feet high, broad, coarsely toothed, rough leaves The plant has a rough, hairy stem, broad, coarsely toothed, rough leaves and circular heads of flowers (Khaleghizadeh, 2011). The heads consist of many individual flowers which mature into seeds on a receptacle base (Seghatoleslami *et al*., 2012). Sunflower is the world's fourth largest oil-seed crop and its seeds are used as food and its dried stalk as fuel. It is already being used as ornamental plant and was used in ancient ceremonies (Harter *et al*., 2004; Muller *et al*., 2011).

Oilseed crops including sunflowers are adversely affected by many pathogens including fungi, nematodes, bacteria and viruses. Among fungal diseases charcoal rot (CR) caused by *Macrophomina phaseolina* (Tassi) Goid has been the most serious disease of sunflowers in the world. Charcoal rot caused 20-60 % loss to the crop in Khyber Pakhtunkhwa (Steven *et al*., 1987). The disease is reported to cause reduction in yield (18-64 %), head diameter (30-35 %), 1000 grain weight (13-36 %) and oil content (5-8 %) (Tikhonv *et al*., 1986). Charcoal rot caused an estimated total yield loss of 2,505 thousand metric tonnes of soybeans in 2006 (Wrather *et al*., 2010). Yield losses as high as 70% have been documented in Africa.

Macrophomina phaseolina (Tassi) Goid, *M. phaseoli* (Mauble) Ashby, *Rhizoctonia bataticola* (Taub) Butler, *Sclerotium bataticola* Butler is reported to be soil borne, seed borne and root and stubble borne (Meyer *et al*., 1973; Meyer *et al*., 1974; Golam *et al*., 1976; Raut 1983). Over 90 diseases caused by several infectious microorganisms affect the quality and yield of the sunflower crop (Mukhtar, 2009 and Prasad *et al*., 2017). The disease develops under warm (30^{0}C and above soil temperature) and dry weather conditions (Abbas *et al*., 2019). *Macrophomina phaseolina* (Tassi) Goid is a member of the family *Botryosphaeriaceae*. Currently, no subspecies or

physiological races, based on morphological or genomic characterizations, have been identified for this fungus (Dhingra and Sinclair, 1978; Crous *et al*., 2006; Gahlot, 2018).

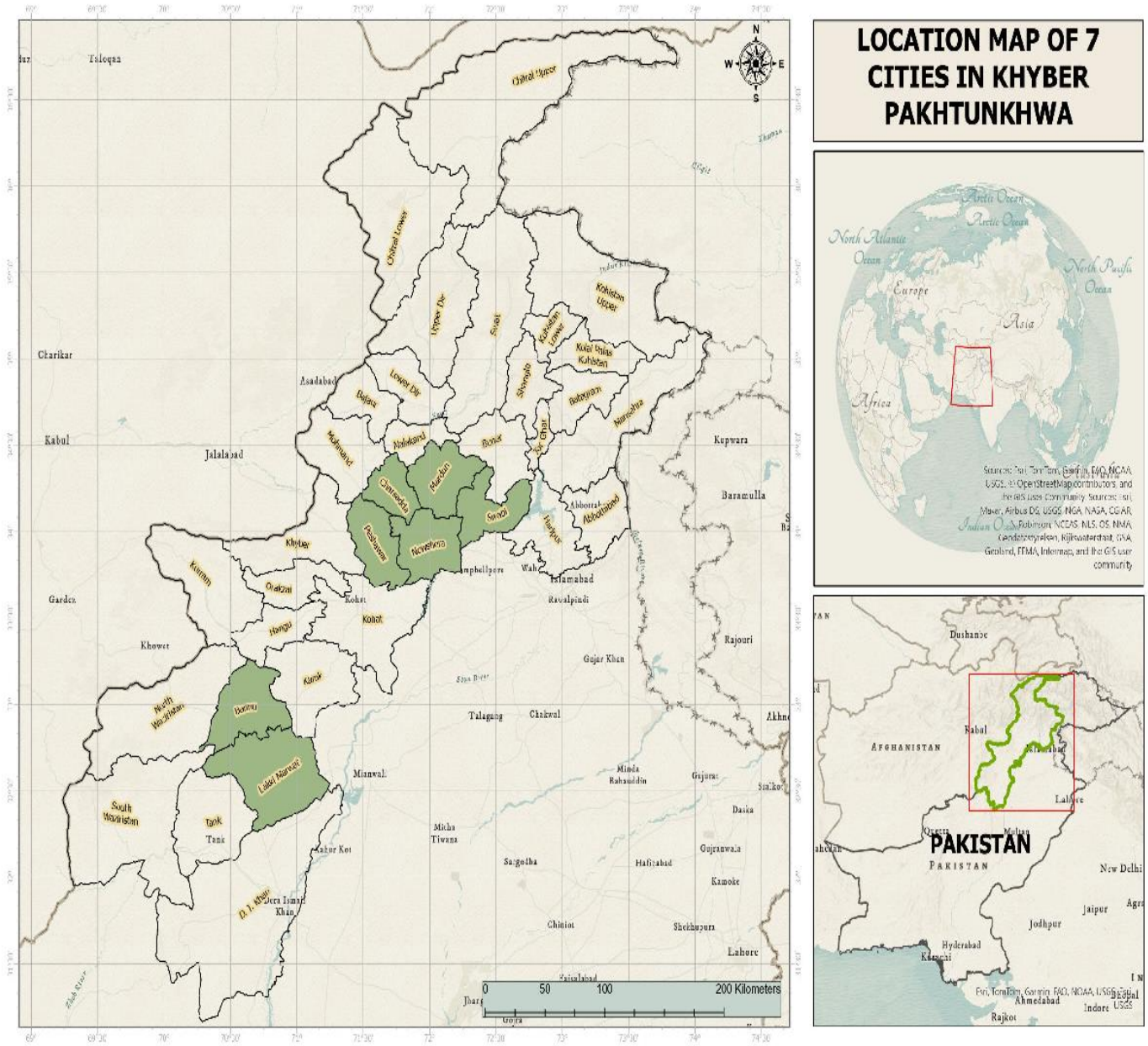
MATERIALS AND METHODS

Survey of Sunflower Crops for Charcoal Rot Incidence

In Khyber Pakhtunkhwa, Pakistan, extensive studies were carried out in 2025 to document the prevalence and severity of charcoal rot in regions that cultivate sunflowers. Peshawar, Charsadda, Nowshera, Swabi, Bannu, Mardan, and Lakki Marwat were the seven districts that were covered. Five sites were chosen from each district, and four fields at each site—fields spaced around two kilometers apart—were surveyed. A zigzag path was used to thoroughly investigate the vegetation in each field. A GPS device was used to record the precise location of each area that was surveyed (Figure 1).

Figure 1

Map of Khyber-Pakhtunkhwa (KP) Province. Colored Spots on the Map Represent the Areas Sampled for Charcoal Rot of Sunflower



Assessment of Charcoal Rot

Disease incidence and severity data in each field were evaluated at five random points. For sampling, 03m^2 quadrate was used. The incidence of the disease was calculated by the following formula.

$$D.I\ \% = \frac{\text{No. of infected plants}}{\text{Total no. of plants}} \times 100$$

Table 1 shows that disease severity was recorded on 05 plants randomly selected with in the quadrate, using disease assessment key of 0-5 described by (Sana *et al*., 2013).

Percent severity of disease was calculated as follows

$$DS\% = \Sigma n/5N \times 100$$

Where n = number of plants with symptoms of the disease, N = total number of plants examined and 5 = the highest infection category (Sana *et al*., 2013).

Table 1

Modified Disease Scale for Rating of Charcoal Rot Disease Described by Sana et al. (2013)

Disease scale	Disease severity	Disease scale Interpretation	Disease response
0	0%	No infection	Immune
1	1 – 9%	Plant resistant against infection and no disease symptoms	Resistant
2	10 – 24%	Smaller number of sclerotia, only inside the stem	Moderately resistant
3	25 – 49%	Sclerotia formed inside the stem, and external stem discoloration also appeared	Moderately susceptible
4	50 – 74%	Large number of sclerotia formed inside the stem and outer discoloration also severe	susceptible
5	75% and above	Whole plant becomes wilt and severe inner and outer stem infection occurs, with pycnidia formation in the host	Highly susceptible

RESULTS

Incidence and Severity of Charcoal Rot of Sunflower

Visual observation made during the survey conducted in 2025 confirmed the presence of characteristics disease symptoms such as yellowing of leaves, brown to red discoloration on lower parts of the stem and wilting (Figure 2).

The locations surveyed in district Bannu were heavily infected with charcoal rot exhibiting different range of incidence and severity of the disease (Table 2). The overall disease incidence in district Bannu was 54.7% whereas disease severity was recorded as 61.2%. Among locations, the highest disease incidence was observed in Surani (61.2%) while the lowest was recorded in Kakki (46.2%). In terms of severity less disease was observed in Ghori Wala (55%) whereas the highest disease severity was recorded in fields visited in Jhando Khel (73.7%).

In district Charsadda varying degrees of disease incidence and severity were recorded (Table 3). The overall disease incidence in district Charsadda was 34.5% whereas disease severity was recorded as 40.5%. Among locations, the highest disease incidence was observed in Utman Zai (46.7%) while the lowest was recorded in Tangi (23.7%). In terms of severity less disease appeared in Sardheri (22.5%) whereas the highest disease severity was assigned to fields visited in Harichand (56%).

Varying degrees of disease, incidence and severity were observed in district Lakki Marwat (Table 4). The overall disease incidence in district Lakki Marwat was 45.1% whereas disease severity was recorded as 54.5%. Among locations, the highest disease incidence was recorded in Manjiwala (66.2%) while the lowest was observed in Kot Kashmir (32.5%). In terms of severity less disease was apparent in Kot Kashmir (30.5%) whereas the highest disease severity was assigned to fields visited in Nar Hakeem Khan (75.2%).

The locations surveyed in district Mardan were infected with varying degrees of disease incidence and severity (Table 5). The overall disease incidence in district Mardan was 25.8% whereas disease severity was recorded as 29.7%. Among locations, the highest disease incidence was recorded in Jalala (37.5%) while the lowest was observed in Mayar (14.5%). In terms of severity less disease was evident in Jalala (25%) whereas the highest disease severity was noticed in fields visited in Mayar (43%).

In district Nowshera, varying degrees of disease incidence and severity were recorded (Table 6). The overall disease incidence in district Nowshera was 9.4% whereas disease severity was recorded as 13.4%. Among locations, the highest disease incidence was observed in Azakhel (20%) while the lowest was recorded in Kheshgi (3.7%). In terms of severity less disease appeared in Akbar Pura (6.2%) whereas the highest disease severity was assigned to fields visited in Azakhel (26.2%).

Varying degrees of disease incidence and severity were observed in district Peshawar (Table 7). The overall disease incidence in district Peshawar was 26.7% whereas disease severity was recorded as 25.2%. Among locations, the highest disease incidence was observed in Badabera (40%) while the lowest was recorded in Tarnab (15%). In terms of severity less disease was evident in Tarnab (6.2%) whereas the highest disease severity was recorded in fields visited in Malakandair (35%).

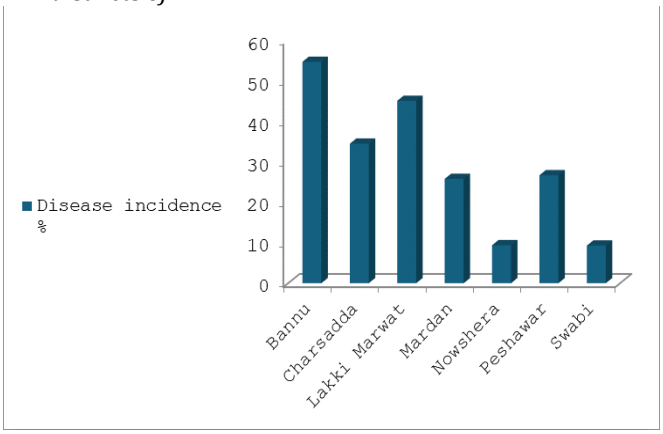
The locations surveyed in district Swabi were infected with varying degrees of disease incidence and severity (Table 8). The overall disease incidence in district Swabi was 9.3% whereas disease severity was recorded as 8.1%. Among locations, the highest disease incidence was observed in Jehangera (15%) while the lowest was recorded in Adina (0%). In terms of severity less disease was noticed in Adina (0%) whereas the highest disease severity was assigned to fields visited in Jehangera (12.5%).

Disease incidence, when compared across districts, showed that it was the highest in southern districts (Bannu and Lakki Marwat) than the mid region districts (Swabi and Nowshera) (Figure 4.2). The highest disease incidence was observed in district Bannu (54.7%) and district Lakki Marwat (45.1%) followed by district Charsadda (34.5%). Converesly, the lowest disease incidence was recorded in district Swabi (9.3%) followed by district Nowshera (9.4%). Similarly, disease severity when compared across districts, showed that it was the highest in southern districts than the mid region districts. The highest severity of the disease was recorded in district Bannu (61.2%) followed by Lakki Marwat (54.5%), while the lowest disease severity was observed in district Swabi (8.1%) followed by district Nowshera (13.4%).

Figure 2

Incidence and Severity of Charcoal Rot of Sunflower across Khyber-Pakhtunkhwa, Pakistan

A. *Incidence of charcoal rot from southern to central districts of KP*



B. *Severity of Charcoal Rot from Southern to Central Districts*

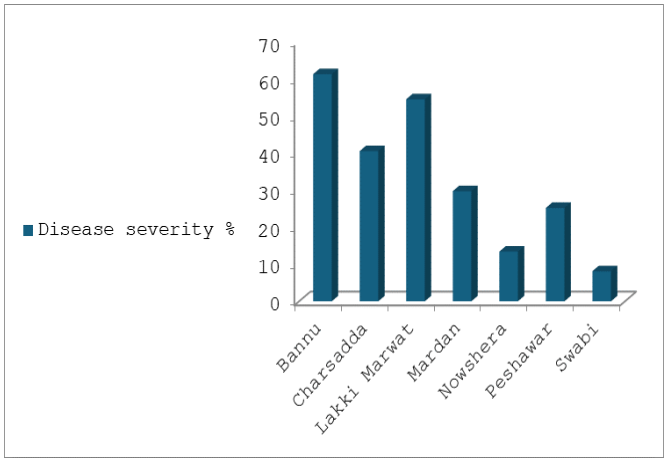


Table 2

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Bannu of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Bannu	Ghori Wala	1	50	70
		2	40	40
		3	70	35
		4	80	75
		Mean	60	55
	Jhando Khel	5	80	75
		6	30	85
		7	30	85
		8	60	50
		Mean	50	73.7
	Kakki	9	45	40
		10	55	70
		11	35	60
		12	50	60
		Mean	46.2	57.5
	Mandan	13	45	50
		14	55	60
		15	60	50
		16	65	70
		Mean	56.2	57.5
	Surani	17	70	80
		18	80	70
		19	50	50
		20	45	50
		Mean	61.2	62.5
	Group mean		54.7	61.2

Table 3

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Charsadda of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Charsadda	Harichand	1	13.3	60
		2	40	30
		3	60	54
		4	20	80
		Mean	34	56
	Prang Ghar	5	40	32
		6	36.7	30
		7	26.7	25
		8	45	35
		Mean	37.1	30.5
	Tangi	9	30	60
		10	20	50
		11	25	23
		12	20	70
		Mean	23.7	50.7
	Sardheri	13	35	20
		14	25	20
		15	30	30
		16	35	20
		Mean	31.2	22.5
	Utman Zai	17	50	30
		18	55	42
		19	27	50
		20	55	50
		Mean	46.7	43
	Group mean		34.5	40.5

Table 4

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Lakki Marwat of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Lakki Marwat	Manjiwala	1	50	70
		2	55	40
		3	70	40
		4	90	75
		Mean	66.2	56.2
	Nar Hakeem Khan	5	40	75
		6	60	85
		7	20	85
		8	45	56
		Mean	41.2	75.2
	Sperly Khel	9	27	35
		10	55	40
		11	45	77
		12	35	73
		Mean	40.5	56.2
	Kot Kashmir	13	25	27
		14	35	35
		15	25	30
		16	45	30
		Mean	32.5	30.5
	Group mean		45.1	54.5

Table 5

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Mardan of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Mardan	Jalala	1	40	15
		2	30	20
		3	45	30
		4	35	35
		Mean	37.5	25
	Mayar	5	15	37
		6	10	30
		7	10	50
		8	23	55
		Mean	14.5	43
	Takhtbahi	9	23	27
		10	30	35
		11	30	30
		12	45	30
		Mean	32	30.5
	Babozai	13	20	15
		14	16.5	20
		15	30	30
		16	25	35
		Mean	22.8	25
	Kati Garhi	17	23.3	10
		18	15	15
		19	36	45
		20	15	30
		Mean	22.3	25
	Group mean		25.8	29.7

Table 6

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Nowshera of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Nowshera	Akbar Pura	1	5	10
		2	10	15
		3	0	0
		4	0	0
		Mean	3.7	6.2
	Pabbi	5	0	0
		6	0	0
		7	30	25
		8	20	20
		Mean	12.5	11.2
	Azakhel	9	15	20
		10	20	25
		11	20	30
		12	25	30
		Mean	20	26.2
	Kheshgi	13	0	0
		14	5	10
		15	10	20
		16	0	0
		Mean	3.7	7.5
	Hakim Abad	17	5	10
		18	5	15
		19	10	20
		20	10	20
		Mean	7.5	16.2
	Group mean		9.4	13.4

Table 7

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Peshawar of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Peshawar	Malakandair	1	20	30
		2	30	55
		3	20	30
		4	25	25
		Mean	23.7	35
	Badabera	5	40	30
		6	20	30
		7	50	25
		8	50	25
		Mean	40	27.5
	Tarnab	9	20	10
		10	0	0
		11	40	15
		12	0	0
		Mean	15	6.2
	Regi	13	50	40
		14	30	30
		15	10	15
		16	20	20
		Mean	27.5	26.2
	Pakhaghulam	17	30	30
		18	15	25
		19	35	30
		20	30	40
		Mean	27.5	31.2
	Group mean		26.7	25.2

Table 8

Disease Incidence and Severity of Charcoal Rot of Sunflower in District Swabi of Khyber Pakhtunkhwa Province of Pakistan

District	Location	No of field surveyed	D. I %	D. S %
Swabi	Adina	1	0	0
		2	0	0
		3	0	0
		4	0	0
		Mean	0	0
	Yarhussain	5	30	25
		6	20	15
		7	0	0
		8	0	0
		Mean	12.5	10
	Jehangera	9	0	0
		10	20	20
		11	40	30
		12	0	0
		Mean	15	12.5
	Maneri	13	10	10
		14	5	10
		15	5	5
		16	20	15
		Mean	10	10
	Group mean		9.3	8.1

DISCUSSION

M. phaseolina the causal agent of charcoal rot, has wide host range of more than 500 plant species. So far it has been found associated with 67 economically important oilseeds, legumes, cereals, fiber and horticultural crops in Pakistan (Iqbal *et al*., 2021).

During the survey growers opined that disease incidence, in general, is increasing progressively, perhaps due to adoption of inadequate control measures including inaccurate fungicides and application methods. The common and easily adopted measure for disease control is the use of fungicide in most areas of the province. However, these are applied without prior knowledge. Selection of appropriate fungicides, spray equipment, and equipment calibration is also common. Further, continuous use of fungicides can lead to selection of resistant strains and evolution of new races of the pathogen resulting in increase in disease pressure (Deising *et al*., 2008).

Survey results indicated that over 80% of growers procured their seed either from local markets or from the grower's own crop harvested during the previous years. The farmers do not adopt cultural control measures (crop rotation, fallow land) or any other preventive measures such as pre-plant soil treatment for eradicating overseasoning inoculum. There were no proper sanitation practices in the province, which could be the cause of the spread of the pathogen across the province.

In district Peshawar, the soil was dryer and majority of the fields surveyed for the disease had low moisture content. Such conditions predispose sunflower crops to *M. phaseolina* attack. Velásquez et al., (2018) made similar observations and remarked that high temperature and low moisture predispose the crop to attack of the pathogen. In general understandings high temperature and low moisture content is favored to development of charcoal rot accompanied with virulent pathogen (Ijaz *et al*., 2013; Reis

et al., 2014).

The soil in districts Bannu and Lakki Marwat was dryer and fields were at low moisture content and were infected with charcoal rot. Farmers were unaware of the use of disease-free seeds (Bhutta *et al*., 2015; Basharat *et al*., 2024). Moreover, farmers use limited number of varieties and do not practice crop rotation. Continuous selection of the same varieties can lead to breakdown of the innate resistance in these varieties and allow the soil-borne inoculum to build up at a level which is difficult to control. Furthermore, mono-culturing affects the fertility of the field, as planting the same crop drains the field from the specific nutrients needed for plant growth. Soil with inadequate nutrients results in poor stands which in turn are more vulnerable to attack by different pathogens.

In district swabi most of the fields were free from the disease, yet in areas where disease was prevalent, it was not at an advance stage. Most growers in this district procured seed from certified companies and known sources. Furthermore, in this district growers regularly practiced crop rotation, which is consistent with the reports that crop rotation limits the incidence of the disease. Crop rotation is also fostering a diverse microbiome in the soil which helps to make nutrients available and control pests (Parveen *et al*., 2021). Studies have shown that crop rotation contributes to improved crop performance, enhanced soil fertility and long-term agricultural sustainability (Berendsen *et al*., 2012; Tiemann *et al*., 2015; Vukicevich *et al*., 2016).

CONCLUSION

Charcoal rot disease was observed in all surveyed sunflower-growing areas of Khyber Pakhtunkhwa, indicating its widespread presence across the province. The pathogen was prevalent in both central and southern districts, showing that the disease has become well established in the region. However, variations in disease intensity were recorded among different locations. The highest disease incidence and severity were noted in the southern districts, particularly Bannu and Lakki Marwat. In comparison, the central districts showed relatively lower levels of infection and disease severity. These differences may be associated with environmental conditions, cropping practices, and higher temperature stress in the southern region, which favor disease development.

Author Contributions

F is researcher and author of manuscript. SSA supervised study conducted. AA guided to conduct research in laboratory and helped in formal analysis. F also worked on the manuscript writing reviews and editing.

Data Availability

The original data of study is available.

REFERENCES

1. Abbas, H. K., Bellaloui, N., Accinelli, C., Smith, J. R., & Shier, W. T. (2019). Toxin production in soybean (*Glycine max* L.) plants with charcoal rot disease and by *Macrophomina phaseolina*, the fungus that causes the disease. *Toxins*, 11(11), Article 645. https://doi.org/10.3390/toxins11110645
2. Andrew, R. L., Kane, N. C., Baute, G. J., Grassa, C. J., & Rieseberg, L. H. (2013). Recent nonhybrid origin of sunflower ecotypes in a novel habitat. *Molecular Ecology*, 22(3), 799–813. https://doi.org/10.1111/mec.12038
3. Basharat, T., Gul, S., Rauf, S., Ahmad, S., & Ortiz, R. (2024). Sunflower hybrids evaluation for charcoal rot resistance in Pakistan. *SABRAO Journal of Breeding and Genetics*, 56(6), 2387–2396. https://doi.org/10.54910/sabrao2024.56.6.20
4. Berendsen, R. L., Pieterse, C. M. J., & Bakker, P. A. H. M. (2012). The rhizosphere microbiome and plant health. *Trends in Plant Science*, 17(8), 478–486. https://doi.org/10.1016/j.tplants.2012.04.001
5. Bhutta, A. R., Rahber-Bhattti, M. S., Nazamni, M. S., & Ahmad, I. (2015). Fungi associated with stored sunflower seeds in Pakistan. *Pakistan Journal of Phytopathology*, 27(2), 139–143.
6. Crous, P. W., Slippers, B., Wingfield, M. J., Rheeder, J., Marasas, W. F. O., & Phillips, A. J. L. (2006). Phylogenetic lineages in the Botryosphaeriaceae. *Studies in Mycology*, 55, 235–253. https://doi.org/10.3114/sim.55.1.235
7. Deising, H. B., Reimann, S., & Pascholati, S. F. (2008). Mechanisms and significance of fungicide resistance. *Brazilian Journal of Microbiology*, 39(2), 286–295. https://doi.org/10.1590/s1517-83822008000200017
8. Dhingra, O. D., & Sinclair, J. B. (1978). Biology and pathology of *Macrophomina phaseolina*. Imprensa Universitaria. https://doi.org/10.1007/bf03212337
9. Gahlot, N. (2018). Physiological and management studies of *Macrophomina phaseolina* causing root rot of mungbean (*Vigna radiata*). (Unpublished M.Sc. thesis). Sri Karan Narendra Agricultural University, India.
10. Golam, A. F., Rao, M. A. H., & Thirumalachar, M. J. (1976). Seed transmission of *M. phaseolina* in sunflower. *Plant Disease Reporter*, 60(9), 736–737.
11. Harter, A. V., Gardner, K. A., Falush, D., Lentz, D. L., Bye, R. A., & Rieseberg, L. H. (2004). Origin of extant domesticated sunflower in eastern North America. *Nature*, 430(6996), 201–205. https://doi.org/10.1038/nature02710
12. Ijaz, S., Sadaqat, H. A., & Khan, M. N. (2013). A review of the impact of charcoal rot (*Macrophomina phaseolina*) on sunflower. *Journal of Agricultural Science*, 151(2), 222–227. https://doi.org/10.1017/S0021859612000512
13. Iqbal, U., Mukhtar, T., Iqbal, S. M., Ul-Haque, I., & Malik, S. R. (2021). Host plant resistance in blackgram against charcoal rot *Macrophomina phaseolina* (*Tassi*) Goid. *Pakistan Journal of Phytopathology*, 22(2), 126–129.
14. Khaleghizadeh, A. (2011). Effect of morphological traits of sunflower hybrids on house sparrow damage rate. *Crop Protection*, 30(3), 360–367. https://doi.org/10.1016/j.cropro.2010.12.023
15. Meyer, W. A., Sinclair, J. B., & Khare, M. N. (1973). Biology of *Macrophomina phaseoli* in soil studied with a selective media. *Phytopathology*, 63(5), 613–620. https://doi.org/10.1094/Phyto-63-613
16. Meyer, W. A., Sinclair, J. B., & Khare, M. N. (1974). Factors affecting charcoal rot of soybean seedlings. *Phytopathology*, 64(6), 845–849. https://doi.org/10.1094/Phyto-64-845
17. Mukhtar, I. (2009). Sunflower disease and insect pests in Pakistan: a review. *African Crop Science Journal*, 17(3), 109–118. https://doi.org/10.4314/acsj.v17i2.54204
18. Muller, M. H., Latreille, M., & Tollon, C. (2011). Population genetic diversity of weedy populations of sunflower

(*Helianthus annuus* L.) in Spain and France. *Evolutionary Applications*, 4(3), 499–514. https://doi.org/10.1111/j.1752-4571.2010.00163.x

19. Parveen, G., Gul, S., Kaleemullah, K., Rahim, Z., & Rafi, M. A. (2021). Survey report of disease fields and crop losses in Khyber Pakhtunkhwa provinces. *Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences*, 64(3), 288–300. https://doi.org/10.52763/PJSIR.BIOL.SCI.64.3.2021.288.300
20. Prasad, P. V. V., Bheemanahalli, R., & Jagadish, S. V. K. (2017). Field crops and the fear of heat stress. *Field Crops Research*, 200, 114–121. https://doi.org/10.1016/j.fcr.2016.09.024
21. Raut, J. G. (1983). Transmission of seed borne *Macrophomina phaseolina* in seed. *Seed Science and Technology*, 11(3), 807–817.
22. Reis, E. M., Boaretto, C., & Danelli, A. L. D. (2014). Density and longevity of *Macrophomina phaseolina* microsclerotia and competitive saprophytic ability. *Summa Phytopathologica*, 40(2), 128–133. https://doi.org/10.1590/0100-5405/1921
23. Sana, S., Shoaib, A., & Khan, S. N. (2013). Screening and histopathological characterization of sunflower germplasm for resistance to *Macrophomina phaseolina*. *Mycologia*, 112(6), 1098–1108. https://doi.org/10.1080/00275514.2020.1810516
24. Seghatoleslami, M. J., Bradaran, R., Ansarinia, E., & Mousavi, S. G. (2012). Effect of irrigation and nitrogen level on sunflower yield and morphological traits. *Pakistan Journal of Botany*, 44(5), 1551–1555.
25. Steven, M., Rana, M. A., & Khan, M. A. (1987). Report on the survey of sunflower crop in Pakistan. Oilseed Programme, NARC, Islamabad, Pakistan.
26. Tiemann, L. K., Grandy, A. S., Atkinson, E. E., Marin-Spiotta, E., & McDaniel, M. D. (2015). Crop rotational diversity enhances soil microbial activity and soil structure. *Soil Biology and Biochemistry*, 89, 272–282. https://doi.org/10.1111/ele.12453
27. Tikhonov, O. I., Nedolko, V. K., & Prestora, T. A. (1986). Infection period and spreading pattern of *Sclerotium bataticola* in sunflower tissue. In *Proc. 7th International Sunflower Conference* (pp. 134–135).
28. Velásquez, A. C., Castroverde, C. D. M., & He, S. Y. (2018). Plant–pathogen warfare under changing climate conditions. *Current Biology*, 28(10), R619–R634. https://doi.org/10.1016/j.cub.2018.03.054
29. Vukicevich, E., Lowery, T., Bowen, P., Úrbez-Torres, J. R., & Hart, M. (2016). Cover crops and crop rotation influence soil microbial diversity. *Soil Biology and Biochemistry*, 97, 1–17. https://doi.org/10.1007/s13593-016-0385-7
30. Wrather, A., Shannon, G., Balardin, R., Carregal, L., Escobar, R., Gupta, G. K., … Tenuta, A. (2010). Effect of diseases on soybean yield in top producing countries. *Plant Health Progress*, 2010(1), 12–25. https://doi.org/10.1094/PHP-2010-0125-01-RS