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KARNAL BUNT SEVERITY: ASSOCIATED CHANGES IN PHYSICAL AND BIOCHEMICAL QUALITY ATTRIBUTES OF WHEAT GRAIN

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ABSTRACT

Karnal bunt is an important disease of wheat that can adversely affect both grain yield and quality. The present study assessed yield and grain quality losses associated with different grades of Karnal bunt infection in wheat genotypes. Ten cultivated wheat varieties, viz., WH 1124, WH 1105, WH 1142, DBW 173, DBW 187, DBW 222, HD 2967, HD 3059, HD 3086 and PBW 771, were evaluated for reduction in test weight across different grades of infection. For grain quality assessment, infected grains of three varieties i.e., PBW 771, WH 1105 and HD 2967 exhibiting different grades of Karnal bunt infection were evaluated for phosphorus content, sedimentation value and total phenolic content. Test weight decreased progressively with increasing grade of infection. The maximum reduction in test weight was recorded at grade 4 infection (28.50%), whereas the minimum reduction was observed at grade 1 (2.94%). Among the wheat varieties, the maximum reduction in test weight was recorded in HD 3059 (11.74%). Grain quality parameters also varied with the grade of Karnal bunt infection. In infected grains, phosphorus and phenolic contents increased with increasing infection grade, whereas sedimentation value decreased. The highest phenolic content was recorded at grade 4 infection (0.627%), while sedimentation value decreased from 41.00 ml at grade 0 to 36.67 ml at grade 4. In contrast, phosphorus content increased from 230.05 to 322.49 mg/100 g with increasing infection grade. Disinfection of infected grains resulted in a decrease in phosphorus and phenolic contents, accompanied by a further reduction in sedimentation value. The study demonstrated that increasing grades of Karnal bunt infection were associated with progressive reductions in test weight and deterioration of selected grain quality characteristics in wheat.

***Key words*:** Karnal bunt; *Tilletia indica*; Wheat grain quality; Disease severity; Test weight; Sedimentation value; Teliospores

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops and plays a central role in global food security. However, its production and grain quality are affected by several fungal diseases, among which Karnal bunt (KB), caused by *Tilletia indica* Mitra [syn. *Neovossia indica* (Mitra) Mundkur], is of particular importance because of its effects on grain quality and international wheat trade. The disease was first reported from Karnal, India, in 1931 and subsequently became established in several wheat-growing regions of the Indian subcontinent and other parts of the world. Unlike many destructive wheat diseases in which substantial yield reduction is the principal concern, the economic importance of Karnal bunt is largely associated with deterioration in grain quality and the quarantine restrictions imposed on infected wheat (Singh and Gogoi, 2011; Sharma *et al*., 2020; Sharma *et al*., 2021).

Karnal bunt is characterized by the partial replacement of the wheat kernel contents by a black mass of teliospores. The disease generally affects only a portion of the kernels within an ear, resulting in the characteristic “partial bunt” symptom. The presence of infected kernels can adversely affect the appearance,

acceptability and processing quality of wheat grain. Even relatively low levels of kernel infection can result in quality concerns, while quarantine regulations in importing countries further increase the importance of the disease. Consequently, the significance of Karnal bunt extends beyond direct production losses to include grain quality, marketability and restrictions on the movement of wheat (Warham, 1990; Sharma *et al*., 2020; Sharma *et al*., 2025).

The magnitude of damage caused by Karnal bunt is closely related to the severity of infection. Increasing infection of individual kernels is expected to alter the physical characteristics of grain, including grain weight. Previous studies and reviews have emphasized that yield losses associated with Karnal bunt are generally limited compared with the deterioration in quality; nevertheless, severe infection of individual kernels can result in considerable loss of grain weight. Therefore, evaluating changes in test weight across different grades of infection provides a direct measure of the physical loss associated with progressively increasing Karnal bunt infection (Sharma *et al*., 2020; Sharma *et al*., 2021). In the present study, Karnal bunt-infected grains were classified into five grades, from grade 0 representing healthy grains to grade 4 representing grains with more than 75% infection or complete conversion into sorus. The classification is consistent with the commonly used Karnal bunt severity scale based on the proportion of the kernel converted into sorus (Aujla *et al*., 1989; Bonde *et al*., 1996; Sharma *et al*., 2020).

In addition to physical loss, Karnal bunt infection can modify the chemical and functional characteristics of wheat grain. Grain quality is particularly important because the consequences of Karnal bunt are determined not only by the quantity of grain harvested but also by the suitability of the grain for processing and consumption. Previous research has reported changes in the chemical composition and flour quality of Karnal bunt-affected wheat, highlighting the need to assess quality deterioration alongside grain-weight loss (Rush *et al*., 2005; Sharma *et al*., 2020). Among the quality characteristics, sedimentation value is an important indicator of flour quality and gluten-related functional properties. A decline in sedimentation value with increasing disease severity may therefore indicate deterioration in the functional quality of flour obtained from infected grain.

The biochemical response of wheat grain to Karnal bunt infection can also be examined through changes in mineral and phenolic constituents. Phosphorus is an important mineral constituent of wheat grain, while phenolic compounds constitute an important group of plant metabolites associated with plant responses to biotic stress. Assessment of these components across different grades of infection can therefore provide information on the biochemical changes accompanying increasing Karnal bunt severity. In the present study, phosphorus content, sedimentation value and total phenolic content were determined in infected and disinfected grains representing different grades of Karnal bunt infection in three wheat genotypes. The relevance of phenolic compounds to the wheat–*T. indica* interaction has previously been demonstrated, with changes in total phenols and individual phenolic compounds being associated with the biochemical response of wheat genotypes to Karnal bunt infection (Gogoi *et al*., 2001).

Despite the recognized importance of Karnal bunt in grain quality and trade, information linking individual grades of kernel infection with quantitative changes in grain weight and selected quality characteristics remains important for understanding the extent of damage caused by progressive infection. Therefore, the present study was undertaken to assess the effect of different grades of Karnal bunt infection on test weight in ten wheat genotypes and to evaluate associated changes in phosphorus content, sedimentation value and total phenolic content in selected wheat genotypes. This approach provides an integrated assessment of the physical and selected biochemical quality changes associated with increasing severity of Karnal bunt.

Materials and Methods

Experimental material and grading of Karnal bunt infection

The effect of different grades of Karnal bunt infection on grain weight was assessed using ten cultivated wheat genotypes, namely WH 1124, WH 1105, WH 1142, DBW 173, DBW 187, DBW 222, HD 2967, HD 3059, HD 3086 and PBW 771 during 2020-21. Karnal bunt-infected grains were separated according to the degree of infection,

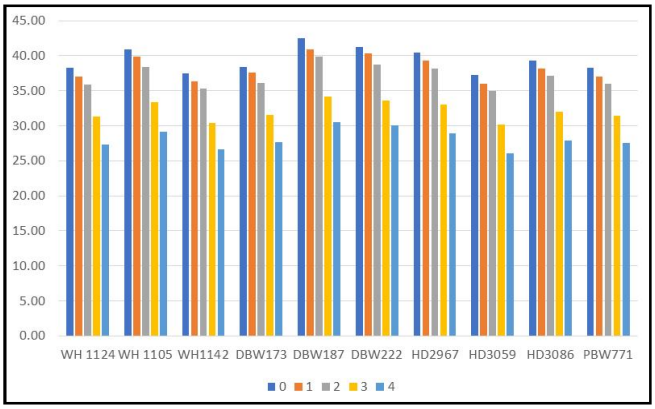


Fig. 1: Graphical representation of test weight having different grade of infection.

while healthy grains were considered as grade 0. The infected grains were categorized into four grades based on the extent of kernel infection following the Karnal bunt grading scale described by Aujla *et al.*, (1989). Grade 1 represented infection at the embryonal end with less than 25% infection, grade 2 represented 25–50% infection, grade 3 represented 50–75% infection, and grade 4 represented more than 75% infection or grains completely converted into sorus. The grading system is consistent with the established Karnal bunt severity scale based on the proportion of the grain converted into sorus (Aujla *et al.*, 1989).

Assessment of test weight

The test weight of wheat grains was determined for each grade of Karnal bunt infection in all ten wheat genotypes. One thousand grains from each infection grade were weighed, and the corresponding test weight was recorded. Healthy grains (grade 0) were used as the reference for determining the reduction in test weight associated with increasing grades of Karnal bunt infection.

Assessment of grain quality parameters

For assessment of grain quality, Karnal bunt-infected grains were collected from three cultivated wheat genotypes, namely PBW 771, WH 1105 and HD 2967. Grains representing different grades of infection were used for estimation of phosphorus content, sedimentation value and total phenolic content. Both infected grains containing teliospore material and corresponding disinfected grains were evaluated for these quality parameters.

Estimation of phosphorus content

Phosphorus content was estimated using the vanadomolybdate method. The reagents used included vanadate–molybdate reagent, 6 N hydrochloric acid, 2,4-dinitrophenol indicator and ammonia solution. Five millilitres of the digested sample aliquot was transferred to a 25-ml volumetric flask, followed by the addition of 2–3 drops of 2,4-dinitrophenol indicator. Ammonia solution was added until a yellow colour appeared, followed by dropwise addition of 6 N HCl until the solution became colourless. Subsequently, 5 ml of vanadomolybdate reagent was added and the volume was made up to 25 ml with distilled water. The solution was mixed thoroughly, and the intensity of the developed yellow colour was measured at 440 nm using a spectrophotometer. A blank was run simultaneously, and phosphorus content was calculated from the standard curve prepared using phosphorus standards.

Estimation of sedimentation value

Sedimentation value was determined following the method described by Axford *et al.*, (1979). The SDS/lactic acid reagent was prepared by dissolving 20 g SDS in one litre of water, followed by the addition of 20 ml of dilute lactic acid prepared by mixing one part lactic acid with eight parts water. For estimation, 6 g of flour was suspended in 50 ml of water in a 100-ml graduated cylinder. The suspension was rapidly shaken horizontally for 15 s and subsequently shaken for 15 s at 2 and 4 min. After the final shaking, 50 ml of SDS/lactic acid reagent was added and the cylinder was inverted four times. The inversion was repeated four times at 6, 8 and 10 min. The suspension was then allowed to stand for 20 min, after which the sedimentation volume was recorded in millilitres.

Estimation of total phenolic content

Total phenolic content was estimated according to the method of Swain and Hillis (1959). Briefly, 0.2 g of finely ground, dried wheat sample was extracted with 10 ml of 70% acetone. The sample was kept in a hot water bath at 37 °C for 2 h and subsequently centrifuged at 10,000 rpm for 20 min. The supernatant was collected and used for phenolic estimation. One millilitre of the extract was transferred to a test tube and the volume was made up to 7.5 ml with distilled water. Thereafter,

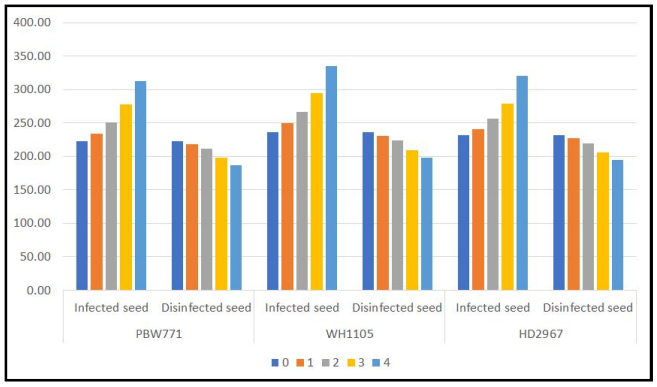


Fig. 2: Graphical representation of phosphorous content with various grade of infection.

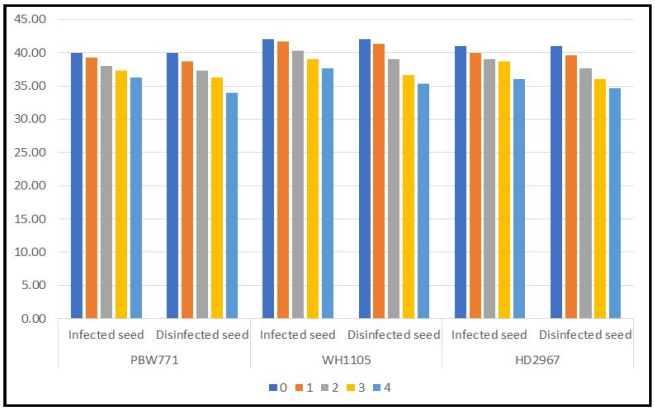


Fig. 3: Graphical representation of sedimentation value with various grade of infection.

Table 1: Effect of Karnal bunt on test weight of wheat on different wheat varieties.

Variety	Grades						% reduction in test wt.
	0	1	2	3	4	Mean	
WH 1124	38.27	37.03	35.89	31.28	27.27	33.95	11.30
WH 1105	40.84	39.81	38.38	33.36	29.10	36.30	11.12
WH1142	37.49	36.35	35.33	30.35	26.66	33.23	11.35
DBW173	38.39	37.54	36.13	31.50	27.66	34.24	10.81
DBW187	42.44	40.85	39.89	34.19	30.49	37.57	11.47
DBW222	41.24	40.27	38.69	33.59	30.05	36.77	10.84
HD2967	40.39	39.28	38.10	33.03	28.86	35.93	11.04
HD3059	37.24	36.00	34.96	30.12	26.02	32.87	11.74
HD3086	39.34	38.11	37.16	31.96	27.88	34.89	11.30
PBW771	38.23	37.02	35.94	31.39	27.57	34.03	10.99
Mean	39.39	38.23	37.05	32.08	28.16		
% reduction in wt.	-	2.94	5.94	18.56	28.50		
CD at 5%	0.52						

0.5 ml of Folin–Coalter reagent was added and mixed thoroughly. After 2–3 min, 1 ml of sodium carbonate solution was added and the final volume was adjusted to 10 ml with distilled water. The reaction mixture was allowed to stand for 1 h, and absorbance was measured at 725 nm using a spectrophotometer against a reagent blank. Total phenolic content was determined from a standard curve prepared using tannic acid.

The original method of Swain and Hillis (1959) describes quantitative analysis of phenolic constituents in plant tissue extracts and was published in the *Journal of the Science of Food and Agriculture*, **10**, 63–68.

Statistical analysis

The data obtained for test weight, phosphorus content, sedimentation value and total phenolic content were subjected to analysis of variance (ANOVA) to determine the effects of wheat genotype, Karnal bunt infection grade and their interaction. The significance of differences among treatment means was assessed using the critical difference (CD) at the specified probability level. The experiment was analysed based on three replications.

Results

Effect of Karnal bunt infection grade on test weight

A progressive decline in test weight was observed with increasing grades of Karnal bunt infection across all ten wheat genotypes (Table 1). The mean test weight decreased from 39.39 g in grade 0 (healthy grains) to 38.23, 37.05, 32.08 and 28.16 g in grades 1, 2, 3 and 4, respectively. Thus, compared with healthy grains, the average reduction in test weight increased progressively from 2.94% in grade 1 to 5.94% in grade 2, 18.56% in grade 3 and 28.50% in grade 4. The difference among infection grades exceeded the critical difference at the 5% probability level (CD = 0.52), indicating a significant effect of increasing Karnal bunt severity on grain weight.

Considerable genotypic variation was also evident. Among the genotypes, the mean test weight ranged from 32.87 g in HD 3059 to 37.57 g in DBW 187, while the corresponding percentage reduction in test weight ranged from 10.81% in DBW 173 to 11.74% in HD 3059. The decline was particularly pronounced at grade 4, demonstrating that severe kernel colonization was associated with substantial loss of grain mass.

Effect of Karnal bunt infection grade on phosphorus content

Phosphorus content showed contrasting responses between infected and disinfected grains. In infected grains containing teliospore material, phosphorus content increased progressively with increasing grade of Karnal bunt infection. The values increased from the healthy-grain level at grade 0 to the highest value at grade 4, with the mean phosphorus content reaching 322.49 mg/100 g at grade 4. Among the three genotypes examined, WH 1105 recorded the highest mean phosphorus content (276.39 mg/100 g), followed by PBW 771 (259.24 mg/100 g). The interaction between genotype and infection grade was reported as significant, indicating that the magnitude of change in phosphorus content varied among genotypes.

In contrast, disinfected grains showed a declining trend in phosphorus content with increasing infection grade. The highest value was recorded in grade 0 (229.83 mg/100 g), followed by grade 1 (225.23 mg/100 g), whereas the lowest value was recorded in grade 4 (193.06 mg/100 g). This contrasting response between infected and disinfected grains indicates that the presence or

Table 2: Effect of Karnal bunt on phosphorous content of infected and disinfected seeds in different wheat varieties.

Grade	Varieties						Mean infected	Mean disinfected
	PBW771		WH1105		HD2967			
	Infected seed	Disinfected seed	Infected seed	Disinfected seed	Infected seed	Disinfected seed		
0	222.33	222.33	236.38	236.38	231.44	231.44	230.05	230.05
1	233.56	217.88	249.52	231.00	240.98	226.81	241.35	225.23
2	250.32	211.41	266.65	223.92	256.32	219.87	257.76	218.40
3	278.00	197.88	294.24	209.78	279.21	205.98	283.82	204.55
4	312.00	186.76	335.15	198.00	320.33	194.41	322.49	193.06
Mean	259.24	207.25	276.39	219.68	265.66	215.70		
CD at 1%	2.37	3.83	3.80	3.98	3.09	5.18		

removal of teliospore-associated material substantially influenced the measured phosphorus concentration.

Effect of Karnal bunt infection grade on sedimentation value

Sedimentation value declined progressively with increasing Karnal bunt infection grade in both infected and disinfected grains (Table 2). In infected grains, the overall mean sedimentation value decreased from 41.00 ml in grade 0 to 40.33, 39.11, 38.33 and 36.67 ml in grades 1, 2, 3 and 4, respectively. The decline was comparatively small at lower infection grades but became more evident at grades 3 and 4.

A more pronounced decline was observed in disinfected grains. The mean sedimentation value decreased from 41.00 ml in grade 0 to 39.89 ml in grade 1, 38.00 ml in grade 2, 36.33 ml in grade 3 and 34.67 ml in grade 4. The genotype × infection-grade interaction was reported to be significant. Among the genotypes, WH 1105 and HD 2967 showed lower mean sedimentation values than PBW 771 in infected grains.

Effect of Karnal bunt infection grade on total phenolic content

Total phenolic content exhibited a clear and contrasting response in infected and disinfected grains (Table 3). In infected grains, the mean phenolic content increased progressively from 0.319% in grade 0 to 0.370, 0.441, 0.517 and 0.627% in grades 1, 2, 3 and 4, respectively. Thus, the highest phenolic accumulation occurred in grains showing the greatest degree of Karnal bunt infection. Among the genotypes, WH 1105 recorded the highest mean phenolic content (0.488%), followed by HD 2967 (0.452%).

In disinfected grains, however, phenolic content followed the opposite trend, declining from 0.319% in grade 0 to 0.310, 0.297, 0.273 and 0.249% in grades 1, 2, 3 and 4, respectively. The reported critical differences indicated significant variation among infection grades and genotypes. These results demonstrate that the apparent increase in phenolic concentration in infected kernels was closely associated with the presence of teliospore-containing material and/or the biochemical response of the grain to infection.

Discussion

Progressive loss in test weight with increasing Karnal bunt severity

The progressive decline in test weight observed in the present study demonstrates that increasing Karnal bunt severity was associated with increasing physical deterioration of wheat kernels. The reduction was relatively modest at grades 1 and 2 but became pronounced at grades 3 and 4, with a maximum mean reduction of 28.50% at grade 4. This pattern is biologically plausible because *Tilletia indica* colonizes the developing ovary and progressively replaces kernel contents with teliospore-bearing soral material, thereby reducing the quantity of normal endosperm accumulated in severely affected kernels. Karnal bunt is generally regarded as a disease in which direct yield loss may be relatively limited, whereas deterioration in kernel quality becomes increasingly important as infection severity increases.

The present results are also consistent with earlier descriptions of a progressive relationship between infection intensity and loss of grain weight. Diagnostic

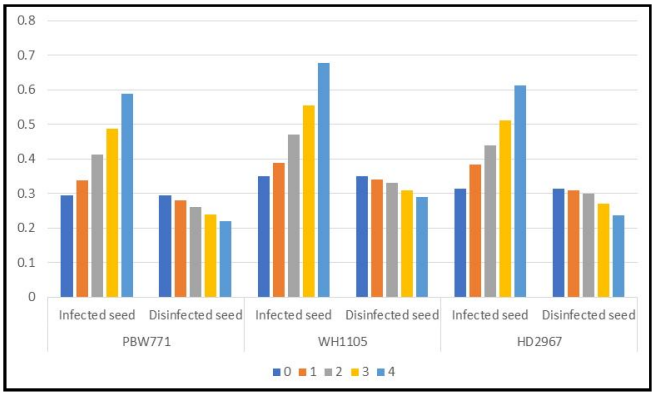


Fig. 4: Graphical representation of phenol content with various grade of infection.

Table 3: Effect of Karnal bunt on sedimentation value (ml) of infected and disinfected grains in different wheat varieties.

Grade	Varieties						Mean infected	Mean disinfected
	PBW771		WH1105		HD2967			
	Infected seed	Disinfected seed	Infected seed	Disinfected seed	Infected seed	Disinfected seed		
0	40.00	40.00	42.00	42.00	41.00	41.00	41.00	41.00
1	39.33	38.67	41.67	41.33	40.00	39.67	40.33	39.89
2	38.00	37.33	40.33	39.00	39.00	37.67	39.11	38.00
3	37.33	36.33	39.00	36.67	38.67	36.00	38.33	36.33
4	36.33	34.00	37.67	35.33	36.00	34.67	36.67	34.67
Mean	38.20	37.27	40.13	38.87	38.93	37.80		
CD at 1%	0.92	1.21	0.92	1.02	0.96	1.88		

and quarantine literature has reported that loss in grain weight increases with the extent of kernel destruction, with substantially greater losses occurring when infection extends beyond the embryonal region. The genotypic variation observed in the present experiment further suggests that the physical consequences of a particular infection grade are not necessarily uniform across wheat backgrounds. Differences in kernel size, grain hardness, endosperm characteristics and host–pathogen interaction may contribute to the observed variation among genotypes. The identification of genotypes showing comparatively lower reductions in test weight may therefore have relevance for maintaining grain quality in areas where Karnal bunt occurs.

Importantly, the present results indicate that infection grade provides a more informative measure of physical grain damage than infection incidence alone. A low overall incidence can mask substantial damage in individual kernels, particularly when a proportion of grains reaches higher infection grades. This is relevant because even relatively low proportions of Karnal-bunt-affected kernels can have disproportionate effects on marketability and flour quality.

Changes in phosphorus content associated with Karnal bunt infection

The increase in phosphorus content recorded in infected grains with increasing infection grade is consistent with earlier observations that Karnal bunt-affected wheat can show elevated phosphorus and ash fractions. A comprehensive review of Karnal bunt reported that infected grains may contain higher phosphorus concentrations than healthy grains, although the magnitude of nutritional and compositional changes depends on the extent of infection and the material retained with the kernel.

The contrasting response observed after disinfection is particularly informative. While infected grains showed increasing phosphorus concentration with increasing grade, disinfected grains showed a progressive decline. This indicates that the higher phosphorus concentration measured in heavily infected kernels cannot necessarily be interpreted simply as an increase in phosphorus accumulation within the healthy wheat tissues. Rather, the result may reflect the contribution of teliospore-associated material and the altered relative proportions of grain tissues following infection. Because the pathogen converts portions of the kernel into soral tissue, compositional measurements expressed on a grain basis can change substantially as the proportion of normal endosperm decreases.

The significant genotype × infection-grade interaction further indicates that the biochemical response was genotype dependent. Such genotype-dependent responses are consistent with the broader literature on wheat–*T. indica* interactions, where wheat genotypes differ considerably in their responses to infection and in the expression of biochemical defence traits.

Decline in sedimentation value indicates deterioration in functional grain quality

The progressive reduction in sedimentation value with increasing Karnal bunt grade provides evidence of deterioration in flour functionality as disease severity increased. The effect was comparatively small at lower grades but became considerably stronger at grades 3 and 4, particularly after removal of teliospore-containing material. Sedimentation value is widely used as an indicator of wheat flour quality and is influenced by the properties of gluten-forming proteins and their ability to hydrate and sediment under the test conditions. Therefore, a reduction in sedimentation value generally reflects deterioration in functional flour characteristics.

The present findings are consistent with the recognized effect of Karnal bunt on wheat processing quality. Previous research has shown that increasing Karnal bunt contamination can adversely affect flour quality, dough characteristics and overall acceptability,

Table 4: Effect of Karnal bunt on phenol content (%) of infected and disinfected seeds in different wheat varieties.

Grade	Varieties						Mean infected	Mean disinfected
	PBW771		WH1105		HD2967			
	Infected seed	Disinfected seed	Infected seed	Disinfected seed	Infected seed	Disinfected seed		
0	0.294	0.294	0.349	0.349	0.315	0.315	0.319	0.319
1	0.337	0.280	0.389	0.340	0.383	0.310	0.370	0.310
2	0.413	0.260	0.471	0.330	0.440	0.300	0.441	0.297
3	0.487	0.240	0.554	0.310	0.511	0.270	0.517	0.273
4	0.588	0.220	0.679	0.290	0.613	0.237	0.627	0.249
Mean	0.424	0.259	0.488	0.324	0.452	0.286		
CD at 1%	0.041	0.03	0.04	0.02	0.05	0.02		

even when the reduction in total grain yield is comparatively limited. The stronger decline observed in disinfected grains is particularly noteworthy because it indicates that the deterioration was not merely an analytical consequence of the physical presence of teliospores. Removal of the external/soral material exposed a grain fraction whose functional quality had already been altered as infection severity increased.

The observed genotype differences are also relevant from a quality-breeding perspective. Wheat genotypes differ inherently in grain hardness and end-use quality, and the same level of Karnal bunt infection may therefore produce different effects on flour properties. Maintenance of high sedimentation values under disease pressure could consequently represent an additional quality attribute when evaluating wheat germplasm for Karnal bunt-prone environments.

Accumulation of phenolic compounds in infected grains

One of the most distinct biochemical responses in the present study was the progressive increase in total phenolic content in infected grains, from 0.319% in healthy grains to 0.627% in grade 4 grains. In contrast, phenolic content declined progressively in disinfected grains. This pattern supports the interpretation that phenolic accumulation is associated with the wheat response to *T. indica* infection and/or with the biochemical contribution of infected tissue.

Phenolic compounds are well-established components of plant defence, and their accumulation following pathogen challenge can contribute to antimicrobial activity, oxidative defence and strengthening of host tissues. In the wheat–*T. indica* interaction specifically, Gogoi *et al*., (2001) demonstrated changes in phenolic metabolism following inoculation and reported differences in phenolic responses between resistant and susceptible wheat genotypes. Similarly, Singh *et al*., (2017) reported greater total phenol levels in Karnal bunt-resistant wheat genotypes than in susceptible genotypes, supporting the involvement of phenolic metabolism in the host response to *T. indica*.

The progressive increase observed in the present study therefore suggests that increasing infection severity was accompanied by enhanced phenolic accumulation in infected kernels. However, because the present experiment measured total phenolic content at different grades of naturally affected grains, the result should be interpreted as an association rather than direct evidence that phenolic accumulation caused resistance or restricted pathogen development. Such causal interpretation would require time-course experiments involving controlled inoculation and simultaneous measurement of specific phenolic compounds and defence enzymes.

The decline in phenolic content after disinfection further strengthens the importance of distinguishing between infected and disinfected grain fractions. The reduction suggests that a considerable proportion of the measured phenolic signal in heavily infected grain may be associated with infected/soral material or with biochemical changes occurring specifically in the diseased tissue. This distinction is important when interpreting grain-quality measurements because whole-kernel analyses can combine host-derived and pathogen-associated components.

Integrated interpretation of physical and biochemical deterioration

Taken together, the results demonstrate that

Table 5: Infected sees showing different grade of infection.

Grade	Symptom
0	Healthy seed, no infection
1	Infection at the embryonal end and less than 25 percent infection
2	Infection of seed between 25 to 50 per cent
3	Infection of seed between 50 to 75 percent
4	Infection of seed more than 75 percent or seed completely converted to sorus

increasing Karnal bunt infection grade was associated with a coordinated deterioration in physical grain weight and flour functionality, accompanied by marked changes in phosphorus and phenolic composition. The most severe infection category, grade 4, showed the greatest reduction in test weight and sedimentation value, while infected grains exhibited the highest phosphorus and phenolic concentrations. The opposite trends observed in disinfected grains indicate that these changes cannot be interpreted solely as simple accumulation of nutrients or metabolites within healthy kernel tissues.

The results are consistent with the broader understanding that the major economic importance of Karnal bunt lies in quality deterioration rather than large-scale yield destruction. The pathogen can alter grain appearance, composition, flour properties and marketability, while quarantine regulations further amplify its economic consequences. Consequently, assessment of individual infection grades provides a more sensitive description of the damage associated with Karnal bunt than disease incidence alone.

Overall, the present findings indicate that progressive kernel infection is associated with increasing physical and functional quality deterioration, together with measurable biochemical shifts in phosphorus and phenolic constituents. The magnitude of these changes varied among wheat genotypes, highlighting the importance of host genetic background in determining the quality consequences of Karnal bunt. These observations support the use of infection-grade-specific grain quality assessment as a useful approach for identifying wheat genotypes that maintain better physical and end-use quality under Karnal bunt pressure.

Conclusion

The present study demonstrated that increasing grades of Karnal bunt infection were associated with progressive deterioration in the physical and selected quality attributes of wheat grain. Test weight declined consistently with increasing infection severity, with the greatest reduction observed in grains belonging to the most severely infected category (grade 4), indicating substantial loss of kernel mass under advanced infection. The magnitude of reduction varied among wheat genotypes, suggesting differential responses of host genotypes to increasing Karnal bunt severity.

Marked changes were also observed in the biochemical and functional characteristics of infected grains. Phosphorus content increased progressively with infection grade in teliospore-containing grains, whereas disinfected grains exhibited a declining trend. Similarly, total phenolic content increased with increasing infection severity in infected grains, indicating an association of phenolic accumulation with Karnal bunt-affected grain tissue. In contrast, sedimentation value decreased progressively with increasing infection grade, particularly in disinfected grains, reflecting deterioration in an important indicator of flour functionality.

Overall, the findings demonstrate that the consequences of Karnal bunt extend beyond visible kernel infection and involve progressive reductions in grain weight and functional quality accompanied by substantial biochemical alterations. Assessment based on individual infection grades therefore provides a more informative measure of grain damage than disease incidence alone. The observed genotypic differences further highlight the importance of host genetic background in determining the extent of quality deterioration. These findings emphasize the need to consider both physical grain loss and end-use quality attributes when evaluating the impact of Karnal bunt and identifying wheat genotypes with comparatively better quality retention under disease pressure.

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