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Resistance to Net-Form Net Blotch and Yield Performance of Local Barley Varieties under Rain-Fed Conditions in Iraqi Kurdistan Region

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ABSTRACT

Net blotch, resulting from Pyrenophora teres, is the most significant disease affecting barley in numerous areas where this crop is grown. This study investigated the host-parasite interactions between several barley varieties and net-form net blotch (NFNB) at the adult plant stage and evaluated the effects on yield and its components under rain-fed conditions across two distinct locations in Iraqi Kurdistan. Eleven local barley varieties were sown, with rigorous assessment of disease severity, infection types, and coefficients of infection. The results revealed significant differences in NFNB resistance among varieties and between locations, Barely varieties could be divided into six groups according to infection type from resistance group contain Rafidain and Qalla varieties with mean disease severity and coefficient of infection were very low, 5% and 1 to susceptible group represents the biggest groups of this study, containing five barely varieties, Movialis, Iba 265, Iba 99, Rihana 02 and N.S. 313, with mean coefficient of infection ranging from 87.50 to 38.33 and 87.50-38.33 % disease severity. Differential responses were also observed in yield components, including spike length, grain weight, spike density, and thousand-grain weight. Varieties with high resistance consistently maintained superior yield and grain quality, whereas susceptible varieties suffered substantial reductions in yield, spike weight, and grain weight. These findings underscore the significance of genetic diversity and local adaptation in breeding programs, reinforcing the value of resistant varieties as an environmentally friendly approach to enhance barley production and mitigate NFNB outbreaks in variable rain-fed agroecosystems.

***Keywords*:** Barley, Net-form net blotch, foliar disease, Mycology, Grain yield .

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most significant cereal crops worldwide, particularly in arid and semi-arid regions, where it often remains the only viable crop under extreme drought conditions **[1].** Global barley production was estimated at 151.62 million metric tons in the 2022-2023 growing season. In Iraq, barley ranks as the second most widely cultivated field crop after wheat with 200,000 tons of production, reflecting its adaptability and importance to resource-limited farmers in Iraq **[2].** It is essential for farmers in numerous developing nations with limited resources. Barley grain contains approximately contains 64.6% carbohydrates, 13% water, 5.5% fibre, 12% protein, 2.1% fat, and 2.8% ash. One kilogram of barley grain equals 1.2 nutritional units **[3].** Barley is a vital cereal used for various purposes, including human food, animal feed, and the brewing and malting industries **[4].**

Barley is affected by various diseases that significantly reduce yield and grain quality. One of the most important diseases is net-form net-blotch disease (NFNB), caused by *Pyrenophora teres f. sp. teres (Ptt)* [5]. The NFNB is named after its characteristic symptoms, which are characterized by narrow, dark brown, longitudinal, and transverse striations on infected leaves **[5].** The NFNB is stubble-borne as the fungus produces pseudothecia as an overwintering structure on infected barley debris left on the surface after harvest **[6].** The pathogen can infect different parts of the barley crop, such as leaves, leaf sheaths, stems, and grains, but infection of the grain can transfer the pathogen into a new field and can serve as the primary inoculum. The net blotch pathogen causes significant damage worldwide, making net blotch a disease of economic importance that can substantially reduce yields in susceptible varieties, resulting in considerable losses **[5].** Barley net blotch is a globally important disease that can potentially cause severe infections and reduce yields by 10-40% if susceptible barley varieties are planted under extreme environmental conditions [5, 6]. Furthermore, infection causes a reduction in grain size, grain quality and bulk density, and adversely affects the malting and feed

quality of barley **[7].** *Pyrenophora teres* Drechsler. Kingdom Fungi; Phylum Ascomycota; Family Pleosporaceae; Genus *Pyrenophora*, forms *teres* and form *maculata* **[5].**
Barley net blotch typically develops in cooler, wetter climates where the infection develops. Infection requires prolonged leaf wetness (10–30 h) under temperatures of 8–33°C, with an optimum of 15–25°C [**8].**
Genetic resistance is the most economical, environmentally friendly, and sustainable strategy for managing NFNB. **[9].** Furthermore, barley net form net blotch can be controlled through the use of fungicides and cultural practices, which form an integral component of the integrated management strategy for NFNB **[10].** Relatively little is known at the molecular level about the mechanisms by which *P. teres* interacts with barley **[6].** Quantitative trait loci (QTLs) conferring resistance to *Pyrenophora teres f. sp. teres* have been identified on each of the seven barley chromosomes. However, further validation and development of linked markers are needed for efficient utilization in breeding and selection. Major resistance loci (*Rpt1*–*Rpt7*) have been mapped across all seven barley chromosomes **[11, 12].** This study evaluated the response of local barley varieties to NFNB at the adult plant stage and assessed its impact on yield and yield components under rain-fed conditions in two locations of the Iraqi Kurdistan Region**.**

Materials And Methods

Seeds of eleven local Iraqi barley varieties were evaluated in a randomized complete block design (RCBD) with three replicates. The experiment was conducted on 15 December 2024 at two locations: the Agricultural Research Centre, Bakrajo (Sulaymaniyah), and the Mwan Agricultural Research Centre, Kanipanka (Halabja). Thirty-three treatments were arranged; each plot consisted of two rows, 2 m in length, with 25 cm spacing between rows and 160 cm between blocks. Seeds were sown at a rate of 200 kg ha^{-1}. Standard agronomic practices, including soil preparation, Urea fertilization at 160 kg ha^{-1}, and manually weed control, were applied uniformly at both sites. The Bakrajo site is located at 35°32′30″N, 45°21′00″E, 760 m elevation, while the Kanipanka site is at 3 5°22′23″N, 45°43′23″E, and 870 m elevation.

Table (1): Names, Pedigree/origin and the sources of barley varieties used in the study

Variety	Scientific name	Pedigree or Sources	Origin
Rihana 02	*H. vulgare* L.	AS46/AVT11 ATHS21-1AP3AP-0AP	ICARDA
Iba 265	*H. vulgare* L.	STJ3//BCR/LKS4	ICARDA
Nawawir - 01	*H. vulgare* L.	(Heiti / Stewart /2/ Mindum / Carleton, Ld308) /3/ Nugget	USA
Rafidain	*H. vulgare* L.	Capeiti 8/ Valnova-	Italy
Iba 99	*H. vulgare* L.	Iraqi agricultural research programs	Iraq
Acsad Strain 14	*H. vulgare* L.	Arab Centre for the Studies of Arid Zones and Drylands	Iraq
N.S. 313	*H. vulgare* L.	SNB//CMH79A955/3*CNO79/3/ATTILA	CIMMYT
Al- Amal	*H. vulgare* L.	PLC/RUFF//GTA/RLT	ICARDA
Amalo	*H. vulgare* L.	-	-
Movialis	*H. vulgare* L.	Adamello/ Appulo-	Iraq
Qalla	*H. vulgare* L.	-	Iraq

Diseases Assesments

Net-form net blotch (NFNB) severity was assessed using a modified Cobb scale (0–100%), based on visual comparison of infected leaves with standard diagrams. Infection types were classified as resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S), with three intermediate classes (R–MR, MR–MS, MS–S) included for greater precision **[13].** The coefficient of infection (CI) was calculated as the product of disease severity and host response coefficient, with values assigned as follows: S = 1.0, MS–S = 0.9, MS = 0.8, MR = 0.4, R–MR = 0.3, and R = 0.2 **[14].** Final scoring was performed at the late dough to physiological maturity stage.

Yield and Yield Components

Yield and its components were measured as follows:

- **Spike length (cm):** Mean length of ten spikes per plot, excluding awns.
- **Spike weight (g):** Mean weight of ten randomly selected spikes per plot.
- **Spike number (m^2):** Number of spikes counted in 1 m row and converted to spikes per m^2.
- **Grains per spike:** Average grain number from ten spikes per plot.
- **Grain weight per spike (g):** Mean grain weight from ten spikes per plot.
- **Thousand-grain weight (g):** Weight of 1000 grains sampled from bulk yield per replicate.

- **Grain yield (t ha⁻¹):** Grain yield estimated from spikes harvested from a 1 m² area at the plot center and extrapolated to tons per hectare **[15].**

Statistical Analysis

Data for CI, yield, and yield components were analyzed using OPSTAT and SPSS software. Analysis of variance (ANOVA) was performed to determine differences among varieties. Duncan's multiple range test (DMRT) at the 5% significance level.

Results

The host response of locally released barley varieties to NFNB disease under natural infection conditions at two locations, Bakrajo and Kanipanka, is presented in Table 2 and Figure 1. Analysis of variance (ANOVA) for the coefficient of infection across eleven barley varieties revealed significant differences among varieties at both locations. Combined analysis further demonstrated significant effects of variety, location, and their interaction.

A wide range of varietal responses to NFNB was observed in both environments. Based on infection type, the barley varieties were classified into six distinct groups:

Group 1 (Highly resistant): This group comprised two varieties (18.18%), Rafidain and Qalla. Both exhibited high resistance to NFNB, with mean disease severity of 5% and a coefficient of infection (CI) of 1. No significant differences were detected between the two varieties. Group 2 (Resistant to moderately resistant): Represented by a single variety (9.09%), Al-Amal, which showed resistance to moderate resistance. The mean disease severity was 7.50%, and the CI was 2.25. Differences between this group and Group 1 were not statistically significant. Group 3 (Moderately resistant): Comprised only of Nawawir-01, which displayed moderate resistance with a mean disease severity of 10.34% and a CI of 4.13. No significant differences were observed compared with Groups 1 and 2. Group 4 (Moderately susceptible): Represented by Amalo, which showed moderate susceptibility. The mean disease severity was 20.83%, and the CI was 16.67. Group 5 (Moderately susceptible): Included Acsad Strain 14, characterized by moderate susceptibility. The mean disease severity was 20.83%, and the CI was 18.75.Group 6 (Susceptible): The largest group, comprising five varieties (45.45%): Movialis, Iba 265, Iba 99, Rihana 02, and N.S. 313. These varieties exhibited susceptible infection types, with CI values ranging from 38.33 to 87.50, corresponding to disease severity levels within the same range. Overall, resistant to moderately resistant barley varieties recorded CI values below 10, whereas moderately susceptible to susceptible varieties consistently exceeded CI values of 15 across both locations.

Table (2): Response of barley varieties to NFNB: mean disease severity, infection type, and coefficient of infection at Kanipanka and Bakrajo during the 2024–2025 growing seasons

Variety	Kanipanka			Bakrajo			Mean		
	DS%	IT	CI	DS%	IT	CI	DS%	IT	CI
Movialis	93.33	S	93.33^{a}	81.67	S	81.67^{a}	87.50	S	87.50^{a}
Iba 265	86.67	S	86.67^{a}	53.33	S	53.33^{b}	70.00	S	70.00^{b}
Iba 99	63.33	S	63.33^{b}	43.33	S	43.33^{bc}	53.33	S	53.33^{c}
Rihana 02	50.00	S	50.00^{b}	33.33	S	33.33^{c}	41.67	S	41.67^{cd}
N.S. 313	56.67	S	56.67^{b}	20.00	S	20.00^{d}	38.33	S	38.33^{d}
Acsad Strain 14	25.00	MS-S	22.50^{c}	16.67	MS-S	15.00^{d-f}	20.83	MS-S	18.75^{e}
Amalo	16.67	MS	13.33^{cd}	25.00	MS	20.00^{de}	20.83	MS	16.67^{ef}
Nawawir-01	4.00	MR	1.60^{d}	16.67	MR	6.67^{d-f}	10.34	MR	4.13^{ef}
Al-Amal	6.67	R-MR	2.00^{d}	8.33	R-MR	2.50^{f}	7.50	R-MR	2.25^{f}
Rafidain	5.00	R	1.00^{d}	5.00	R	1.00^{f}	5.00	R	1.00^{f}
Qalla	2.33	R	0.47^{d}	7.67	R	1.53^{f}	5.00	R	1.00^{f}
L.S.D (0.05) Variety			3823.53*			1961.24*			5461.17*
Locations									1671.07*
Varieties x Locations									338.85*
Error			78.73			54.475			72.91

*DS%: Disease Severity, IT: Infection type, CI: Coefficient of infection, S: Susceptible, MS-S: Moderate Susceptible to Susceptible, MS: Moderate Susceptible, MR: Moderate resistance, R-MR: Resistance to Moderate resistance: R: Resistance.

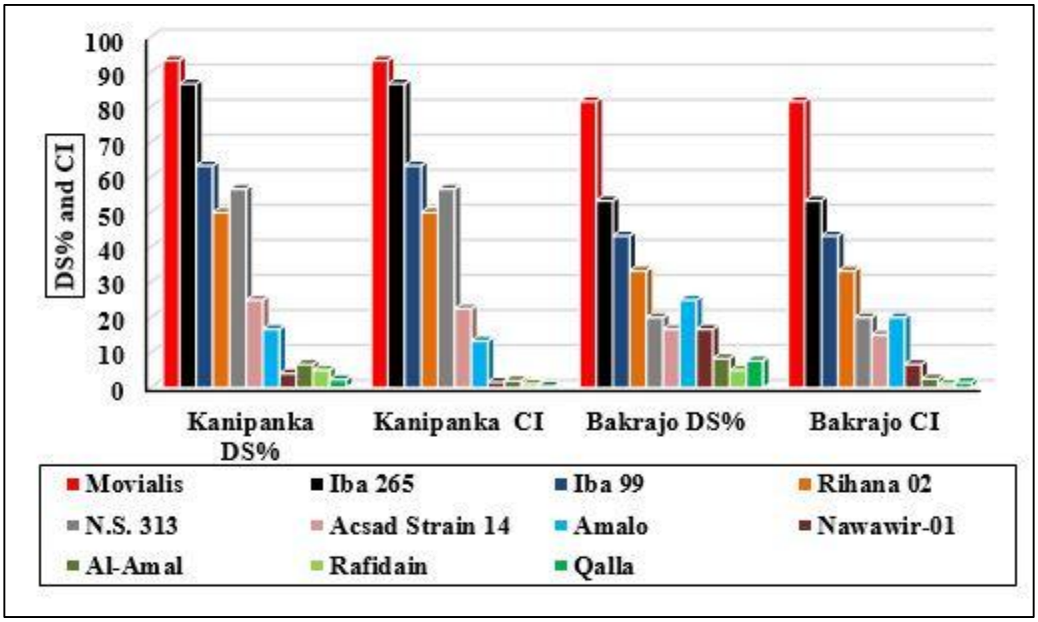

Figure 1. Mean NFNB Disease severity percentage and coefficient of infection of some barley varieties in both locations

Table 3 presents the grain yield and yield component traits of some released barley varieties in the presence of NFNB disease at the Kanipanka field in Halabja during the 2024-25 growing season, representing a rain-fed cultivation system in Iraq. Analysis of variance for seven agronomic traits revealed significant differences among the tested varieties, indicating substantial genetic variation in response to NFNB pressure. According to Table 3, Al-Amal variety had the highest spike length value of 9.40 cm, followed by Rafidain and Nawawir–01 with 8.98 and 8.81 cm, respectively. There were non-significant differences between them, but they surpassed all other varieties, with the lowest spike length of 5.23 cm recorded by the Rihana 02 variety. Al- Amal recorded the highest spike weight with 3.31 g, while Qalla recorded the lowest spike weight with 1.55 g. This result may be due to the Al-Amal variety having the longest spike length among all other varieties. Barley variety Acsad Strain 14 revealed the highest number of spikes per square meter in this study, with 756.43 spikes, surpassing all other varieties by a broad range, while the lowest spike number per unit area was found in barley variety N.S. 313, with 155.00, as shown in Table 3. According to the results, significant differences were observed among the tested barley varieties in the number of grains per spike. Iba 99 had the highest grain number, with 66.07. Qalla gave the lowest number of grains, with 24.67. The variance analysis of the collected data reveals significant differences between the varieties regarding grain weight per spike. Al-Amal exhibited the highest grain weight per spike with values of 2.77 g, followed by Iba 99 and Rafidain with 2.65 and 2.54 g, respectively. On the other hand, Qalla recorded the lowest spike grain weight with values of 1.27 g. This result may be related to other character studies because the Al-Amal variety has the longest spike length, whereas the Qalla variety has the lowest values for spike weight and grain number per spike. Thousand□grain weight (TGW) showed significant variation, ranging from 31.93 g in Movialis to 54.47 g in Qalla. Despite its low spike weight and grain number, Qalla maintained a relatively high TGW, suggesting larger individual grains.

Grain yield differed markedly among varieties. Acsad Strain 14 achieved the highest yield (10.3 Mg/ha), which corresponded with its high spike density and grain number per spike. In contrast, N.S. 313 produced the lowest yield (3.25 Mg/ha), consistent with its low spike density and susceptibility to NFNB. Overall, the results demonstrate significant genetic variation among barley varieties under NFNB stress, with Acsad Strain 14 and Al□Amal showing superior yield performance, while N.S. 313 and Qalla were the most adversely affected.

Table (3): Grain yield and yield component traits of eleven barley varieties under NFNB infection at Kanipanka field, Halabja, Iraq (2024–2025 rain□fed season)

Variety	Spike Length (cm)	Spike weight (g)	Spikes/m^2	Grain /Spike	Grain Weight /Spike (g)	1000 grain weight (g)	Grain Yield ton/ha
Rihana 02	5.23^{d}	2.67^{a-c}	347.68^{cd}	53.8^{b}	2.18^{ab}	39.61^{cd}	7.42^{b}
Iba 265	5.83^{cd}	2.62^{a-c}	344.05^{cd}	52.53^{b}	2.19^{ab}	42.88^{c}	7.50^{b}
Nawawir-01	8.81^{a}	1.90^{cd}	450.90^{bc}	26.93^{c}	1.55^{bc}	53.89^{a}	6.98^{b}
Rafidain	8.98^{a}	3.12^{ab}	235.28^{de}	58.6^{ab}	2.54^{a}	42.35^{c}	5.67^{bc}

Iba 99	5.84^{cd}	3.20^{ab}	298.71^{cde}	66.07^{a}	2.65^{a}	39.28^{cd}	7.98^{ab}
Acsad Strain 14	6.93^{b}	1.62^{d}	756.43^{a}	27.33^{c}	1.37^{c}	51.40^{ab}	10.30^{a}
N.S. 313	5.72^{cd}	2.52^{a-c}	155.00^{e}	59.4^{ab}	2.04^{a-c}	34.56^{d}	3.25^{c}
Al- Amal	9.40^{a}	3.31^{a}	295.92^{c-e}	60.87^{ab}	2.77^{a}	44.72^{bc}	8.08^{ab}
Amalo	7.19^{b}	2.78^{ab}	352.01^{cd}	54.53^{b}	2.35^{a}	42.92^{c}	8.10^{ab}
Movialis	6.74^{bc}	2.33^{b-d}	328.44^{c-e}	64.8^{a}	2.03^{a-c}	31.93^{d}	6.68^{b}
Qalla	7.61^{b}	1.55^{d}	532.96^{b}	24.67^{c}	1.27^{c}	54.47^{a}	6.70^{b}
L.S.D (0.05)	0.342	0.205	7956.921	29.296	0.167	16.597	1.726

*Note: Values are means of replicated plots. Statistical significance was determined using ANOVA followed by LSD ($p \leq 0.05$). Different letters within a column indicate significant differences among varieties

Based on the information in Table 4, the results indicate significant differences between the barley varieties for all studied traits in Bakrajo, highlighting the presence of considerable genetic diversity. Rafidain and Al-Amal varieties showed the maximum values for spike length, at 9.07cm and 8.93cm, respectively. It significantly surpassed all other varieties, while the minimum length of the spike was recorded by Iba 99 and Rihana 02 varieties with 5.15 cm and 5.34cm, respectively. The barley variety Rafidain has the highest spike weight mean, arriving at 3.44 g, significantly surpassing most of the other varieties. At the same time, Nawawir-01 was recognized to have the shortest spike weight of 1.31 g. This difference appears to be associated with spike length, as longer spikes generally corresponded to heavier spike weights. Acsad Strain 14 and Qalla varieties exhibited the highest spike numbers per square meter, with values of 355.56 and 336.09, respectively. What's more, the minimum value was recorded by the N.S. 313 variety with 132.30. Barley Variety Movialis, with 71.67, had the maximum grain number /Spike, significantly surpassing all of the studied varieties. On the other hand, the Nawawir-01 variety produced the lowest values with 20.67. Grain weight per spike was highest in Rafidain (2.90 g) and lowest in Nawawir□01 (1.06 g), reflecting the combined influence of spike length, spike weight, and grain number the Rafidain variety recorded the highest values for these traits t; while, Nawawir-01 has the minimum value of spike weight and number of grains per spike. The maximum value of thousand grain weight was detected in barely variety Acsad Strain 14 with 53.27g, which significantly surpassed all other varieties, while the lowest value of thousand grain weight was recorded in Movialis variety with 31.63g. Rihana 02, Iba 99, and Acsad Strain 14 varieties exhibited the highest value grain yield with 9.30, 8.44 and 7.58 ton/ha, respectively, these varieties significantly outperformed others. The lowest values of this trait were 3.44 and 3.96, as shown by N.S. 313 and Nawawir-01, as shown in Table 4. The high yield of the Rihane 02 variety can be attributed to its superior combination of yield components: a high spike density (319.03 spikes/m²), a good number of grains per spike (62.60), and a high grain weight per spike (2.54 g). This indicates a balanced yield architecture, compensating for its relatively shorter spike length (5.34 cm). Nawawir□01 yielded poorly (3.96 ton/ha), primarily due to its low grain number per spike (20.67) and grain weight per spike (1.06 g), despite having a moderate spike density (302.88 spikes/m²). This suggests susceptibility to net blotch, which may have impaired seed set and grain filling. Similarly, N.S. 313 exhibited low yield (3.44 ton/ha), largely due to its very low spike density (132.30 spikes/m²), despite a moderate grain number per spike (58.77). A notable example is Acsad Strain 14, which achieved a high yield (7.58 tons/ha) primarily due to its highest spike density (355.56 spikes/m²) and weight of thousand grain (53.27 g), despite having one of the lowest numbers of grains per spike (26.90). This demonstrates that yield compensation can occur through different physiological mechanisms, emphasizing the complex interplay among yield components in barley.

Table (4): Means of grain yield and yield components traits of the released barley varieties in the presence of NBNF disease in the field during the 2024-25 growing season in Bakrajo

Variety	Spike Length (cm)	Spike weight (m)	Spike /m^{2}	Grain /Spike	Grain Weight /Spike (g)	1000 grain weight (g)	Grain Yield ton/ha
Rihana 02	5.34^{d}	2.94^{ab}	319.03^{ab}	62.60^{b}	2.54^{ab}	40.51^{ef}	9.30^{a}
Iba 265	6.40^{b-d}	3.06^{ab}	226.17^{b-d}	55.80^{b-d}	2.51^{ab}	44.94^{cde}	6.75^{b-d}
Nawawir-01	7.57^{b}	1.31^{e}	302.88^{ab}	20.67^{e}	1.06^{c}	51.09^{ab}	3.96^{ef}
Rafidain	9.07^{a}	3.44^{a}	189.17^{cd}	61.40^{bc}	2.90^{a}	47.17^{b-d}	6.40^{cd}
Iba 99	5.15^{d}	2.81^{a-c}	302.61^{ab}	58.03^{b-d}	2.45^{ab}	42.16^{de}	8.44^{ab}
Acsad Strain 14	7.42^{b}	2.17^{cd}	355.56^{a}	26.90^{e}	1.43^{c}	53.27^{a}	7.58^{a-c}
N.S. 313	5.79^{cd}	2.60^{bc}	132.30^{d}	58.77^{b-d}	2.11^{b}	35.93^{fg}	3.44^{f}

Al-Amal	8.93^{a}	2.85^{a-c}	272.09^{a-c}	53.03^{cd}	2.39^{ab}	45.06^{c-e}	7.75^{a-c}
Amalo	6.91^{bc}	2.52^{bc}	204.40^{cd}	50.97^{d}	2.22^{b}	44.08^{c-e}	5.05^{d-f}
Movialis	6.52^{bc}	2.48^{bc}	273.60^{a-c}	71.67^{a}	2.27^{b}	31.63^{g}	6.80^{b-d}
Qalla	7.05^{b}	1.68^{de}	336.09^{a}	28.43^{e}	1.39^{c}	49.56^{a-c}	5.62^{de}
L.S.D (0.05)	0.411	0.145	2446.338	25.033	0.083	10.468	0.989

Based on the data in Table 5, significant differences were observed among the eleven barley varieties across two governorates for all studied traits.

The combined analysis revealed that the tested characters of barley varieties across two locations were significant for variety, location, and variety x location interaction, except for spike number/m², grain weight/spike, 1000-grain weight, and grain yield characters, which showed non-significant differences between locations. The presence of significant differences between varieties and locations shows that barley varieties differ in their adaptability to environmental changes. The variety x location interaction is essential to the evaluation of performance and stability. The performance of different environmental factors within a given location is referred to as stability. Understanding the varieties x locations reaction is important to improve barley efficiency. Further stability analysis can be performed if the characters' variety x location interaction is significant. These results indicate that the study responded differently to environmental conditions. Spike length is a genetically controlled trait and is influenced by environmental factors, plays an important role in determining yield potential the number of grains increases with the spike length and directly correlates with yield. Al-Amal variety showed the maximum value for spike length, followed by Rafidain and Nawawir-01 at 9.17cm, 9.02cm, and 8.19cm, respectively. It significantly surpassed all other varieties, while the minimum length of the spike was recorded by Rihana 02 with 5.29cm. The results of this study demonstrate the effect of barley varieties on spike weight. The maximum weight of the spike was 3.28g, recorded by Rafidain; on the other hand, the lowest spike weight was recorded by the Qalla variety with 1.62g. This finding might be associated with spike length, given Rafidain variety has superior spike length. Data regarding the 2024-25 growing season in the average of both locations, Acsad Strain 14, exhibited the highest value of spike/m^{2} with 555.99; in contrast, the lowest values of this trait were 143.65, as shown by N.S. 313. However, there is no significant difference between locations. Results showed significant differences between barley varieties for the number of grains per spike at ($P \leq 0.05$) probability under rain-fed conditions for the average of both locations (Table 5). The maximum mean value of the number of grains per spike was observed in Movialis with 68.23, while the lowest mean value was in Qalla, which was 26.55. The results in Table 5 showed the analysis of variance, which revealed significant differences among the varieties in their response to grain weight /spike; the effect of interactions (varieties x locations) was significant ($p < 0.05$). However, the impact of locations was non-significant. Rafidain had a higher grain weight /spike of 2.72g, while the Nawawir-01 variety gave the minimum value with 1.30g, followed by the Qalla variety with 1.33 g. The weight of a thousand grains is one of the key parts of the final grain yield in barley. As shown in Table 5, significant differences existed between all barley varieties, interaction varieties x location in the 1000-grain weight, while for the effect on locations, there were non-significant differences. The results showed that the highest 1000-grain weight was produced by Nawawir-01 with 52.49g, while the minimum value was obtained by Movialis with 31.78g. Grain yield, the primary objective trait, was significantly affected by variety and by the variety × location interaction, but not by location alone. Acsad Strain 14 achieved the highest grain yield (8.94 t/ha), while N.S. 313 produced the lowest (3.34 t/ha). These results highlight the complex interplay of yield components and the importance of evaluating both genetic potential and environmental adaptability in barley breeding programs.

Table (5): Means of grain yield and yield components traits of the released barley varieties in the presence of NBNF disease in the field of average both locations during the 2024-25 growing season

Variety	Spike Length (cm)	Spike weight (m)	Spike /m^{2}	Grain /Spike	Grain Weight /Spike (g)	1000 grain weight (g)	Grain Yield ton/ha
Rihana 02	5.29^{f}	2.81^{ab}	333.36^{b-d}	58.20^{b}	2.36^{a}	40.06^{b-d}	8.36^{ab}
Iba 265	6.11^{d-f}	2.84^{ab}	285.11^{cd}	54.17^{b}	2.35^{a}	43.91^{b}	7.13^{a-c}
Nawawir-01	8.19^{ab}	1.61^{d}	376.89^{bc}	23.80^{c}	1.30^{b}	52.49^{a}	5.47^{cd}
Rafidain	9.02^{a}	3.28^{a}	212.23^{de}	60.00^{ab}	2.72^{a}	44.76^{ab}	6.04^{bc}
Iba 99	5.50^{f}	3.01^{ab}	300.66^{cd}	62.05^{ab}	2.55^{a}	40.72^{bc}	8.21^{ab}
Acsad Strain 14	7.17^{b-d}	1.89^{cd}	555.99^{a}	27.12^{c}	1.40^{b}	52.34^{a}	8.94^{a}
N.S. 313	5.76^{ef}	2.56^{a-c}	143.65^{e}	59.08^{ab}	2.08^{a}	35.25^{cd}	3.34^{d}
Al-Amal	9.17^{a}	3.08^{ab}	284.01^{cd}	56.95^{b}	2.58^{a}	44.89^{ab}	7.91^{ab}
Amalo	7.05^{cd}	2.65^{a-c}	278.20^{c-e}	52.75^{b}	2.29^{a}	43.50^{b}	6.58^{a-c}

Movialis	6.63^{c-e}	2.41^{b-d}	301.02^{cd}	68.23^{a}	2.15^{a}	31.78^{d}	6.74^{a-c}
Qalla	7.33^{bc}	1.62^{d}	434.53^{b}	26.55^{c}	1.33^{b}	52.01^{a}	6.16^{bc}
Location	1	0.617*	0.009$^{n.s}$	190989.643*	0.219$^{n.s}$	0.018$^{n.s}$	7.442$^{n.s}$
Varieties	10	10.801*	2.040*	71947.654*	1536.306*	1.623*	275.475*
Varieties x Location	10	0.427*	0.225*	20515.313*	50.343*	0.129*	10.574*
L.S.D (0.05)	0.384	0.190	5097.462	26.908	0.137	19.010	1.625

Discussion

The host–parasite interaction of highly susceptible barley varieties with *Pyrenophora teres f. teres* (net form net blotch, NFNB) was consistent across both test locations, as indicated by the absence of differences in infection types. This stability suggests that varietal susceptibility is genetically determined and not strongly modified by local environmental conditions. However, infection intensity varied significantly between sites, with higher infection percentages and coefficients of infection observed in Kanipanka, except for the Amalo variety.

The elevated incidence of NFNB in Kanipanka can be attributed to favorable environmental conditions, particularly increased rainfall and more uniform rainfall distribution during the growing season. Moisture availability is a critical factor in the epidemiology of NFNB, as prolonged leaf wetness facilitates spore germination, infection, and lesion expansion. The observed differences between locations, therefore, highlight the importance of microclimatic factors in disease development, even when infection type remains stable.

The exception of the Amalo variety, which did not exhibit elevated infection levels in Kanipanka, suggests potential partial resistance or tolerance mechanisms. This observation warrants further investigation, as it may indicate genotype‑specific interactions with the pathogen that are less sensitive to environmental variation. Identifying such traits is valuable for breeding programs aiming to enhance disease resistance under rain‑fed conditions.

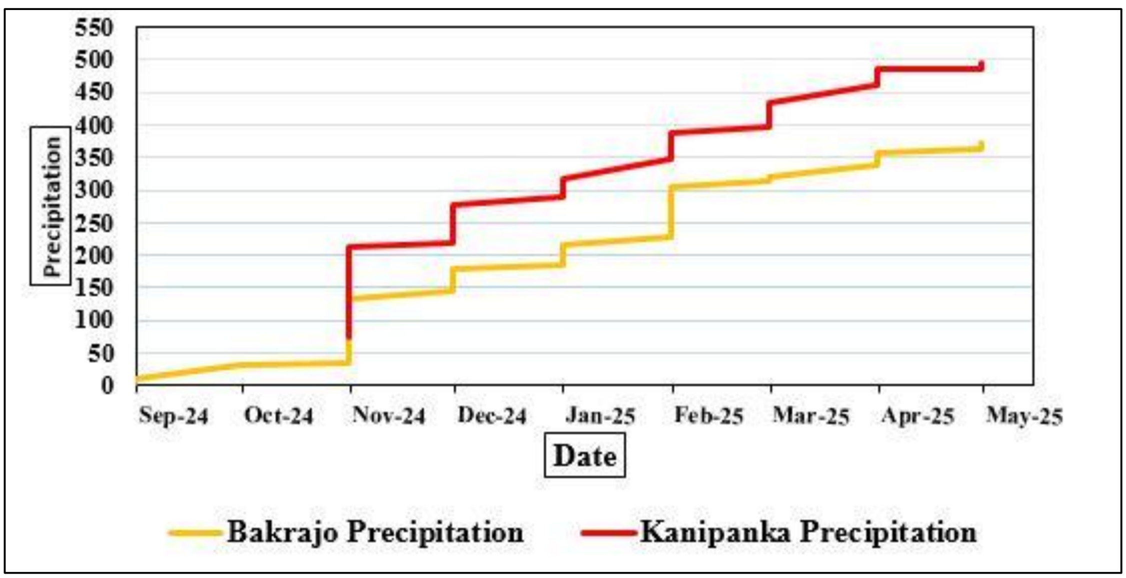

Figure 2. Average precipitation during the experimental period between September and May at the two locations in the 2024/25 growing season

The resistant reaction observed in the Qalla and Rafidain varieties, as well as the R-MR reaction in the Al-Amal varieties and the MR reaction in the Nawawir-01 variety, may be attributed to the presence of multiple resistant genes in their genetic backgrounds. These resistant genes are not found in other susceptible varieties. The high coefficient of infection levels of NFNB disease in the susceptible varieties during both locations, ranging from 93.33 in the highly susceptible barley variety Movialis in Kanipanka and 81.67 in the Bakrajo region, can be attributed to the favourable environmental conditions for disease development, as well as the presence of susceptible hosts and virulent pathogens. The low coefficient of infection was recorded by Qalla and Rafidain with 1.00 in both locations. The coefficient of infection value helps to statistically rank the impact of barley varieties' performance against NFNB disease. Combining two distinct factors into a single value results in an almost equal coefficient derived from different disease scores. Resistant varieties with low DS%, favourable IT ratings (R or MR), and low CI represent valuable sources of disease control. Field resistance observed here mirrors recent global findings of durable resistance in certain accessions and supports the crucial role of genetic resistance as a frontline management strategy for NFNB. The net blotch pathogen causes significant damage worldwide, making net blotch a disease of economic importance that can substantially reduce yields in susceptible varieties, resulting in considerable losses **[5].** According to **[16],** illustrated that NFNB occurred in most barley-cultivating regions of the world, but was the most severe in temperate regions with high rainfall rates, and Iraq was one of the countries documented as the country of existence of the disease in the world. The existence of diseases in nearby regions such as Iran, Syria and Turkey and the impact on yields in barley **[17, 18].** Barley net blotch is an exotic disease that can potentially cause severe infections and lead to losses of up to 10-40% **[5, 6].** Yield loss due to this disease reaches up to 100% in susceptible varieties under severe epidemics **[19].** The low incidence of NFNB diseases in varieties such as Nawawir–01, Al-Amal, Rafidain, and Qalla makes them suitable candidates for cultivation and further improvement in the Kanipanka and Bakrajo regions, due to their stability of resistance to moderate disease severity and low coefficient of infection in both locations. Furthermore, incorporating this method into the breeding program is a key part of integrated disease management strategies to reduce fungicide reliance, as it is both eco-friendly and cost-effective. This result aligns with the fact that the most effective and environmentally friendly method to control net blotch is through the use of resistant barley varieties **[20],** while susceptible varieties such as Movialis, Iba 265, Iba 99, Rihana 02 and N.S. 313 require deployment of complementary control strategies like fungicides. Different barley NFNB infection types and disease severity are supported by other research, such as **[12, 21]**; they survived many fields and recorded different disease parameters from many barley varieties. Choosing varieties based on their infection types and severity is important in agricultural planning; furthermore, host resistance may lead to reduced disease management costs and improved yield stability. Other research conducted in Erbil Province, Iraq, has demonstrated that Net Form Net Blotch (NFNB) poses a significant threat to barley cultivation **[22].** There are many ways to reduce yield losses caused by barley net blotch disease. For example, agricultural practices such as crop rotation, biological control, the deployment of resistant varieties and fungicide application can be used to manage net blotch of barley **[21].** The main aim of this study is to discover the local barley varieties that are resistant to NFNB diseases under field conditions in different locations in Iraq to reduce losses caused by this disease, because disease resistance is an important agronomical character in all plants, and the use of resistant varieties is often the most environmentally friendly and economically beneficial method to control a disease. However, integrated disease management is one of the main strategies that should be followed to reduce the effect of plant diseases in crops. A promising approach to achieve this aim while reducing the use of fungicides is to apply and combine different agricultural practices that contribute to increasing crop yield by decreasing plant diseases directly or indirectly **[19].** The integration of resistance from field data with information structure of pathogen population, such as the genetic diversity of *Pyrenophora teres* f. *teres* populations documented regionally, will further increase resistance durability.

These results of spike length are affirmed by the findings of **[23],** showing a significant difference in spike length for barley grown at two seasons under rain-fed conditions. Furthermore, the spike weight of cereals plays an important role in determining grain yield. The different components of the spike, including spikelets, florets and glumes, affect each other. The number and arrangement of these components directly affect spike weight and other yield component characters, which ultimately contribute to the final grain yield per spike **[24].** In most cereals, the economic grain yield depends on the number of spikes/area, which already depends on the genetic makeup and the condition of the environment during crop growth **[14].** The results of the number of spikes/m^2 in this study could be attributed to the genetic variability among the tested varieties and the response of each variety to the environmental conditions during both locations. This is consistent with the findings of **[25]** that the number of spikes correlated with grain yield. Acsad Strain 14 has the maximum value of grain yield and spike number per unit area. Moreover, the number of grains per spike in cereals is one of the major yield components directly related to yield. It defines the amount of yield that will be produced; this means the number of grains per spike is directly proportional to high-yield production, which confirms the final yield of the varieties. It is an inevitable yield-mediating trait to achieve high productivity **[14].** It is observed that the Qalla variety has the lowest value of spike weight; this could be associated with the value of the number of grains per spike trait. Barley genetics was strongly influenced by the number of grains per spike **[25].** What's more, it’s clearly shown results of grain weight per spike are associated with the spike weight and number of grains per spike, as the Qalla variety has a minimal value of both traits, and the effect of grain weight /spike. Additionally, different barley varieties may have variations in their 1000-grain weight, which could be attributed to genetic differences and environmental factors **[25]**. This trait was indicated to be genetically stable among other stable and grain yield traits of the barley crop **[2].** Grain yield has a positive correlation with most of the growing and yielding characteristics. Significant associations of barley grain yield with yield components and agronomic characteristics have also been stated previously [2], indicating these traits as an efficient approach to improving grain yield and end-use efficiency of barley **[26].** This result agrees with the finding by **[27],** when studying ten barley varieties under three environments.

In the relation between NFNB disease and measurements of yield, and yield components, the barley variety Rafidain show significant differences with most of the other barely varieties in some important plant characteristics such as spike weight, grain weight per spike and the high value of other traits such as spike length, number of grain per spike, 1000 grains weight and grain yield, this variety had resistance infection type and the low values in NFNB diseases severity and coefficient of infection in both locations and average of both locations. On the other hand, the barley variety, Al-Amal, has an R-MR infection type with low IT and CI values that recorded the maximum spike length and high values of spike weight, number of grains per spike, thousand grain weight and grain yield. Nawawir-01 has an MR infection type that recorded the maximum thousand-grain weight in the average of both locations and a high length of spike. Qalla has R reaction with a low degree of IT, and CI produced the minimum value of the most studied character; this is due to the fact that this variety is more prone to lodging. However, some susceptible varieties, such as Movialis, Iba 265, Iba 99, Rihana 02 and N.S. 313, record the low value of the majority of studied characters, except the Movialis variety for grain number per spike character. The case of Acsad Strain 14 variety with S reaction to disease demonstrates a different successful strategy: compensating through high spike density. Despite a markedly reduced number of grains per spike, probably due to disease damage to floral structures or a shortage of assimilates, its exceptionally high spike density allowed it to attain competitive yields. As a result, NFNB severity affected the yield and the yield components of barley. These results align with other research that has shown that net blotch reduces spike weight, thousand-grain weight and grain size and grain yield in net blotch-infected plots when compared to crops that were controlled by regular fungicide sprays **[19]**, or Yield losses due to disease that effect of upper leaves, particularly the flag leaf, can reduce grain yield by up to 42% under natural conditions as mentioned by **[28].** The large differences between studied characters between the locations indicated that environments were diverse, which caused most of the variation in the study's traits, and this means the environment has the greatest role in determining the characters. These results are in harmony with those obtained **[2].** The variation in response of varieties to each location may be due to the genetic variation between the varieties, and these varieties may have different adaptations to certain climatic conditions. Differences in grain yield are mainly attributed to the interaction between the genetic makeup of the varieties during growth periods and the prevailing environmental factors during their development **[14].** Identifying varieties with different successful strategies (balanced architecture in Rihane 02 variety, compensatory tillering in Acsad Strain 14) provides valuable genetic resources for breeding programs. Incorporating these diverse resistant mechanisms could lead to the development of varieties with broader-spectrum resistance and greater yield stability under net form net blotch pressure. Future research should focus on multi-year, multi-location screening, integrate molecular diagnostics for resistance gene characterization, and consider climate change-related disease risk projections.

Conclusion

This study demonstrated substantial genetic variation among local barley varieties in their resistance to net form net blotch (NFNB) under field conditions at the adult plant stage. Resistant varieties such as Rafidain and Qalla consistently exhibited low disease severity and low coefficients of infection, coupled with high grain yield, whereas highly susceptible varieties such as Movialis and Iba 265 suffered significant yield reductions. These findings confirm that deploying resistant varieties represents an effective, environmentally sustainable strategy for NFNB management and contributes to resilient barley production systems.

Varieties including Rafidain, Qalla, Al□Amal, and Nawawir□01 showed promising resistance profiles and yield performance under high NFNB pressure, making them suitable candidates for breeding programs and wider cultivation. The results underscore the critical role of genetic diversity and local adaptation in enhancing disease resistance and yield stability.

To ensure durable resistance, ongoing multi□location trials and genetic analyses are required to capture genotype × environment interactions and to identify stable sources of resistance. Integrating resistant germplasm into breeding pipelines will be essential for developing varieties that combine high yield potential with robust disease resistance, thereby supporting sustainable barley production in rain□fed agro□ecosystems.

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مقاومة مرض التبقع الشبكي وأداء أصناف محصول الشعير المحلية تحت ظروف الزراعة المطرية في إقليم كردستان العراق

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الخلاصة

يُعدّ مرض التبقع الشبكي الناجم عن الفطر ***Pyrenophora teres*** من أهم الأمراض التي تصيب محصول الشعير في العديد من مناطق زراعته. هدفت هذه الدراسة إلى تحليل التفاعل بين العائل والطفيلي في عدد من أصناف الشعير المحلية مع الشكل الشبكي من التبقع ***(NFNB)*** في مرحلة النبات البالغ، وتقييم تأثيره على المحصول ومكوناته تحت ظروف الزراعة المطرية في موقعين مختلفين ضمن إقليم كردستان العراق. جرى زرع أحد عشر صنفاً محلياً من الشعير، مع إجراء تقييم دقيق لشدة الإصابة، وأنماط العدوى، ومعاملات العدوى.

أظهرت النتائج وجود فروق معنوية في مقاومة أصناف الشعير للمرض بين الأصناف والمواقع. وقد أمكن تقسيم الأصناف إلى ست مجموعات وفقاً لنمط العدوى؛ حيث تميزت الأصناف المقاومة مثل رافدين وقلة بانخفاض متوسط شدة الإصابة ومعامل العدوى (5% و1 على التوالي)، في حين شكّلت الأصناف عالية القابلية للإصابة المجموعة الأكبر، والتي ضمّت خمسة أصناف هي: موفياليس، إيبا 265، إيبا 99، ريحانة 02، و***N.S. 313***، بمتوسط معاملات عدوى تراوحت بين 87.50 و38.33% وشدة إصابة ضمن نفس النطاق.

كما لوحظت استجابات متباينة في مكونات المحصول، بما في ذلك طول السنبلة، وزن الحبة، كثافة السنابل، ووزن الألف حبة. أظهرت الأصناف المقاومة مستويات إنتاجية وجودة حبوب متفوقة بشكل ثابت، في حين عانت الأصناف الحساسة من انخفاضات كبيرة في المحصول ووزن السنبلة ووزن الحبة.

تؤكد هذه النتائج أهمية التنوع الوراثي والتكيف المحلي في برامج التربية، وتبرز قيمة الأصناف المقاومة كنهج صديق للبيئة لتعزيز إنتاجية الشعير والحد من تفشي مرض التبقع الشبكي في النظم الزراعية المطرية المتباينة.

الكلمات المفتاحية: الشعير ، مرض التبقع الشبكة الشكلية ، مرض الاوراق ، علم الفطريات ، حاصل الحبوب.