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Effect of Chemical Inducers and Fungicides on Powdery Mildew ((*Blumeria graminis* f.sp. *hordei*)Disease and Yield Traits of Two Barley Cultivars (*Hordeum vulgare* L.)

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Abstract: Powdery mildew, caused by *Blumeria graminis* f.sp. *hordei*, represents one of the most significant biotic threats to barley (*Hordeum vulgare* L.) cultivation in arid and semi-arid regions. This study evaluated the effectiveness of selected four chemicals inducers (salicylic acid, oxalic acid, tannic acid, and benzothiazole) and two fungicides (mancozeb and thiophanate-methyl [Topsin-M70%]) in reducing disease severity and improving yield-related traits in two barley cultivars ('Areg' and 'Wady Bargoge') under Libyan field conditions. The experiments were laid out in a randomized complete block design (RCBD) with three replications. Foliar treatments were applied at the heading stage and ten days later. Data were collected on disease incidence, disease severity, and key agronomic traits, including grain yield, 1000-grain weight, and harvest index. The results revealed that Benzothiazole was the most effective treatment, significantly reducing disease severity and incidence while enhancing grain yield, grain weight per spike, and biological yield. The Areg cultivar responded more favourably than Wady Bargoge, indicating varietal differences in resistance and productivity under induced systemic resistance. In contrast, Topsin-M70% exhibited the lowest performance in both disease control and yield improvement. The study underscores the potential of chemical resistance inducers, particularly Benzothiazole, as sustainable alternatives to conventional fungicides. These findings support the integration of such inducers into eco-friendly disease management strategies and highlight the need for further optimisation and combination with biological agents to enhance barley resilience in low-input production systems.

Keywords: *Hordeum vulgare*, powdery mildew, benzothiazole, induced resistance, fungicides, disease severity, Libya.

تأثيربعض المحفزات الكيميائية والمبيدات الفطرية على مرض البياض الدقيقي (*Blumeria graminis* f.sp. *hordei*) وخصائص الانتاج لصنفين من الشعير (*Hordeum vulgare* L.)

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المستخلص: يُعد مرض البياض الدقيقي، الذي يسببه الفطر *Blumeria graminis* f.sp. *hordei*، من أبرز التهديدات الحيوية التي تواجه زراعة الشعير (*Hordeum vulgare* L.) في المناطق الجافة وشبه الجافة. هدفت هذه الدراسة إلى تقييم فعالية عدد من المحفزات الكيميائية المختارة (حمض الساليسيليك، حمض الأوكساليك، حمض التانيك، والبنزوثيازول) والمبيدات الفطرية (مانكوزيب، وثيوفانات- ميثيل -Topsin]

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([M70%في خفض شدة المرض وتحسين الصفات المرتبطة بالإنتاج لصنفين من الشعير ("أريق" و"وادي برقوج") تحت ظروف الحقل الليبي. تم تنفيذ التجارب وفق تصميم القطاعات العشوائية الكاملة (RCBD) بثلاث مكررات، وجرى تطبيق المعاملات الرشية عند مرحلة التسنبل، ثم تكرارها بعد عشرة أيام. تم جمع البيانات حول نسبة وشدة الإصابة بالمرض، إلى جانب بعض الصفات الزراعية المهمة، مثل غلة الحبوب، ووزن ألف حبة، ومعامل الحصاد.أظهرت النتائج أن البنزوثيازول كان العلاج الأكثر فعالية، إذ أدى إلى خفض معنوي في شدة المرض ونسبة الإصابة، إلى جانب تحسين غلة الحبوب ووزن الحبة والإنتاج البيولوجي. وأبدى الصنف "أريق" استجابة أفضل مقارنةً بـ"وادي برجوج"، مما يشير إلى وجود اختلافات صنفية في المقاومة والإنتاجية تحت تأثير المقاومة الجهازية المستحثة. في المقابل، سجّل المبيد Topsin-M70% الأداء الأدنى في السيطرة على المرض وتحسين الغلة. وتبرز هذه الدراسة إمكانيات المحفزات الكيميائية للمقاومة، خاصة البنزوثيازول، كبدائل مستدامة للمبيدات الفطرية التقليدية حيث كان تأثير البنزويثازول على تحسين غلة الحبوب 67.833 جم/ وزن الحبة . وتدعم النتائج دمج هذه المحفزات ضمن استراتيجيات الإدارة البيئية للأمراض، مع التأكيد على أهمية تحسين استخدامها وربطها بالعوامل الحيوية لتعزيز صمود الشعير في نظم الإنتاج ذات المدخلات المنخفضة.

الكلمات المفتاحية: الشعير (*Hordeum vulgare*)، البياض الدقيقي ، البنزوثيازول، المقاومة المستحثة، مبيدات فطرية، شدة المرض، ليبيا.

1. Introduction:

Barley (Hordeum vulgare L.) is a fundamental cereal crop cultivated globally for its nutritional, industrial, and agronomic significance. It ranks among the top four cereals worldwide in terms of cultivation area and production volume. In regions with marginal soils and limited water availability, such as North Africa and the Middle East, barley plays a pivotal role in dryland agriculture due to its tolerance to drought, salinity, and low soil fertility (Sainju et al., 2003; Agrios, 2005). In Libya, barley continues to be an essential crop for human consumption, livestock feed, and cultural practices. However, its productivity is significantly constrained by several biotic stresses, notably powdery mildew.

Powdery mildew, caused by the obligate fungal pathogen *Blumeria graminis* f.sp. *hordei* (Bgh), is among the most prevalent and economically damaging foliar diseases of barley. The disease appears as characteristic white powdery patches on the leaf surface, resulting in chlorosis, reduced photosynthetic activity, early leaf senescence, and substantial yield reductions. Under favourable environmental conditions moderate temperatures and elevated humidity disease outbreaks may reach epidemic proportions, causing up to 40% yield loss in susceptible cultivars (Leath & Heun, 1990; Walters et al., 2013).

For decades, chemical fungicides have served as the primary means of controlling powdery mildew. Agents such as thiophanate-methyl (Topsin-M 70%) and mancozeb are commonly used due to their effective antifungal properties and economic feasibility. Nevertheless, prolonged and repeated application has triggered multiple concerns, including the emergence of fungicide-resistant Bgh strains, environmental degradation, phytotoxicity, and food safety risks arising from pesticide residues (Mahlein, 2016; Abd-ElGawad *et al*., 2023). As agriculture shifts towards more sustainable and health-conscious practices, alternative solutions to synthetic fungicides are urgently required.

One promising strategy involves the use of chemical resistance inducers non-toxic compounds that activate the plant’s innate defence mechanisms. Compounds such as salicylic acid (SA), oxalic acid (OA), tannic acid (TA), and benzothiadiazole (BTH) exemplify this group. These inducers can trigger systemic acquired resistance (SAR) or induced systemic resistance (ISR), involving complex signal transduction pathways and the expression of defence-related genes including pathogenesis-related (PR) proteins and enzymes like phenylalanine ammonia-lyase (PAL), which are associated with reactive oxygen species generation and cell wall fortification (Görlach et al., 1996; Fritz, 2005; Hayat et al., 2010).

Salicylic acid is particularly well characterised for its central role in SAR activation, especially against biotrophic pathogens such as BTH. Oxalic and tannic acids, although primarily known for their antimicrobial activity, also contribute to enhancing physical plant barriers. Benzothiadiazole, a synthetic functional analogue of SA, similarly induces SAR and has shown efficacy in enhancing disease resistance and improving crop performance (Görlach *et al*., 1996; Abdel-Kader *et al*., 2023).

However, the performance of resistance inducers may vary considerably based on environmental factors, application method and timing, dosage, and most critically the genetic makeup of the target crop. Barley genotypes differ in their susceptibility to pathogens and responsiveness to chemical elicitors, which necessitates genotype-specific evaluation under realistic agronomic conditions. Understanding these genotype treatment pathogen interactions is essential for incorporating resistance inducers into practical disease management programmes and breeding efforts (Walters *et al*., 2013; Szabó *et al*., 2020).

Accordingly, this study was conducted to investigate the effectiveness of selected chemical inducers (salicylic acid, oxalic acid, tannic) and fungicides (benzothiazole, mancozeb, and Topsin-M 70%) in controlling powdery mildew disease in two barley cultivars (Areg and Wady Bargoge) under Libyan field conditions. In addition to disease parameters, the study also evaluates important agronomic traits such as grain yield, straw yield, biological yield, 1000-grain weight, and harvest index. The findings aim to contribute toward sustainable and environmentally friendly disease management approaches that enhance crop productivity and inform integrated pest management (IPM) strategies.

3. Materials and Methods

3.1 Study Location and Experimental Design

Field and greenhouse experiments were carried out during two distinct winter growing seasons (2014/2015 and 2021/2022) in Taguora City, located in the north-western coastal region of Libya. The experimental layout followed a Randomized Complete Block Design (RCBD) with three replications to account for variability and ensure the reliability of statistical inference, in accordance with standard agronomic trial protocols (Gomez & Gomez, 1984).

Taguora is characterised by a semi-arid Mediterranean climate with mild, wet winters and hot, dry summers. During the barley growing season (December to March), the average daily temperatures range from 8°C to 20°C, with relative humidity fluctuating between 50% and 75%. Annual precipitation is typically low, averaging around 250 mm, with most rainfall concentrated between November and February. Soils in the region are predominantly sandy loam, slightly alkaline (pH 7.6–8.1), and moderately low in organic matter content, which can limit nutrient retention and water-holding capacity. These conditions not only constrain barley growth and yield potential but also favour the development and spread of foliar fungal pathogens such as powdery mildew, particularly under moderate humidity and temperature regimes (FAO, 2022; Libyan National Meteorological Centre, 2021).

3.2 Plant Materials and Applied Treatments

Two barley (*Hordeum vulgare* L.) cultivars, namely ‘Areg’ and ‘Wady Bargoge’, were selected based on their agronomic relevance and contrasting susceptibility to powdery mildew. Six treatments were evaluated for their efficacy in disease management:

Salicylic acid (SA) at 1 g/L, Oxalic acid (OA) at 1 g/L, Tannic acid (TA) at 1 g/L, Mancozeb (DI) (a dithiocarbamate fungicide) at 3 g/L, Benzothiazole (BTH, a resistance inducer) at 3 g/L, Topsin-M 70% (TM) WP (thiophanate-methyl, a systemic fungicide) at 3 g/L

A control group of untreated plants was maintained under identical environmental and agronomic conditions to serve as a baseline for comparison.

3.3 Pathogen Inoculation and Disease Establishment

Inoculation with the powdery mildew pathogen *Blumeria graminis* f.sp. *hordei* was achieved through the integration of naturally infected susceptible barley plants (cv. Giza 123) used as spreader rows surrounding each plot. This method ensured uniform and natural disease pressure throughout the trial period under field conditions conducive to disease development, such as moderate temperatures and high humidity (Leath & Heun, 1990; Walters et al., 2013).

3.4 Foliar Treatment Applications

All chemical inducers and fungicides were applied as foliar sprays using a handheld sprayer to ensure even coverage. Applications were performed at two critical growth stages: the heading stage (approximately 75 days post-sowing) and again 10 days later. This timing aligns with the period of active foliar development and maximal disease susceptibility in barley (Mahlein, 2016).

3.5 Disease Assessment and Agronomic Measurements

Disease progression was monitored using standard visual assessment protocols. Disease severity was rated five times at five-day intervals using the Horsfall–Barratt scale, which categorises symptom intensity into defined percentage ranges (Horsfall & Barratt, 1945). Disease incidence was calculated as the percentage of visibly infected plants per plot.

In addition to disease parameters, several agronomic traits were recorded to evaluate treatment impacts on plant performance. These included:

Grain yield (t/ha), Straw yield, Biological yield, Number of grains per spike, Grain weight per spike, 1000-grain weight, Harvest index (%).

These metrics provide a comprehensive understanding of both protective and productivity-related effects of the treatments.

3.6 Statistical Analysis

All collected data were subjected to analysis of variance (ANOVA) appropriate for the RCBD structure. Treatment means were compared using Fisher’s Least Significant Difference (LSD) test at the 5% probability level to detect statistically significant differences among treatments. Statistical computations were conducted using CoStat software version 6.311 (CoHort Software, 2004), which is widely adopted for agricultural data analysis.

Results and Discussion

1. **Number of Grains per Spike**

Benzothiazole (BTH) significantly enhanced the number of grains per spike (67.833 grains, Table 1) compared to other treatments (SA, 66.500 , OA, 61.500 , TA, 61.166 , DI, 55.833 **TM, 56.166 , C, 48.166)** . The differences were statistically significant ($LSD_{0.05}$(T) = 5.896, C = 3.151, T × C = 8.338). This enhancement may be linked to its ability to induce systemic acquired resistance (SAR), which promotes not only defence responses but also cell division and floral differentiation (Görlach et al., 1996). By reducing disease pressure, Benzothiazole may have extended the grain-setting phase, allowing more florets to be fertilised. The Areg cultivar responded more positively, which aligns with reports suggesting that responsiveness to elicitors is often genotype-dependent (Szabó *et al*., 2020).

Table1 . Effect of chemical inducers and fungicides on Number of grains/spike

Treatments (T)	Number of grains/spike		
	Cultivars C))		
	Wady bargoge	Areg	Mean
Salicylic acid (SA)	55.333 de	77.666 a	66.500 ab
Oxalic cacid (OA)	52.000 ef	71.000 ab	61.500 bc
Tannic acid (TA)	59.333 cde	63.000 bcd	61.166 bc
Mancozeb (DI)	59.333 cde	52.333 ef	55.833 c
Topsin-M70% (TM)	46.000 fh	66.333 bc	56.166 c
Benzothiazol (BTH)	65.333 bc	70.333 ab	67.833 a
Contro (C)	41.333 h	55.000 de	48.166 d
Mean	54.095 a	65.095 b	

LSD0.05 (T) = 5.896 LSD0.05 (C) = 3.151 LSD0.05 (T x C) = 8.338

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P\leq 0.05$).

2. **Grain Weight per Spike**

Grain weight per spike was highest under Benzothiazole **(BTH)** (2.241 g, Table 2) with significant statistical differences compared to other treatments ($LSD_{0.05}$(T) = 0.377, C = 0.201, T × C = 0.533). This indicates an improvement in grain-filling efficiency, possibly due to enhanced photosynthetic rate and delayed senescence, as SAR activation often leads to prolonged metabolic activity and increased antioxidant production (Hayat *et al*., 2010). The poor performance of Topsin-M70% may result from reduced green leaf area due to disease severity or phytotoxic effects that impair carbon assimilation.

Table 2. Effect of chemical inducers and fungicides on Grain weight/spike (g)

Treatments (T)	Grain weight/spike (g)		
	Cultivars C))		
	Wady bargoge	Areg	**Mean**
Salicylic acid (SA)	2.259 cd	3.250 a	**2.755 b**
Oxalic cacid (OA)	1.996 d	2.023 d	**2.009 d**
Tannic acid (TA)	2.646 bc	2.243 cd	**2.444 bc**
Mancozeb (DI)	2.101 d	2.118 cd	**2.1097 cd**
Topsin-M70% (TM)	2.0836 d	2.399 bcd	**2.241 cd**
Benzothiazol (BTH)	3.472 a	2.908 b	**3.190 a**
Contro (C)	1.450 e	2.381 bcd	**1.916 d**
Mean	**2.287 a**	**2.474 a**	

LSD0.05 (T) = 0.377 LSD0.05 (C) =0.201 LSD0.05 (T x C) = 0.533

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P \leq 0.05$).

3. 1000-Grain Weight

Benzothiazole (BTH) also produced the heaviest 1000-grain weight (47.267 g, Table 3), surpassing other treatments ($LSD_{0.05}$(T) = 4.97, C = 2.656, T × C = 7.028). This trait is an important indicator of final sink strength. Its enhancement suggests efficient source-to-sink assimilate transfer, supported by reduced pathogen stress and optimal hormonal balance. In contrast, Oxalic cacid (OA) - treated plants had the lowest 1000-grain weight, likely due to suboptimal application timing or dosage, which may have disrupted growth–defence trade-offs (Fritz, 2005).

Table 3. Effect of chemical inducers and fungicides on 1000- grain weight (g)

Treatments (T)	1000(- grain weight (gm		
	Cultivars C))		
	Wadybargoge	Areg	**Mean**
Salicylic acid (SA)	40.649 bcd	42.350 bc	**41.500 b**
Oxalic cacid (OA)	38.361 bcd	28.434 e	**33.398 c**
Tannic acid (TA)	43.283 b	35.658 cd	**39.471 b**
Mancozeb (DI)	34.892 de	40.304 bcd	**37.599 b**
Topsin-M70% (TM)	45.296 b	36.0366 cd	**40.667 b**
Benzothiazol (BTH)	53.186 a	41.347 bcd	**47.267 a**
Contro (C)	35.249 cde	43.544 b	**39.397 b**
Mean	**41.560 a**	**38.239 b**	

LSD 0.05 (T x C) = 7.028. LSD 0.05 (C) = 2.656 LSD 0.05 (T) = 4.97

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P \leq 0.05$).

4. Grain Yield

Benzothiazole (BTH) led to the highest grain yield (2.007 t/ha, Table 4), significantly different from other treatments ($LSD_{0.05}$(T) = 0.036, C = 0.019, T × C = 0.051). This yield advantage reflects its comprehensive impact: reducing disease severity, enhancing photosynthetic efficiency, and promoting reproductive development. These results are consistent with previous studies reporting increased crop productivity under induced resistance even in the absence of severe infection (Abd-ElGawad et al., 2023).

Table.4 Grain yield (tons/ha.) as influenced by application method.

Treatments (T)	**Grain yield tons/ha)) (Cultivars C)**		
	Wadybargoge	Areg	**Mean**
Salicylic acid (SA)	1.710 d	2.167 b	1.939 b
Oxalic cacid (OA)	1.772 c	0.738 i	1.255 d
Tannic acid (TA)	1.289 f	0.769 i	1.029 f
Mancozeb (DI)	1.600 e	0.648 j	1.124 e
Topsin-M70% (TM)	2.215 b	0.628 j	1.421 c
Benzothiazol (BTH)	3.171 a	0.844 h	2.007 a
Contro (C)	0.984 g	1.027 g	1.005 f
Mean	1.820 a	0.974 b	

LSD 0.05 (T x C) = 0.051. LSD 0.05 (C) = 0.019. LSD 0.05 (T) = 0.036

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P \leq 0.05$).

5. Straw Yield

Straw yield also increased significantly under Benzothiazole(BTH) (1.615. Table 5) with $LSD_{0.05}$(T) = 0.034, C = 0.018, T × C = 0.049. The increase in vegetative biomass may be a result of SAR-induced hormonal cross-talk involving salicylic acid, jasmonic acid, and ethylene, which together improve structural growth and enhance tolerance to stress (Walters et al., 2013). In semi-arid Libyan systems, higher straw biomass contributes to soil moisture conservation and can be reused as animal feed or organic mulch.

Table:5 Straw yield (tons/ha.) as influenced by chemical inducers

Treatments (T)	Straw yield (tons/ha) Cultivars C))		
	Wady bargoge	Areg	**Mean**
Salicylic acid (SA)	0.833 i	3.505 a	**2.1693 a**
Oxalic cacid (OA)	0.495 k	2.267 c	**1.381 e**
Tannic acid (TA)	1.056 h	1.859 d	**1.457 d**
Mancozeb (DI)	0.688 j	2.339 b	**1.513 c**
Topsin-M70% (TM)	0.729 j	1.734 e	**1.232 f**
Benzothiazol (BTH)	1.714 e	1.517 f	**1.615 b**
Contro (C)	0.310 l	1.334 g	**0.822 g**
Mean	**0.832 b**	**2.079 a**	

LSD 0.05 (T x C) = = 0.049 LSD 0.05 (C) = 0.018، LSD 0.05 (T) = 0.034

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P \leq 0.05$).

6. Biological Yield

Biological yield, the sum of grain and straw yield, followed a similar trend (3.695 . Table 6), with Benzothiazole (BTH) showing the highest values and significant differences ($LSD_{0.05}$(T) = 0.186, C = 0.099, T × C = 0.263). This suggests that Benzothiazole not only increases yield components individually but also enhances the overall growth system through improved physiological coordination between vegetative and reproductive processes.

Table: 6 Biological yield as influenced by chemical inducers

Treatments (T)	Biological yield (tons/ha) Cultivars C))		
	Wady bargoge	Areg	**Mean**
Salicylic acid (SA)	2.543 de	5.673 a	**4.108 a**
Oxalic cacid (OA)	2.258 f	3.005 c	**2.632 c**
Tannic acid (TA)	2.345 ef	2.895 cd	**2.620 c**
Mancozeb (DI)	2.289 ef	2.987 cd	**2.638 c**
Topsin-M70% (TM)	2.944 cd	2.363 ef	**2.653 c**
Benzothiazol (BTH)	4.885 b	2.506 ef	**3.695 b**
Contro (C)	1.294 g	2.361 ef	**1.827 d**
Mean	**2.651 b**	**3.113 a**	

LSD 0.05 (T x C) = 0.263 LSD 0.05 (C) = 0.099 LSD 0.05 (T) = 0.186

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P \leq 0.05$).

7. Harvest Index (HI)

Although Topsin-M70% recorded the highest : (Table 7, HI %), the overall productivity was low, indicating a disproportionate allocation of assimilates due to limited vegetative growth. The LSD values (T = 1.878, C = 1.004, T × C = 2.656) confirmed significant differences. In contrast, Benzothiazole achieved a more balanced HI, reflecting efficient partitioning of biomass into grain, which is preferable in dryland systems where both yield and stability are essential (Abdel-Monaim, 2012).

Table.7 Harvest index (%) as influenced by chemical inducers

Treatments (T)	Harvest index HI)) (%) Cultivars C))		
	Wadybargoge	Areg	**Mean**
Salicylic acid (SA)	67.785 b	38.204 f	**52.994 b**
Oxalic cacid (OA)	77.728 a	24.548 g	**51.138 bc**
Tannic acid (TA)	54.968 d	27.004 g	**40.986 e**
Mancozeb (DI)	69.899 b	21.699 h	**45.799 d**
Topsin-M70% (TM)	65.015 c	**35.754** f	**50.384 c**
Benzothiazol (BTH)	75.230 a	26.587 g	**50.908 c**
Contro (C)	76.021 a	43.370 e	**59.695 a**
Mean	**69.521 a**	**31.023 b**	

LSD 0.05 (T x C) = 2.656 LSD 0.05 (C) = 1.004 LSD 0.05 (T) = 1.878

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P\leq 0.05$).

8. Disease Severity

Benzothiazole treatment led to the lowest disease severity (21.464%, Table 8), significantly lower than the untreated control and Topsin-M70% (66.47%) with $LSD_{0.05}$(T) = 0.550, C = 1.029, T × C = 1.456. This confirms its role as a powerful SAR inducer, leading to pre-infection priming and post-infection defence amplification through PR-protein synthesis, callose deposition, and oxidative bursts (Fritz, 2005; Görlach et al., 1996).

Table .8 Effect of chemical inducers and fungicides on disease severity (DS%) of two of the tested barely cultivar.

Treatments (T)	Disease Severity DS)%)		
	Cultivars C))		
	Wadybargoge	Areg	**Mean**
Salicylic acid (SA)	57.237 d	9.595 j	33.416 e
Oxalic cacid (OA)	65.641 c	18.555 h	42.098 d
Tannic acid (TA)	69.311 b	30.053 f	49.682 b
Mancozeb (DI)	66.645 c	27.650 g	47.147 c
Topsin-M70% (TM)	58.258 d	8.614 j	33.436 e
Benzothiazol (BTH)	37.214 e	5.714 k	**21.464 f**
Contro (C)	95.387 a	37.553 e	66.470 a
Mean	64.242 a	19.676 b	

LSD 0.05 (T x C) = 1.456 LSD 0.05 (C) = 1.029 LSD 0.05 (T) = 0.550

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P\leq 0.05$).

9. Disease Incidence

The lowest disease incidence was again observed under Benzothiazole (8.132%, Table 9), with clear statistical significance ($LSD_{0.05}$(T) = 0.483, C = 0.904, T × C = 1.278). This reduction demonstrates the effectiveness of pre-emptive defence mechanisms induced by Benzothiazole, which limits pathogen establishment and spread across host tissues. Reduced incidence is especially important in maintaining crop uniformity and minimising yield variability under field conditions (Mahlein, 2016; Abd-ElGawad et al., 2023).

Table .9 Effect of chemical inducers and fungicides on disease Incidence (DI%) of two of the tested barely cultivar.

Treatments (T)	Disease Incidence DI%))		
	Cultivars C))		
	Wadybargoge	Areg	**Mean**
Salicylic acid (SA)	79.899 f	2.871 m	41.385 f
Oxalic cacid (OA)	83.069 e	5.490 k	44.279 e
Tannic acid (TA)	98.333 b	9.329 i	53.83 b
Mancozeb (DI)	95.331 c	6.951 j	51.141 c
Topsin-M70% (TM)	93.584 d	3.117 m	48.351 d
Benzothiazol (BTH)	14.559 g	1.704 n	8.132 g
Contro (C)	100.00 a	11.272 h	55.636 a
Mean	80.682 a	5.819 b	

LSD 0.05 (T x C) = 1.278 LSD 0.05 (C) = 0.904 LSD 0.05 (T) = 0.483

Values followed by the same letter(s) in each column didn't differ significantly according to Fisher's LSD Test ($P\leq 0.05$).

Integrated Insight

Benzothiazole consistently outperformed all other treatments across all measured parameters—yield, biomass, resistance, and quality traits—with statistical validation. Its dual action as a growth enhancer and defence activator makes it an ideal component for integrated disease management in barley cultivation, particularly under semi-arid Libyan environments where both biotic and abiotic stressors converge.

Findings

The results from this study clearly demonstrate that the application of chemical resistance inducers, particularly Benzothiazole, significantly improved both disease resistance and yield-related traits in barley under field conditions. The Areg cultivar exhibited superior performance across most parameters compared to Wady Bargoge. Benzothiazole consistently enhanced physiological attributes such as grain number and grain weight, while also reducing disease severity and incidence. These outcomes affirm the dual role of certain chemical inducers in mitigating pathogen pressure and improving crop productivity. Other treatments, such as Mancozeb and Oxalic Acid, showed moderate benefits, while Topsin-M70% was less effective under the conditions tested.

Conclusion

This study confirms the efficacy of Benzothiazole as a promising chemical elicitor for controlling powdery mildew (Blumeria graminis f.sp. hordei) and improving agronomic traits in barley, particularly under semi-arid Libyan conditions. Its impact on enhancing both vegetative and reproductive growth, combined with effective disease suppression, highlights its potential in sustainable crop production. The differential responses observed between the two cultivars also underscore the importance of genotype-specific evaluations when implementing induced resistance strategies. The overall findings support the integration of resistance inducers as part of a broader, eco-friendly approach to crop protection and productivity enhancement in cereals.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

Adoption of Benzothiazole: Incorporating Benzothiazole in barley disease management programmes is highly recommended due to its consistent performance in reducing disease and enhancing yield.

Genotype-specific Strategies: Future applications of chemical inducers should consider varietal responses. Areg cultivar demonstrated greater responsiveness and may be prioritised in resistance management plans.

Optimisation of Application Timing: Further research is needed to determine the most effective timing, frequency, and concentration of inducers to maximise their efficacy without compromising plant safety.

Integration with Biological Control: Combining chemical inducers with biological agents (e.g., Trichoderma spp.) and organic amendments may provide synergistic effects and contribute to sustainable pest management.

Environmental and Economic Assessment: Long-term field trials should be conducted to evaluate the environmental impact and cost-benefit ratios of these treatments under diverse agro-ecological zones in Libya.

Policy Support for Eco-Friendly Inputs: Agricultural policies should support the registration, regulation, and adoption of safe resistance inducers within integrated pest management (IPM) frameworks.

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