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Evaluation of Superoxide Dismutase Activity, Malondialdehyde Content, and Yield of Various Wheat Genotypes (*Triticum aestivum* L.) in the Midlands West Sumatra

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Abstract

Developing wheat (*Triticum aestivum* L.) in the midlands is an alternative way to expand cultivation areas in Indonesia, but relatively high environmental temperatures can increase oxidative stress and reduce crop productivity. This study aimed to evaluate superoxide dismutase (SOD) enzyme activity, malondialdehyde (MDA) content, and yield of various wheat genotypes in the midlands of West Sumatra. The experiment used a Completely Randomized Design with 14 genotypes and three replications. SOD activity and MDA content were analyzed descriptively, while yield per hectare was analyzed using analysis of variance followed by orthogonal contrast tests at a 5% significance level. SOD activity ranged from 0.42–1.25 units/g fw, while MDA content ranged from 1.65–3.58 µmol/g fw. Yields per hectare showed differences across the compared genotype groups, with GURI 1 producing the highest productivity of 1.70 tons/ha. This study provides information on the variation in physiological responses and productivity of various wheat genotypes in midland environments, thus providing a basis for identifying genotypes with better adaptation to high temperature stress. The GURI 1 genotype has the potential to be recommended for wheat cultivation development in the midland areas of West Sumatra. At the same time, SOD activity and MDA content can serve as physiological indicators to support selection and breeding programs for wheat adapted to relatively high-temperature environments.

Keywords: Adaptation, Antioxidants, High Temperature Stress, Lipid Peroxidation, Oxidative

1. Introduction

Wheat (*Triticum aestivum* L.) is a strategic food commodity that plays a vital role in meeting global food needs. In Indonesia, wheat demand continues to increase annually but is still largely met through imports (Suliansyah, 2019). Data from the Central Statistics Agency (BPS) shows that Indonesia's wheat imports in 2024 will reach 11.715 million tons, an increase of 10.65% from 2023 and 25.29% from 2022 (BPS, 2025). This situation shows strong demand for wheat and a significant opportunity to develop domestic wheat cultivation to reduce import dependence and support national food security.

Wheat development in Indonesia still faces challenges due to limited suitable agro-climatic conditions. Wheat is a subtropical crop that requires temperatures of 15–20°C for optimal growth and production (2021). These conditions are generally found in the highlands, but wheat cultivation in these areas must compete with horticultural commodities with higher economic value (Firmansah *et al*., 2024). Therefore, the mid-latitudes represent a potential alternative for expanding wheat planting areas in Indonesia.

Wheat cultivation in the midlands faces challenges in the form of relatively high environmental temperatures. higher than in the highlands. This condition limits production because rising temperatures, especially during the reproductive phase, can disrupt photosynthesis, accelerate leaf senescence, inhibit grain filling, and reduce yields. Every 1°C increase in Temperature can reduce wheat yields by 6-10% (Ninasari, 2024). In line with this,

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the results of research by Firmansah *et al* . (2024) reported that wheat productivity in higher temperature environments in the lowlands only reached 0.06 tons/ha, while in cooler environments in the highlands it reached 1.35 tons/ha. This decrease is linked to high temperatures that inhibit photosynthesis and biomass production, shorten the vegetative period, reduce tillering capacity and grain differentiation, and increase oxidative stress that accelerates plant aging (Cohen et al. 2021; Zheng et al. 2025).

Oxidative stress under high temperatures occurs because of increased formation of reactive oxygen species (ROS), which can damage cell membranes, proteins, and nucleic acids, disrupting various plant physiological processes. One of the plant's defense mechanisms against these conditions is the enzymatic antioxidant system, in which the enzyme superoxide dismutase (SOD) plays a role in catalyzing the dismutation of superoxide radicals into hydrogen peroxide and oxygen (Akter *et al*., 2021). Conversely, malondialdehyde (MDA), an end product of lipid peroxidation, is widely used as an indicator of the level of cell membrane damage due to oxidative stress (Mishra *et al* ., 2023). Therefore, SOD activity and MDA content are widely used as physiological indicators in evaluating plant responses to high temperature stress.

Various studies have shown that superoxide dismutase (SOD) enzyme activity and malondialdehyde (MDA) content are important physiological indicators for evaluating wheat responses to high temperature stress. Altuhaish (2014) reported that wheat genotypes sensitive to high temperatures had higher MDA content but lower SOD enzyme activity than tolerant genotypes, so these two parameters can differentiate physiological responses between genotypes. Another study by Vedi & Pandey (2024) reported that high temperature stress increased MDA content by 38.9% compared to normal conditions, indicating cell membrane damage due to oxidative stress. Both studies indicate that SOD activity and MDA content are effective indicators of wheat physiological responses to high temperature stress. However, studies on wheat physiological responses based on SOD activity and MDA content in mid-latitude conditions in Indonesia remain limited. In addition, studies on the physiological responses of genotypes representing various wheat germplasm groups to high-temperature conditions in mid-latitudes remain limited. To address these limitations, this study evaluated SOD activity, MDA content, and yield in genotypes representing four wheat germplasm groups: introduced varieties, highland-adaptive national varieties, midland-adaptive national varieties, and convergent cross lines of the F-8 generation, cultivated in midland conditions in West Sumatra. This study is expected to provide additional information on the physiological responses and yields of various wheat germplasm groups under these conditions.

2. Material and Methods

The research was conducted from July to December 2025 in Jorong Labuah, Nagari Sungai Batang, Tanjung Raya District, Agam Regency, West Sumatra, at an altitude of ±517 m above sea level at the geographical coordinates - 0°20”7'S 100°14'1"E. Physiological and agronomic analyses were conducted at the Agronomy Laboratory, Faculty of Agriculture, Andalas University, and the PT Wiwiadi Bintang Sains Laboratory, Padang. The genetic materials used consisted of four groups of wheat germplasm, namely introduced varieties, national varieties adapted to highlands and midlands, and convergent cross lines of the F-8 generation. Supporting materials included cow manure, Urea fertilizer, TSP, KCl, carbofuran, pesticides with active ingredients profenofos and propineb, and various chemicals for the analysis of malondialdehyde (MDA) levels and superoxide dismutase (SOD) enzyme activity. The equipment used included hand tractors, analytical scales, centrifuges, UV-Vis and visible spectrophotometers, ovens, water baths, seed moisture meters, and other supporting laboratory equipment.

The experiment was arranged using a Completely Randomized Design (CRD) with 14 wheat genotypes, consisting of two introduced varieties (IS Jarissa and VEE), seven national varieties (GURI 1, GURI 2, GURI 3 Agritan, GURI 4 Agritan, GURI 7 Agritan, Ganesha, and Dewata), and five lines resulting from convergent crosses of the F-8 generation (CBF6-4, CBF6-15, CBF6-17, CBF6-18, and CBF6-20). We replicated each genotype three times, yielding 42 experimental units. The size of the experimental plot was 2 m × 1.25 m with a distance between plots of 50 cm. Each plot measured 2.0 m × 1.25 m with a distance between plots of 50 cm. Each plot consisted of five planting rows of 1.8 m in length with a distance between rows of 25 cm.

The research stages included initial soil analysis, land preparation, seed planting in rows, plant maintenance, including watering, weeding, fertilization with urea, TSP, and KCl according to recommendations, and pest and disease control. Harvesting was carried out when more than 80% of the plants reached physiological maturity. The harvested panicles were then dried, threshed, hulled, and stored until the seed moisture content reached ≤14%.

Observations included environmental conditions during the growing season, malondialdehyde (MDA) content, superoxide dismutase (SOD) enzyme activity, and yield per hectare. Data on air temperature, air humidity, rainfall, and solar radiation intensity were obtained from the West Sumatra Meteorology, Climatology, and Geophysics Agency (BMKG) during July–October 2025. MDA and SOD observations were conducted once in the early generative phase when the flag leaf appeared, using flag leaf samples taken from four plants in each replication and composited for each genotype. MDA content was analyzed using the thiobarbituric acid (TBA) method

according to Ono *et al*. (1995), while SOD activity was analyzed using the method of Pritchard *et al*. (2000) through inhibition of nitro blue tetrazolium (NBT) reduction. Yield per hectare was calculated from the seed weight of each plot, converted to tons/ha. At seed moisture content ≤14%. Environmental conditions, SOD activity, and MDA content are presented descriptively. We did of statistically analyze SOD and MDA because we composited physiological samples for each genotype. Yield data per hectare were analyzed using analysis of variance (F test) at the 5% significance level, followed by an orthogonal contrast test at the 5% significance level if a significant effect was observed. Data analysis used Statistical Tool for Agriculture Research (STAR) ® software and Microsoft Excel® 2021. The research implementation is presented in the following flowchart:

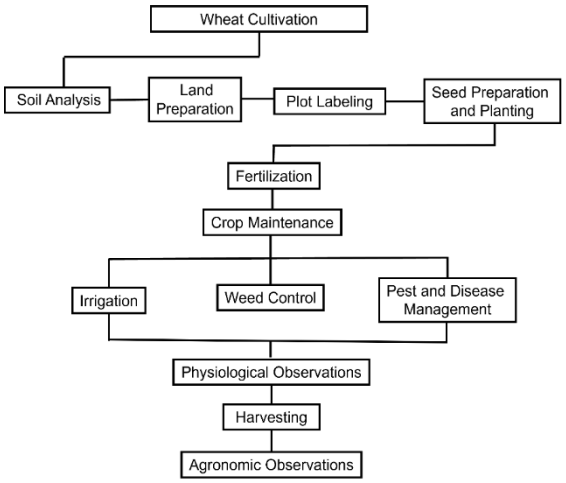


Figure 1. Research flow diagram.

3. Results and Discussion

3.1. Environmental Conditions During the Planting Season

Based on observations during the planting season in Tanjung Raya District, environmental conditions were generally not optimal for wheat growth and production. Environmental conditions during the study are presented in Table 1.

Air temperatures during the growing season ranged between 27.4–29.7°C, higher than the optimum wheat growth temperature range of 15–20°C. Humidity ranged from 61.7–73.9%, while the highest rainfall occurred in September, reaching 278 mm. Solar radiation intensity was also relatively high, ranging from 370.3–391.7 W/m².

These conditions indicate that wheat plants are cultivated in an environment that has the potential to cause stress, particularly due to air temperatures exceeding the optimum growth range. High temperatures increase respiration rates, accelerate leaf senescence, and decrease photosynthetic efficiency, thereby reducing biomass accumulation (Li et al., 2024). According to Maulana *et al*. (2024), light intensity indicates conditions that affect photosynthesis. On the other hand, relatively high rainfall during the generative phase has the potential to disrupt flowering, pollination, and seed filling so that yield formation is less than optimal (Putri *et al* ., 2013).

Environmental conditions during the study, with temperatures of 27.4–29.7°C, which exceeded the optimum range for wheat growth (15–20°C), triggered high temperature stress, which impacted the physiological response of the plant, which was reflected in the activity of the superoxide dismutase (SOD) enzyme of 0.42–1.25 units/g. fw and malondialdehyde (MDA) content of 1.65–3.58 µmol/g fw, thus indicating variations in genotypes' ability to manage oxidative stress and the level of membrane damage due to lipid peroxidation. Increasing temperature increases the formation of *reactive oxygen species* (ROS), which, if not effectively reduced, can cause cellular damage. These results are in line with Kumar *et al* . (2023) who reported that under terminal heat stress (59.27–146.88 units/min / g fw), SOD activity in the tolerant genotype increased by up to 33%, while in the susceptible genotype it decreased by up to 26% compared to normal conditions, as well as Zulfugarova *et al* . (2026) who showed an increase in MDA of up to 22.8–25.1 µmol/g fw under high temperature stress conditions with higher values in sensitive genotypes. This indicates that tolerant genotypes better maintain oxidative balance and cell membrane integrity under high-temperature stress. Furthermore, high temperature stress was reported by Mirosavljevic *et al* . (2024) to cause a decrease in wheat yield of around 32-59%, thus indicating that increasing Temperature directly affects the decrease in productivity. Thus, variations in SOD activity and MDA content reflect differences in genotypes' adaptive capacity in high-temperature stress, which contributes to low yields under suboptimal environmental conditions.

Table 1. Environmental conditions during the growing season

Planting Period (Month)	Ambient Temperature (^{o}C)	Air Humidity (%)	Rainfall (mm)	Radiation Intensity (W/m ^{2})
July	27.4	73.9	72	373.2
August	29.5	68.5	137	370.3
September	28.9	75.4	278	349
October	29.7	61.7	31	381.7

Description: ^{o} C: degrees Celsius; %: percent; mm: millimeters; W/m ^{2} : Watts per square meter. Source: West Sumatra Meteorology, Climatology and Geophysics Agency (BMKG).

3.2. Malondialdehyde (MDA) Compound Levels

Malondialdehyde (MDA) levels are used as an

indicator of oxidative stress in plants and their ability to cope with oxidative stress, such as that caused by high temperatures. The results of malondialdehyde (MDA) levels in several wheat genotypes in the midlands of West Sumatra are presented descriptively in Table 2.

Table 2. Malondialdehyde compound levels of several wheat genotypes in the midlands of West Sumatra

Genotype Source	Genotype	MDA levels (µmol/ g fw)
Introduction	IS-Jarissa	2.13
Introduction	VEE	2.29
Highland Adaptive	GURI 1	3.58
Highland Adaptive	GURI 2	3.26
Highland Adaptive	GURI 3 Agritan	3.35
Highland Adaptive	GURI 4 Agritan	3.26
Highland Adaptive	Ganesha	2.61
Highland Adaptive	Gods	1.81
Adaptive Midland	GURI 7 Agritan	1.65
Convergent Cross Lines	CBF6-4	3.58
Convergent Cross Lines	CBF6-15	3.58
Convergent Cross Lines	CBF6-17	2.29
Convergent Cross Lines	CBF6-18	2.42
Convergent Cross Lines	CBF6-20	1.97

Description: Data are derived from 3 replicates per genotype, each replicate consisting of 2 samples. All samples from all replicates were composited to obtain one composite sample per genotype for analysis. Units: µmol = micromoles; g = grams; fw = *fresh weight*

Table 2 shows that malondialdehyde (MDA) levels in several wheat genotypes ranged from 1.65–3.58 µmol/g fw. This value is higher than the results of Markovic *et al*. (2020), who reported 0.74–1.24 µmol/g fw at an average temperature of 26°C. This difference is due to the higher environmental Temperature during this study, namely 27.4–29.7°C. High temperatures increase the formation of *reactive oxygen species* (ROS), thereby accelerating the occurrence of cell membrane lipid peroxidation as indicated by increased MDA content (Hasanuzzaman *et al*..(2020). The results of this study are in line with the reports of Vedi & Pandey (2024) and Markovic *et al* . (2020), who showed that high temperature stress causes an increase in MDA content in wheat plants.

Descriptively, MDA content varied among genotypes, with GURI 7 Agritan having the lowest MDA content at 1.65 µmol/g fw, while GURI 1, CBF6-4, and CBF6-15 had the highest content at 3.58 µmol/g fw. This variation indicates differences in physiological responses to high-temperature stress among genotypes. The results of this study are in line with Mohi-ud-din *et al* . (2021), who reported that MDA content in wheat increased to 33.0–67.0 nmol/g fw, or approximately 42–108% higher than optimum conditions. The greater increase in MDA content in sensitive genotypes indicates more intensive lipid peroxidation, resulting in higher levels of cell membrane damage compared to tolerant genotypes. These findings align with the results of this study, where genotypes with higher MDA content indicated greater levels of oxidative stress than genotypes with lower MDA content.

3.3. Superoxide Dismutase (SOD) Antioxidant Enzyme Activity

The superoxide dismutase (SOD) antioxidant enzyme activity test is a method for measuring how effectively plants respond to oxidative stress, one of which is caused by high temperatures. The results of the superoxide dismutase antioxidant enzyme activity test of several wheat genotypes in the midlands of West Sumatra are descriptively presented in Table 3.

Table 3 shows that superoxide dismutase (SOD) enzyme activity in several wheat genotypes ranged from 0.42–1.25 units/g fw, lower than the results of research by Altuhaish (2014), which reported SOD activity of 1.30–1.50 units/g fw in the midlands of West Java (24.7–27.5°C). The relatively low SOD activity in this study was related to the higher environmental Temperature during the growing season.

High temperatures increase ROS formation, so that under continuous stress conditions, the capacity of the enzymatic antioxidant system can decrease (Kumar *et al.* 2023). Decreased SOD activity reduces the plant's ability to detoxify superoxide radicals, increasing the risk of oxidative damage.

Descriptively, the highest SOD activity was found in the CBF6-20 genotype at 1.25 units/g fw, while the lowest activity was found in GURI 1 at 0.42 units/g fw. This is in contrast to GURI 1, which also had the highest MDA content but produced the highest yield per hectare compared to other genotypes. This difference in pattern indicates that SOD activity and MDA content observed before anthesis do not fully reflect the plant's physiological response until the yield-formation phase. These results are in line with the research of Isgandarova *et al* . (2024), which showed that SOD activity in wheat changes dynamically during grain development. SOD activity was

reported to increase from approximately 10 to 35 units/mg protein at 7–21 days after anthesis, then decreased to approximately 6 units/mg protein at 35 days after anthesis. This pattern indicates that the capacity of the antioxidant system continues to adjust during the reproductive phase, so that measurements before anthesis do not necessarily represent the physiological condition of the plant at the time of grain filling. Therefore, yield per hectare is not only influenced by SOD activity and MDA content at one growth phase, but also by the dynamics of the antioxidant system and other physiological adaptation mechanisms that occur during plant development.

Table 3. Levels of the antioxidant enzyme superoxide dismutase in several wheat genotypes in the midlands of West Sumatra

Genotype Source	Genotype	SOD activity (unit/g fw)
Introduction	IS-Jarissa	0.83
Introduction	VEE	1.24
Highland Adaptive	GURI 1	0.42
Highland Adaptive	GURI 2	0.80
Highland Adaptive	GURI 3 Agritan	1.03
Highland Adaptive	GURI 4 Agritan	1.09
Highland Adaptive	Ganesha	0.66
Highland Adaptive	Gods	0.85
Adaptive Midland	GURI 7 Agritan	0.98
Convergent Cross Lines	CBF6-4	1.07
Convergent Cross Lines	CBF6-15	0.79
Convergent Cross Lines	CBF6-17	0.88
Convergent Cross Lines	CBF6-18	1.05
Convergent Cross Lines	CBF6-20	1.25

Description: Data are derived from 3 replicates per genotype, each replicate consisting of 2 samples. All samples from all replicates were composited to obtain one composite sample per genotype for analysis. Units: g = gram; fw = *fresh weight*

Table 3 shows that superoxide dismutase (SOD) enzyme activity in several wheat genotypes ranged from 0.42–1.25 units/g fw, lower than the results of research by Altuhaish (2014), which reported SOD activity of 1.30–1.50 units/g fw in the midlands of West Java (24.7–27.5°C). The relatively low SOD activity in this study was related to the higher environmental Temperature during the growing season.

High temperatures increase ROS formation, so that under continuous stress conditions, the capacity of the enzymatic antioxidant system can decrease (Kumar *et al.* 2023). Decreased SOD activity reduces the plant's ability to detoxify superoxide radicals, increasing the risk of oxidative damage.

Descriptively, the highest SOD activity was found in the CBF6-20 genotype at 1.25 units/g fw, while the lowest activity was found in GURI 1 at 0.42 units/g fw. This is in contrast to GURI 1, which also had the highest MDA content but produced the highest yield per hectare compared to other genotypes. This difference in pattern indicates that SOD activity and MDA content observed before anthesis do not fully reflect the plant's physiological response until the yield-formation phase. These results are in line with the research of Isgandarova *et al* . (2024), which showed that SOD activity in wheat changes dynamically during grain development. SOD activity was reported to increase from approximately 10 to 35 units/mg protein at 7–21 days after anthesis, then decreased to approximately 6 units/mg protein at 35 days after anthesis. This pattern indicates that the capacity of the antioxidant system continues to adjust during the reproductive phase, so that measurements before anthesis do not necessarily represent the physiological condition of the plant at the time of grain filling. Therefore, yield per hectare is not only influenced by SOD activity and MDA content at one growth phase, but also by the dynamics of the antioxidant system and other physiological adaptation mechanisms that occur during plant development.

3.4. Yield per Hectare

Analysis of variance showed that genotype significantly affected yield per hectare at the 5% significance level. Therefore, we continued the analysis using an orthogonal contrast test to evaluate differences between genotype groups based on germplasm sources, as presented in Table 4.

Table 4 shows that yield per hectare differs significantly between genotype groups and within each genotype group. These differences occur between (1) the genotype group of introduced varieties and three other genotype groups, (3) between the genotype group of candidate convergent cross varieties and two other genotype groups, (4) within the group of candidate convergent cross varieties, namely between the CBF6-4 line and the CBF6-15, CBF6-17, CBF6-18, and CBF6-20 lines, (5) between the CBF6-15 line and the CBF6-17, CBF6-18, and CBF6-20 lines, and (9) within the genotype group of national highland adaptive varieties, namely the

GURI 1 variety and the GURI 2, GURI 3 Agritan, GURI 4 Agritan, Ganesha, and Dewata varieties.

Table 4. Yield per hectare of several wheat genotypes in the midlands of West Sumatra

No.	Sources of Diversity	Yield Per Hectare (Ton/Ha)	
1.	(A, B) vs (C, D, E, F, G, H, I, J, K, L, M, N)	0.96 ± 0.229 a	1.26 ± 0.383 b
2.	A vs B	0.82 ± 0.114 a	1.10 ± 0.241 a
3.	(C, D, E, F, G) vs (H, I, J, K, L, M, N)	0.99 ± 0.325 a	1.45 ± 0.296 b
4.	C vs (D, E, F, G)	0.71 ± 0.016 a	1.06 ± 0.329 b
5.	D vs (E, F, G)	0.68 ± 0.057 a	1.18 ± 0.276 b
6.	E vs (F, G)	1.39 ± 0.154 a	1.08 ± 0.274 a
7.	F vs G	1.26 ± 0.283 a	0.90 ± 0.101 a
8.	(H, I, J, K, L, M) vs N	1.43 ± 0.314 a	1.57 ± 0.111 a
9.	H vs (I, J, K, L, M)	1.70 ± 0.489 b	1.38 ± 0.259 a
10.	I vs (J, K, L, M)	1.53 ± 0.378 a	1.34 ± 0.227 a
11.	J vs (K, L, M)	1.34 ± 0.326 a	1.34 ± 0.210 a
12.	K vs (L, M)	1.35 ± 0.074 a	1.34 ± 0.261 a
13.	L vs M	1.17 ± 0.104 a	1.51 ± 0.273 a
	KK =	19.40%	

Caption: IS-Jarissa (A), VEE (B), CBF6-4 (C), CBF6-15 (D), CBF6-17 (E), CBF6-18 (F), CBF6-20 (G), GURI 1 (H), GURI 2 (I), GURI 3 Agritan (J), GURI 4 Agritan (K), Ganesha (L), Dewata (M), GURI 7 Agritan (N). Numbers followed by the same lowercase letter in the same row indicate no significant difference in the 5% orthogonal contrast test.

The results show variations in yield per hectare between genotype groups based on the germplasm grouping used in the study, as well as variations within the same genotype group, namely in the convergent cross-bred line group and the highland adaptive national variety group. In the highland adaptive national variety group, GURI 1 produced a yield per hectare of 1.70 tons/ha, higher than GURI 2 (1.53 tons/ha), Dewata (1.51 tons/ha), GURI 4 Agritan (1.35 tons/ha), GURI 3 Agritan (1.34 tons/ha), and Ganesha (1.17 tons/ha). However, all varieties produced lower yields per hectare compared to the average grain yield in the variety description, namely GURI 1 at 5.8 tons/ha, GURI 2 at 5.6 tons/ha, GURI 3 Agritan at 3.5 tons/ha, GURI 4 Agritan at 3.8 tons/ha, Ganesha at 5.6–6.4 tons/ha, and Dewata at 2.96 tons/ha, with a decrease of 70.7%, 72.7%, 61.7%, 64.5%, 79.1–81.7%, and 49.0%, respectively (Cereal Crop Research Institute, 2020; Cereal Crop Instrument Standard Testing Institute, 2024). This indicates that in overall, the yield per hectare of all tested genotypes remains below the average grain yield reported in the description of each variety.

Environmental conditions influence low productivity during the growing season, particularly air temperatures exceeding the optimal range for wheat growth and relatively high rainfall during the generative phase. These conditions accelerate plant development, shorten the grain-filling period, and reduce the accumulation of photosynthates in the seeds. Consequently, grain formation and filling are suboptimal, resulting in lower yields per hectare. These findings align with those of Mirosavljevic et al. (2021) and Yadav & Bhatt (2024), who stated that high-temperature stress from anthesis to grain filling is one of the main factors limiting wheat yields. This is supported by the research of Djanaguiraman et al. (2020), reporting that high temperatures during anthesis and grain filling reduced yields by 29% and 44%, respectively. According to Efderilla et al. (2024), yield per hectare is also influenced by production components, namely the number of panicles per hill, the number of seeds per panicle, the weight of 1000 grains, and the percentage of full grains.

4. Conclusion

This study shows that various wheat genotypes cultivated in the midlands of West Sumatra show variation in SOD enzyme activity (0.42 to 1.25 units/g fresh weight), MDA content (1.65 to 3.58 µmol/g fresh weight), and yield per hectare. GURI 1 produces the highest yield, at 1.70 tons/ha, making it a potentially suitable genotype for wheat development in the midlands of West Sumatra.

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