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Nutritional responses of wheat under heat stress condition

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Abstract
This study was performed to explore heat stress tolerance indices to judge terminal heat tolerance genotypes from nine wheat genotypes viz: AKAW 5023, AKAW 4927, PBN 4905, PBN 4751-02, NIAW 3523, NIAW 2891, AKAW 4210-6 (C), NIAW 34 (C), NIAW 1994 (C) at Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MH) during Rabi 2016-17 and 2017-2018. The trial was setup in RBD design with three replications. Yield and Nutritional traits were recorded and correlated with yield. Genotype NIAW 2891 noted significantly high reducing sugar (4.35%), non-reducing sugar (1.87%) in seed, exhibited more protein content (8.66%), zinc content (46.54 mg kg^{-1}), iron content (57.42 mg kg^{-1*}), manganese content (18.98 mg kg^{-1}) and copper content(3.92 mg kg^{-1}) in seed and more grain yield ha^{-1} (35.65 q/ha) followed by genotype NIAW 3523 (33.83 q/ha) during both the year and noted as heat tolerance genotypes against the best check AKAW 4210-6. Correlation analysis showed that yield under stress environment had positive significant correlate with reducing sugar content (0.687**), non reducing sugar content (0.634*), protein content (0.634*), zinc content (0.722**), iron content (0.827**), copper content (0.632*) and manganese content (0.768**) in seed. Hence, due emphasis should be given to these attributes for genetic improvement in wheat under heat stress condition.

Keywords: Heat stress, wheat, reducing & non reducing sugar, zinc, iron, manganese, copper, protein content in seed

Introduction

Wheat is a thermo-sensitive long-day crop highly influenced by temperature, with low temperatures being optimal for growth. Global climate change, projected to raise Earth's temperature by 1.5 °C in the next two decades, poses a threat to wheat. Wheat is a crucial food source for a billion people, providing 20% of total food calories in 43 countries (Khichar and Nivas 2007) [8]. It has high nutritional value, containing more protein than other cereals, essential amino acids, and valuable minerals. Wheat consumption is increasing globally due to higher incomes and urbanization, making its nutritional quality vital for human health, especially in developing countries. The grain quality of wheat is influenced by genotype, environment, and their interactions. Adverse conditions, such as extreme temperatures during anthesis and grain filling, can affect protein content and micronutrient levels.

Balanced food with sufficient calories, proteins, and micronutrients is crucial for proper growth. Around three billion people worldwide suffer from malnutrition due to micronutrient deficiencies, including iron, calcium, and zinc (Anonymous, 2000) [2]. Phytic acid, found in wheat, can limit the availability of these nutrients, leading to concerns about deficiencies (Ekhlom *et al*., 2003) [6]. Mineral nutrients play a vital role in biological systems, and the nutritional status of wheat genotypes is considered in breeding programs. Micronutrient malnutrition, particularly iron and zinc, is a global concern due to the low levels of these nutrients in staple cereals like wheat. Creating contrasting environments, such as late-sown crops exposed to higher temperatures during grain filling, helps evaluate wheat genotypes under natural field conditions and address the impact of climate change on wheat productivity.

Materials and Methods

The study was carried out during 2016-17 and 2017-18 wheat season in the research field of

Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola (M.S). Akola is situated in the subtropical zone at the latitude of 200 42' North and longitude of 770 02' East. Altitude of the place is 307.41 m above the mean sea level. Treatments were 9 wheat genotypes (AKAW 5023, AKAW 4927, PBN 4905, PBN 4751-02, NIAW 3523, NIAW 2891, AKAW 4210-6 (C), NIAW 34 (C), NIAW 1994 (C)) sown on late (December 1-10) condition in randomized block design with three replications. For late-sown conditions, management and inputs were same except the seeding date. Each unit plot size was Gross-6.0 m × 2.16 m (12 rows) and net plot size 6.0 m × 1.80 m (10 Middle rows) length of each. Seeds were sown continuously in 18 cm apart rows at a seed rate of 125 kg ha^{-1}. Recommended fertilizer doses 90:60:40 NPK kg ha^{-1} respectively was applied. Half N and a complete dose of P_2O_5 and K_2O were given as a basal dose at sowing while the remaining N was applied at 18 days after sowing. A uniform pre-sowing soaking irrigation was given to all the plots during both the experiments. In all, the crop received seven to eight need based irrigations at different critical growth stages. Intercultural operations were done properly as per WRC recommendation and when necessary. Iron, zinc, copper and manganese present in the seeds were measured using the Atomic Absorption spectrophotometer (AAS). The readings from Atomic Absorption spectroscopy were multiplied with dilution factor and readings were recorded in milligram of nutrient per 1000 gram of seed (mg/1000 g). Statistical analysis was done by employing standard statistical methods for randomized block design as suggested by Panse and Sukhatme (1967) [12] and correlation analysis was done as per the formula suggested by Karl Pearson's correlation coefficient.

Results and Discussion

Reducing Sugar content in seed (%)

Mean reducing sugar significantly increased in second year (3.76%) relative to first year (3.62%) in wheat. The 3.91% increased sugar content noticed in second year as compared to first year. The genotype NIAW 2891 (4.35%) significantly excelled all the genotypes followed by NIAW 3523 (4.19%) and AKAW 5023 (3.96%) and found *at par* with best check (3.91%). However, significantly lowest sugar content in seed were found in genotype PBN 4751-02 (3.56%), AKAW 4927 (3.44%) and PBN 4905 (3.11%).

Singh (2012) [14] stated that remobilization of sugar in leaves from flowering to maturity were least affected by heat stress. Genotypic differences were reported by Dias *et al.* (2009) [5] and Asthir *et al.* (2009) [3]. Tan *et al.* (2011) [15] revealed that, heat stress significantly increased the reducing sugar content by 47% in soybean.

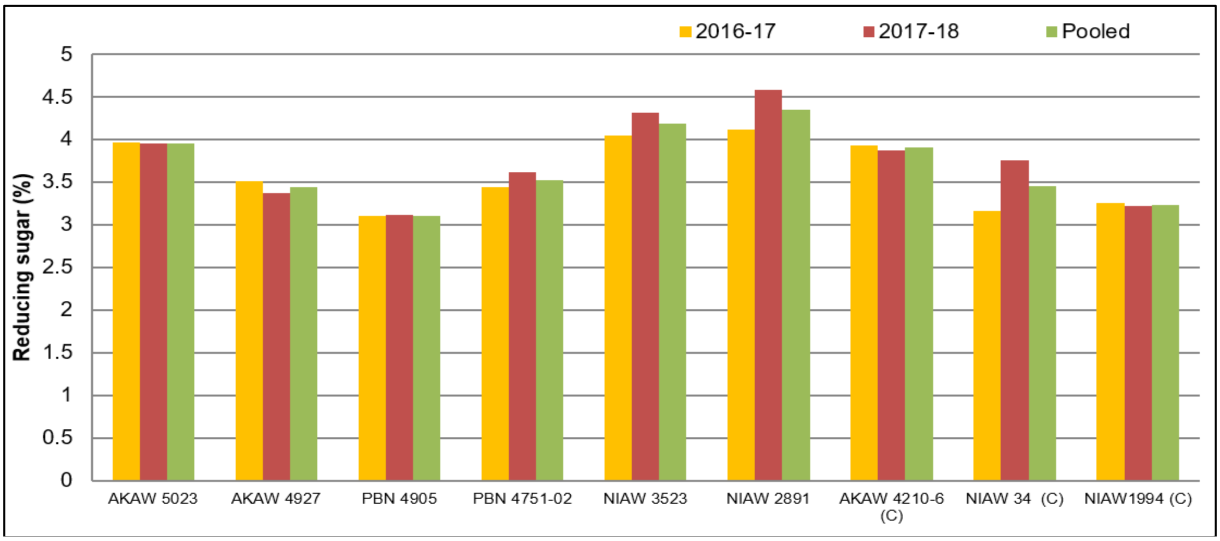

Fig 1: Effect of heat stress on reducing sugar of wheat under heat stress condition

Non reducing sugar content in seed (%)

Non reducing sugar significantly decreased in first year (1.04%) as compared to second year sown crop (1.62%). genotype NIAW 2891 (1.87%) and NIAW 3523 (1.74%) recorded maximum non-reducing sugar content in seed compared to best check AKAW 4210-6 (1.46%). Genotype AKAW 5023 (1.57%) was found *at par* with best check AKAW 4210-6 (1.46%). However, lowest values were found in PBN 4905 (0.79%), AKAW 4927 (1.18%) and PBN 4751-02 (1.23%).

Genetic tolerance to high temperature in wheat is observed at later phase of plant development i.e. shooting and heading (Wisniewaki and Zagdanska, 2001). It well known that soluble sugar play a complex essential role in plant metabolism as product of hydrolytic process, substrate in biosynthetic processes and energy production as well as in sugar sensing and signaling system (Gibson, 2005) [7].

Protein Content in seed (%)

The statistically highest seed protein content was recorded in genotypes NIAW 2891(8.66%), NIAW 3523 (8.38%), AKAW 5023 (8.15%) and PBN 4751-02 (7.28%) and found *at par* with superior check AKAW 4210-6 (7.84%) and rest of the genotypes. However, genotypes AKAW 4927 (5.88%) and PBN 4905 (4.89%) recorded significantly lowest protein content in seed in heat stress condition. About 5.76% seed protein content increased due to high temperature stress induced by late sowing.

Under heat stress, the protein content increased significantly in all genotypes. These results agree with the conclusion reached by Correll *et al.* (1994) [4] that during grain filling high temperatures (>30 °C) were related to a rise in grain protein levels. Ram *et al.* (2012) [13]. Asthir *et al.* (2009) [3] stated that protein metabolizing enzymes amino transferases are affected under high temperature stress with an increase in protein content at the cost of starch.

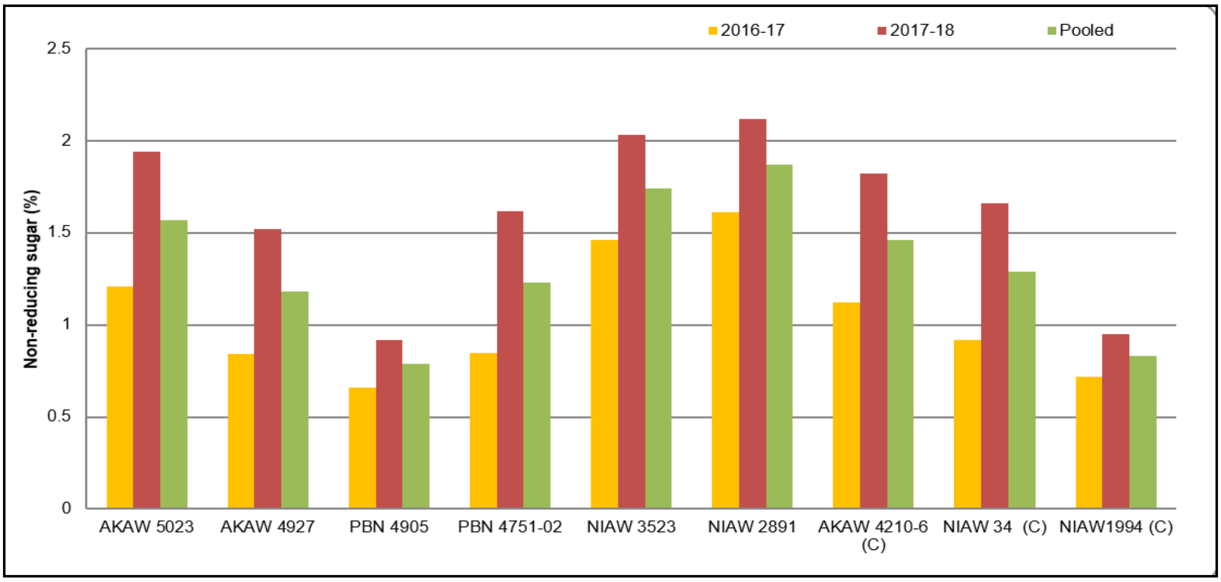

Fig 2: Effect of heat stress on non-reducing sugar of wheat under heat stress condition

Zinc Content in seed (mg/kg)

Zinc content (mg/kg) in seed after harvest significantly highest in genotypes, NIAW 2891 (46.54 mg kg^{-1}), NIAW 3523 (45.58 mg kg^{-1}) and AKAW 5023 (45.30 mg kg^{-1}) found *at par* with superior check AKAW 4210-6 (44.35 mg kg^{-1}). However, significantly least zinc content was observed in PBN 4905 (34.97 mg kg^{-1}) followed by AKAW 4927 (37.26 mg kg^{-1}) and PBN 4751-02 (40.44 mg kg^{-1}) over best check AKAW 4210-6 under heat stress condition (delayed sowing by one month). The overall 13.93% reduction occurred due to heat stress in second year over first year.

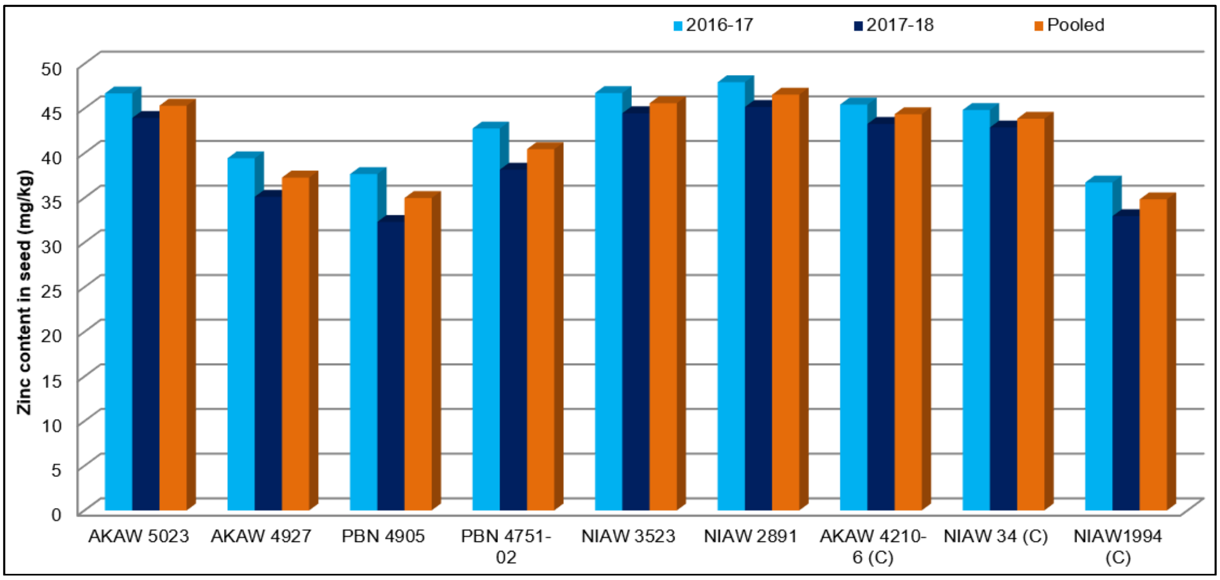

Fig 3: Effect of heat stress on zinc content in seed of wheat under heat stress condition

Iron content in seed (mg/kg)

Significantly highest seed iron content was recorded by genotypes NIAW 2891 (57.42 mg kg^{-1}) and NIAW 3523 (53.19 mg kg^{-1}) when compared with best check genotype AKAW 4210-6 (49.70 mg kg^{-1}). Genotypes AKAW 5023 (52.55 mg kg^{-1}) and PBN 4751-02 (46.72 mg kg^{-1}) remained *at par* with check AKAW 4210-6. However, significantly lowest seed iron was content noted in PBN 4905 and AKAW 4927 (39.43 and 43.85 mg kg^{-1}, respectively).

Manganese Content in seed (mg/kg)

Among wheat genotypes, under study, NIAW 2891 (18.98 mg kg^{-1}) exhibited significantly highest manganese content when compared with superior check AKAW 4210-6 (17.01 mg kg^{-1}). However, genotypes NIAW 3523 (18.18 mg kg^{-1}), AKAW 5023 (17.83 mg kg^{-1}), PBN 4751-02 (16.35 mg kg^{-1}) and AKAW 4927 (15.84 mg kg^{-1}) were found *at par* with superior check AKAW 4210-6. Significantly lowest manganese content was found in genotype PBN 4905 (14.26 mg kg^{-1}) in seed.

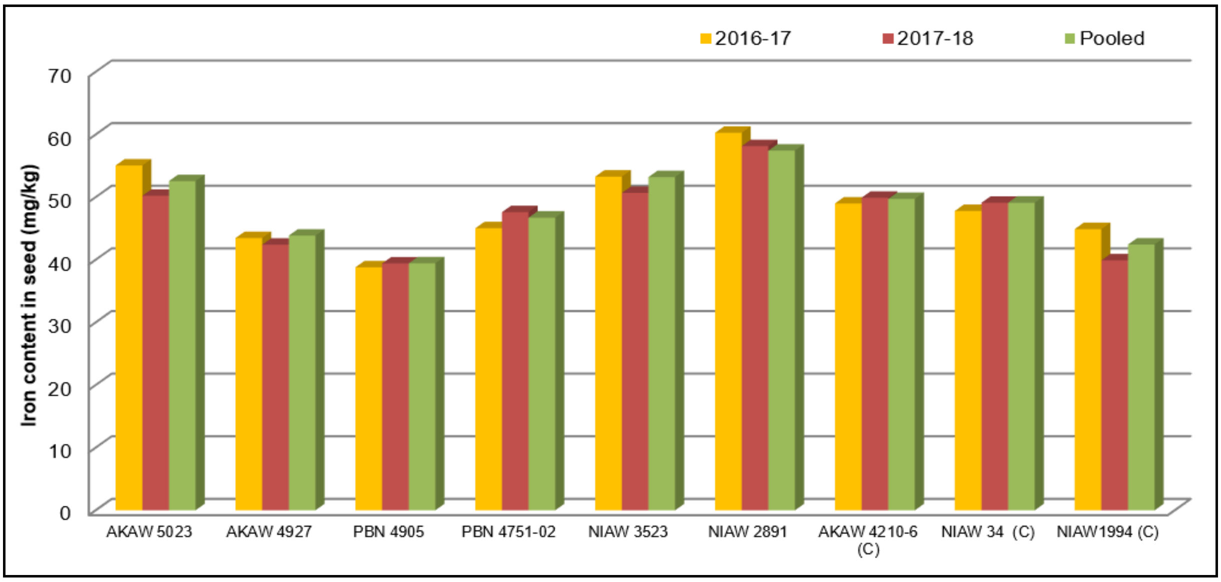

Fig 4: Effect of heat stress on iron content in seed of wheat under heat stress condition

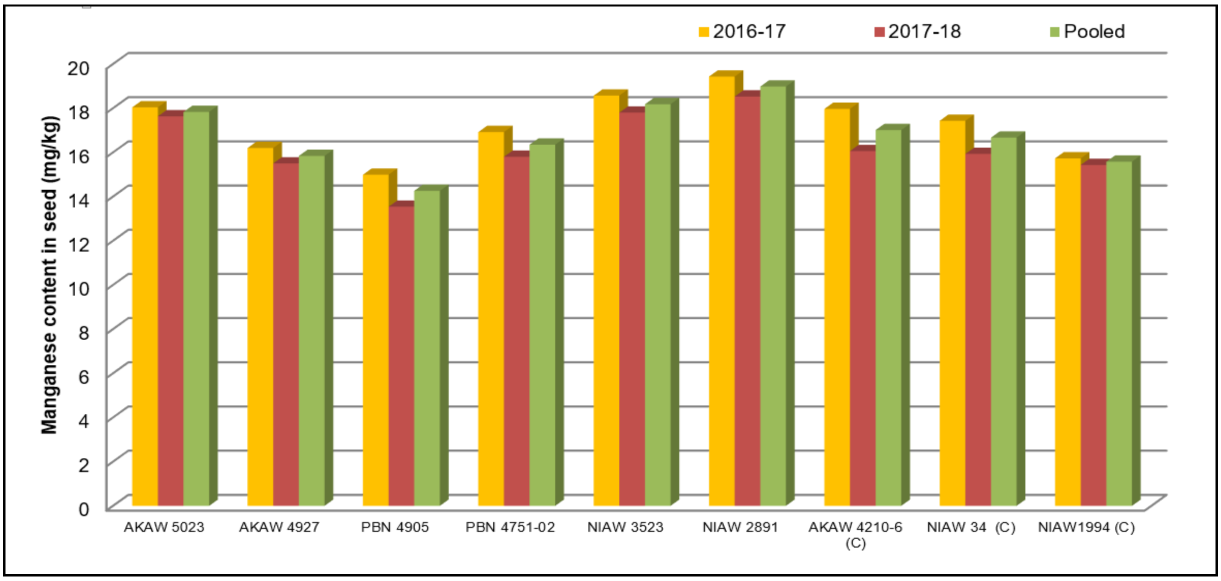

Fig 5: Effect of heat stress on manganese content in seed of wheat under heat stress condition

Copper content in seed (mg/kg)

Among the genotypes tested, the genotype NIAW 2891 (3.92 mg kg^{-1}) significantly excelled all the genotypes and superior check AKAW 4210-6 (3.41 mg kg^{-1}). While, lowest copper content was found in genotype NIAW 1994 (2.90 mg kg^{-1}) followed by PBN 4905 (3.08 mg kg^{-1}) heat stress under condition. On the basis of percent reduction in second year than first year the genotype NIAW 1994 showed the minimum percent reduction of 1.03% next to it NIAW 2891 (2.51%) and maximum percent reduction 33.51% by the genotype PBN 4905 heat stress condition.

The present investigation delayed sowing resulted in decreased micronutrients in genotypes PBN 4905 i.e. Zn-5.49%, Fe-9.24% and slightly increased Mn-8.72% and Cu-13.64% on reduction percent basis over a best check AKAW 4210-6. So under heat stress condition the genotypes NIAW 2891 and NIAW 3523 are best genotypes for breeding programs aimed at mineral biofortification in wheat grains. Amarshettiwar *et al.* (2018) [1] reported similar findings and also Singh *et al.* (2012) [14].

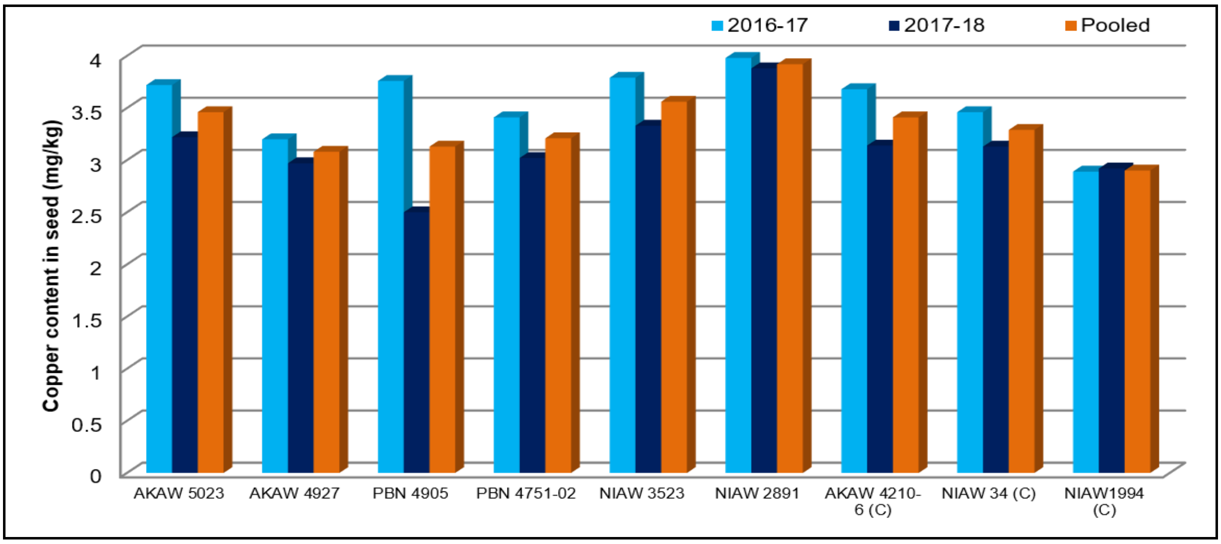

Fig 6: Effect of heat stress on copper content in seed of wheat under heat stress condition

Grain Yield

Top ranking genotype NIAW 2891 has recorded significantly highest grain yield of 35.65 qt ha^{-1} followed by NIAW 3523 (33.83 qt. ha^{-1}) over superior check AKAW 4210-6 (29.55 ha^{-1}) and among all the genotypes tested. Genotypes AKAW 5023 (31.41 qt. ha^{-1}) and PBN 4751-02 (28.39 qt. ha^{-1}) found at par with superior check AKAW 4210-6. However, significantly lowest grain yield was recorded in PBN 4905 and AKAW 4927 (22.48 and 26.66 qt. ha^{-1}, respectively) in heat stress condition. The reduction in general mean grain yield (kg ha^{-1}) to the extent of 0.11% in second year when compared with first year. Similar result has been showed by Neware *et al*. (2019) [10] and Neware *et al.* (2023) [11].

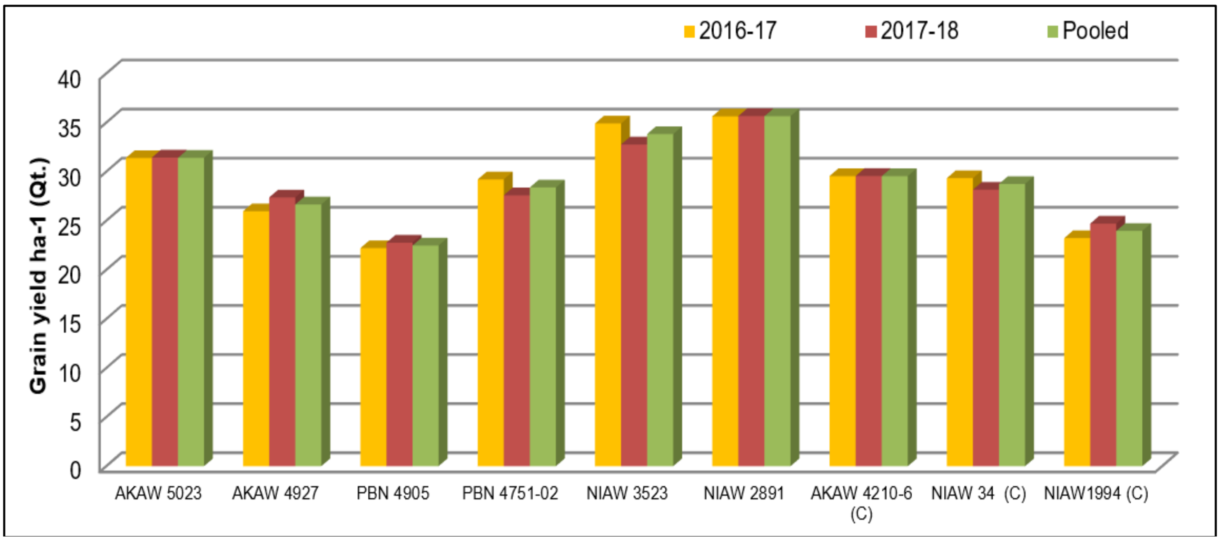

Fig 7: Effect of heat stress on grain yield ha^{-1} of wheat under heat stress condition

The correlation between nutritional parameters with grain yield are presented in Table 1 indicated that the nutritional parameters reducing sugar content in seed (0.687**), non reducing sugar content in seed (0.634*), protein percent in seed (0.634*), zinc content in seed (0.722**), iron content in seed (0.827**), copper content in seed (0.632*) and manganese content in seed (0.768**) showed positive and significant correlation with grain yield. Kumar *et al.* (2013) [9] a strong positive correlation has been observed between the non-reducing sugar accumulation and tolerance against abiotic stresses.

Table 1: Correlation study of biochemical parameters with yield of wheat under heat stress condition

	CC 30 DAS	**CC 45 DAS**	**CC 60 DAS**	**CC 75 DAS**	**Pro 30 DAS**	**Pro 45 DAS**	**Pro 60 DAS**	**Pro 75 DAS**	**POX 60 DAS**	**POX 75 DAS**	**CAT 60 DAS**	**CAT 75 DAS**	**Reducing Sugar**	**Non-reducing**	**N%**	**Protein%**	**Z**	**Fe**	**Cu**	**Mn**	**Yield/ha**
CC 30 DAS	1	0.198	-0.051	0.172	-0.097	-0.018	0.112	-0.016	0.098	0.135	0.006	-0.010	0.041	0.074	-0.013	-0.012	-0.065	-0.068	-0.140	0.041	0.053
CC 45DAS		1	0.550	0.422	0.517	0.637*	0.587*	0.527	0.791**	0.785**	0.649*	0.628*	0.526	0.811**	0.331	0.357	0.254	0.421	0.015	0.276	0.522
CC 60 DAS			1	0.417	0.400	0.638*	0.593*	0.669*	0.392	0.364	0.696**	0.613*	0.619*	0.663*	0.465	0.456	0.534	0.668*	0.366	0.547	0.716**
CC 75 DAS				1	0.306	0.499	0.305	0.414	0.412	0.334	0.428	0.384	0.382	0.513	0.424	0.433	0.378	0.352	0.205	0.401	0.513
Pro 30 DAS					1	0.653*	0.531	0.580*	0.586*	0.493	0.666*	0.693**	0.572*	0.633*	0.477	0.486	0.329	0.493	0.326	0.364	0.770**
Pro 45 DAS						1	0.679*	0.787**	0.590*	0.552	0.821**	0.835**	0.740**	0.815**	0.607*	0.621*	0.528	0.728**	0.312	0.524	0.770**
Pro 60 DAS							1	0.546	0.635*	0.621*	0.672*	0.704**	0.741**	0.779**	0.432	0.423	0.329	0.511	0.196	0.382	0.566*
Pro 75 DAS								1	0.416	0.344	0.805**	0.756**	0.758**	0.686**	0.705**	0.699**	0.635*	0.784**	0.461	0.633*	0.786**
POX 60 DAS									1	0.960**	0.597*	0.589*	0.463	0.840**	0.299	0.315	0.020	0.209	-0.167	0.030	0.321
POX 75 DAS										1	0.549	0.536	0.435	0.812**	0.221	0.236	-0.031	0.175	-0.260	-0.004	0.240
CAT 60 DAS											1	0.938**	0.820**	0.807**	0.702**	0.702**	0.623*	0.773**	0.491	0.625*	0.756**
CAT 75 DAS												1	0.844**	0.802**	0.672*	0.684**	0.560	0.735**	0.457	0.583*	0.719**
Reducing Sugar													1	0.744**	0.717**	0.690**	0.614*	0.746**	0.449	0.641*	0.687**
Non-reducing														1	0.584*	0.587*	0.412	0.595*	0.183	0.420	0.634*
N%															1	0.970**	0.730**	0.735**	0.584*	0.653*	0.631*
Protein%																1	0.732**	0.731**	0.576*	0.638*	0.634*
Z																	1	0.767**	0.686**	0.759**	0.722**
Fe																		1	0.651*	0.838**	0.827**
Cu																			1	0.782**	0.632*
Mn																				1	0.768**
Yield/ha																					1

*Significance at 5%, ** significance at 1%

Conclusion

In conclusion, the study identified NIAW 2891 as a wheat genotype exhibiting superior heat tolerance, characterized by elevated levels of reducing and non-reducing sugars, protein, and essential micronutrients in seeds. The positive correlation between grain yield under heat stress and these nutritional attributes underscores their importance. This suggests that NIAW 2891 holds promise for genetic improvement in heat-tolerant wheat varieties with enhanced nutritional quality, addressing challenges associated with rising temperatures in wheat-growing regions.

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