Agriculture and Food Sciences Research
Vol. 11, No. 1, 30-35, 2024
ISSN(E) 2411-6653/ ISSN(P) 2518-0193
DOI: 10.20448/aesr.v11i1.5486

Agro-morphological analysis of yield and yield attributing traits of wheat under heat stress condition

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Abstract

Wheat is the most important cereal crop worldwide and ranks third in Nepal. Improvements in wheat yield can be done effectively by selection for yield attributing traits. In this experiment, twenty wheat genotypes were evaluated in the terai region of Nepal at Paklihawa, Rupandehi in Alpha lattice design under heat stress conditions. The characters were evaluated to find their correlation and direct and indirect effects on yield. Positive significant correlation of grain yield with No. of spikes m-2 (0.405) and harvest index (0.647) were found whereas Spike weight (-0.322) showed a significant negative correlation with grain yield. Similarly, Path analysis showed that the Harvest index (0.5511) and No. of spikelets per spike (0.3365) had a high direct effect, whereas Thousand kernel weight, Spike m-2, and Plant height showed a lower positive direct effect on grain yield. Ten spikes weight, spike length, and No. of grains per spike showed low negative direct effects. The conclusions drawn from this analysis can be useful for breeding programs under heat stress by providing information on which characteristics significantly affect the yield. However, multi-locations and multi-year trials need to be done for further verifications on the selection of such traits for improving yield.

Keywords: Correlation, Heat-stress, Path-coefficient analysis, Plant breeding, Selection, Wheat parameters.

Citation | Bhattarai, P., Gyanwali, P., Pokharel, N. P., Bashyal, P., Mainali, R., & Khanal, R. (2024). Agro-morphological analysis of yield and yield attributing traits of wheat under heat stress condition. *Agriculture and Food Sciences Research*, *11*(1), 30–35. 10.20448/aesr.v11i1.5486
History:
Received: 27 December 2023
Revised: 30 January 2024
Accepted: 15 February 2024
Published: 21 March 2023

Publisher: Asian Online Journal Publishing Group

Funding: This research is supported by Institute of Agriculture and Animal Science, Pakhlihawa Campus, Tribhuvan University (Grant number: 21-1104).
Institutional Review Board Statement: The Ethical Committee of the Institute of Agriculture and Animal Science, Pakhlihawa Campus, Tribhuvan University, Nepal has granted approval for this study on 21 August 2023 (Ref. No. 15 0823).
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Contents

Contribution of this paper to the literature
This paper builds on the existing knowledge of wheat breeding and helps guide wheat breeding by providing information regarding the major parameters that have the maximum effect on wheat yield. It helps highlight the parameters to look out for and prioritize during selection.

1. Introduction

1.1. Background

Wheat is one of the most important crops in the world, providing a staple diet for 2 billion people [1]. It accounts for 28% of world cereal production and 41.5% of all cereal trade globally [2]. It was cultivated on 215.9 million hectares worldwide in 2019, yielding 765.8 million tonnes with productivity of 3.54 mt/ha [3]. Wheat is the third most cultivated cereal after rice and maize in Nepal. The area, productivity, and production of wheat in Nepal are 711ha, 2.99 mt/ha, and 2,127,276 mt respectively [4]. The wheat productivity in Nepal is far behind compared to a nation like New Zealand with a high productivity status [5].

Wheat accounts for about 55% of all carbohydrates and 20% of all food calories consumed worldwide [1]. The demand for wheat is expected to rise by 60% in 2050 [6]. Increment in wheat production by 2% annually is needed to fulfill this demand [7]. The developing nations should increase their wheat production by 77% to meet future demands [8]. This emphasizes various crop improvement practices for increment of both production and productivity as a necessity of the 21st century [9]. This can be accomplished by producing high-yielding, climate-smart, and stress-tolerant varieties of wheat by intense selection under field circumstances [10].

The average global temperature has increased by 1.04°C between 1880 to 2019 [11]. The temperature is estimated to increase further by 1.5°C in the next twenty years [12]; so, global wheat production is predicted to fall by 6% for every 1°C rise in temperature [13]. The impact of Heat stress is determined by the length and severity of the stress, along with genetic factors [14]. Terminal heat stress in wheat is observed when the mean temperature exceeds 31°C at the grain-filling stage [15]. Increment of 1°C average temperature during March and April causes a seven-day reduction in the length of the wheat crop and a yield decrease of around 400 kg/ha [16]. The Terai region of Nepal has a significant temperature increase starting in mid-March, which coincides with anthesis and is subject to scorching winds from the west [17]. It was reported that the maximum temperature rose by 1 °C in the Terai region of Nepal over the previous 25 years which will be detrimental to wheat cultivation in the future [18].

Yield is a complex quantitative trait that is considerably affected by, and depends on the environment. The selection of genotypes based on various components of yield is effective in comparison to the selection regarding yield alone [19]. The study aims to understand the relationship between various components of 20 wheat genotypes and the yield in heat stress conditions. The associations will help determine the most important characters affecting the yield and set a standard selection guide of traits to look out for selection.

1.2. Statement of Problem

The major physiological functions like chlorophyll degradation and photosynthesis are affected by heat stress condition [20]. The grain filling period , pollen abortion, poor seed set are also observed under this condition [21]. It is estimated that a 1°C increase in temperature would result in a 6% decrease in global wheat yield [5]. Increased temperature in the future will hugely impact the yield of wheat worldwide [22]. Research activities exploring the relationship between yield and yield attributing characters among various genotypes have been conducted by numerous researchers, but only a few have been conducted under a heat-stress environment, especially in the western region of Nepal. This will help us in creating an efficient selection of genotypes under heat stress condition.

1.3. Rationale of Study

Heat stress resulted in a total of 36.03 billion in wheat yield loss in the year 2020 in the context of Nepal [9]. The development of wheat genotypes with high yield potential and the capacity to sustain output in all conditions, including heat stress, is one of the key objectives of wheat breeders. But, the practice of unilateral selection for agronomic features and inadequate understanding of the interactions between multiple characters usually leads to unsatisfactory results in wheat breeding. Hence, this study is performed to determine which characteristics have a significant impact on wheat output. Plant breeders would then be able to prioritize these traits for further yield enhancement, as the study of yield-contributing components concerning their genetic mechanism is very important for yield improvement.

2. Materials and Methods

Twenty wheat genotypes including 15 Nepal-lines (NL), 3 Bhairahawa-lines (BL) and 2 check varieties i.e. Bhrikuti and Gautam, were collected from National Wheat Research Program, Bhairahawa. The research was conducted in Paklihawa campus, Rupandehi, during 2021-2022.

Yield and yield attributing traits like Plant height (Ph), Spike length (SL), Spike weight (SW), Spikes per m^2 area (SPMS), Number of grains per spike (NGPS), Number of spikelets per spike (NSPS), Thousand kernels weight (TKW) and Harvest Index (HI) were noted from ten randomly selected plants per plot.

Agro-meteorological data were recorded at the experimental site from 26th December 2021 to 17th April 2022, and average was found as in Figure 1. Line sowing of seeds was done on 26th December, so as to reach the reproductive stage of wheat in the hot weather of April inducing heat stress condition.

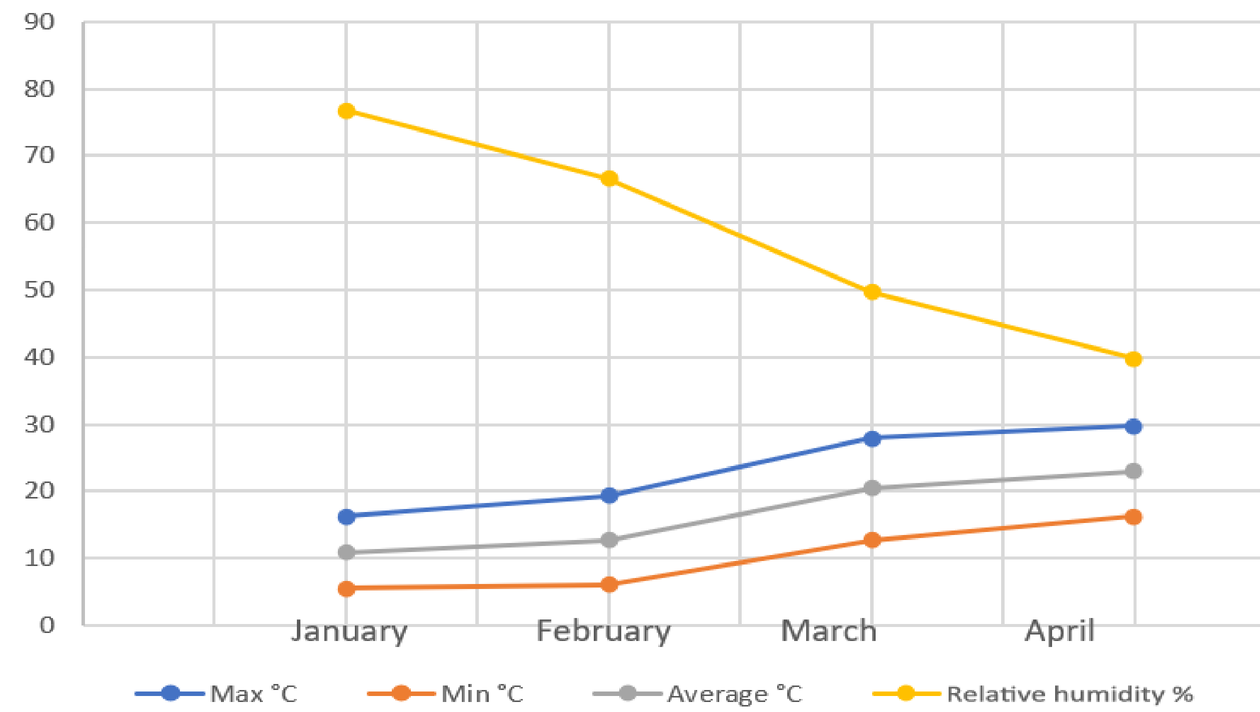

Figure 1. Agro-meteorological data of temperature and relative humidity recorded at the site of experiment through crop period.

The experiment was carried out in alpha-lattice design replicated twice with five blocks Figure 2. One meter space was maintained between two replications. The plot size was maintained at 4m*2.5m each.

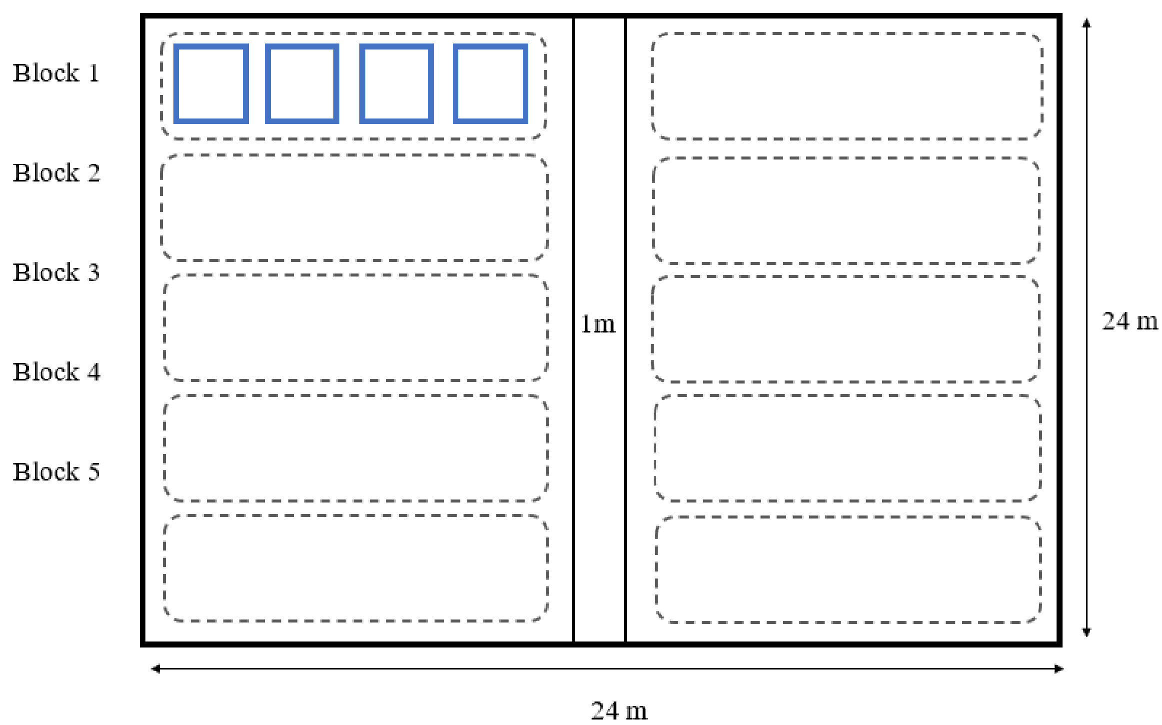

Figure 2. (Alpha lattice design) layout of the field.

Data entry was done by using Microsoft Excel Spreadsheet Software. SPSS version 25 and Microsoft Excel were used to perform co-relation and path coefficient analysis.

3. Result and Discussion

3.1. Correlation

The association of grain yield and yield attributing traits are presented in Table 1. Plant height showed a positive correlation with NSPS, SW, SPMS and a negative correlation with NGPS, TKW, GY, and HI. Dwarf wheat varieties increase lodging resistance which leads to higher nitrogen use efficiency. Wheat plants tend to use stem reserve when they are under heat stress thus developing a positive correlation with yield [23]. It was found that selecting dwarf plants with thick stems may boost yield when coping with late heat stress [23]. Plant height was found to have a positive correlation with all studied traits except maturity, grain yield, and harvest index for both genetic and phenotypic levels [24].

Number of grains per spike showed a highly positive significant correlation with NSPS (0.68), and SW (0.58) and a non-significant positive correlation with SL, and SPMS. It showed a significant negative correlation with TKW (-0.33) and a non-significant negative correlation with PH, GY, and HI. It was found that NGPS showed a positive and highly significant correlation with SW and NSPS [25].

Table 1. Correlation of different wheat parameters.

Parameters	Ph	NGPS	NSPS	SL	SW	TKW	GY	SPMS	HI
Ph	1	-0.044	0.071	0.299	0.125	-0.232	-0.026	0.026	-0.114
NGPS	-0.044	1	0.685**	0.290	0.587**	-0.330*	-0.177	0.045	-0.216
NSPS	0.071	0.685**	1	0.442**	0.460**	-0.212	0.037	0.177	-0.175
SL	0.299	0.290	0.442**	1	0.510**	0.104	-0.172	-0.222	-0.091
SW	0.125	0.587**	0.460**	0.510**	1	0.119	-0.322*	-0.293	-0.252
TKW	-0.232	-0.330*	-0.212	0.104	0.119	1	0.229	-0.160	0.263
GY	-0.026	-0.177	0.037	-0.172	-0.322*	0.229	1	0.405**	0.647**
SPMS	0.026	0.045	0.177	-0.222	-0.293	-0.160	0.405**	1	0.123
HI	-0.114	-0.216	-0.175	-0.091	-0.252	0.263	0.647**	0.123	1

Note: Ph= Plant height, NGPS= Number of grains per spike, NSPS= Number of spikelets per spike, SL= Spike length, SW= Ten spikes weight, TKW= Thousand kernels weight, GY= Grain yield, SPMS= Number of spikes per m^2.
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Number of spikelets per spike showed a significantly high positive correlation with SL (0.44), SW (0.46), and NGPS (0.68) and a non-significant positive correlation with PH, GY, and SPMS. It showed a negative correlation with TKW, and HI. A similar relationship of NSPS with SW and NGPS was found by Thapa, et al. [25].

Spike length showed a significantly high positive correlation with NSPS (0.44) and SW (0.51). It showed a non-significant positive correlation with PH, NGPS, and TKW. It exhibited a negative correlation with GY, SPMS, and HI. It was shown that SL had a positive and highly significant correlation with SW but in contrast, it had a negative and highly significant correlation with NSPS [25].

Spike weight showed a highly significant positive correlation with NGPS (0.58), NSPS (0.46), and SL (0.51) and a non-significant positive correlation with TKW, and PH. It showed a significant negative correlation with GY (-0.32) and non-significant negative correlation with HI. Heat stress accelerates the spike development process resulting in fewer grains and reduced harvest index [26].

Thousand kernel weight showed a significantly negative correlation with NGPS (-0.33) and a non-significant negative correlation with PH, NSPS, and SPMS. It showed a positive correlation with SL, SW, GY, and HI. There is a decrement in the life cycle of the wheat crop under heat stress [26]. This results in a reduction of the grain filling period [27]. This lowers the thousand kernel weight and grain size, degrading the quality of the seed and its yield [28].

Grain yield showed a significantly negative correlation with SW (-0.32) and a non-significant negative correlation with PH, NGPS, and SL. It showed a highly significant positive correlation with SPMS (0.40) and HI (0.64) and a non-significant positive correlation with TKW. In another research, it was found that grain yield showed a significantly positive correlation with harvest index and spike per meter square which is similar to our finding [29].

Number of spikes per m^2 showed a negative correlation with SL, SW, and TKW. It showed a highly significant positive correlation with GY (0.40) and a non-significant positive correlation with PH, NGPS, NSPS, and HI.

Harvest Index showed a negative correlation with PH, NGPS, NSPS, SL, and SW. It showed a highly significant positive correlation with GY (0.64) and a non-significant positive correlation with TKW, and SPMS. It was found that the Harvest index showed a significant negative correlation with NSPS but in contrast, it showed a significant negative correlation with grain yield [30].

3.2. Path Coefficient Analysis

The path coefficient analysis helps us determine the direct and indirect effects of the yield parameters and quantifies their role over one another. The positive and negative values of parameters determine the direction of yield, whether it increases or decreases when there are changes in the parameters.

Table 2. Path Coefficient analysis of different wheat parameters.

Parameters	Ph	NGPS	NSPS	SL	SW	TKW	SPMS	HI	Correlation with yield
Via Ph	**0.146**	-0.006	0.01	0.044	0.018	-0.034	0.004	-0.017	-0.026
Via NGPS	0.001	**-0.026**	-0.018	-0.008	-0.016	0.009	-0.001	0.006	-0.177
Via NSPS	0.024	0.23	**0.336**	0.149	0.155	-0.071	0.06	-0.059	0.037
Via SL	-0.052	-0.05	-0.077	**-0.174**	-0.089	-0.018	0.039	0.016	-0.172
Via SW	-0.028	-0.129	-0.101	-0.112	**-0.22**	-0.026	0.065	0.055	-0.322
Via TKW	-0.06	-0.085	-0.055	0.027	0.031	**0.259**	-0.041	0.068	0.229
Via SPMS	0.005	0.009	0.038	-0.047	-0.063	-0.034	**0.213**	0.026	0.405
Via HI	-0.062	-0.119	-0.096	-0.05	-0.139	0.145	0.068	**0.551**	0.647

Note: Ph= Plant height, NGPS= Number of grains per spike, NSPS= Number of spikelets per spike, SL= Spike length, SW= Ten spikes weight, TKW= Thousand kernels weight, GY= Grain yield, SPMS= Number of spikes per m^2.

Direct effect of yield attributing character (bold in Table 2) showed that HI had the highest positive direct effect (0.55114) on the grain yield. Following the HI, exhibiting the second highest positive direct effect is NSPS (0.33647). Likewise, TKW (0.25882), SPMS (0.21340), and Ph (0.14572) had similar direct positive effects. Confirmatory similar positive results were also obtained by Meena, et al. [31]. The other parameters showed a negative direct effect on yield, where NGPS showed the lowest direct effect (-0.0266), followed by SL (-0.17366) and SW (-0.22019). Contradicting results regarding Ph and SL were obtained by Mohanty, et al. [23]. Likewise, positive direct effects by NGPS and Ph on grain yield were obtained by Oliveira, et al. [32]. The direct effects have a greater possibility of determining the outcome while selecting the yield as they do not depend upon the other parameters. The traits or parameters whose direct effect value is close to the correlation coefficient value, usually have little to no indirect effect on the grain yield. This suggests that selection for such traits is beneficial and much more effective in observing the improved grain yield [33]. The traits having positive correlation with the yield but no positive direct effect is not considered while selecting for the improved yield since other traits are responsible for the yield indirectly [34].

The indirect effects weren't as pronounced as the direct effects, with the majority having a nearly negligible magnitude. The highest positive indirect effect on yield was shown by NGPS via NSPS (0.23048), followed by SW via NSPS (0.15478), SL via NSPS (0.14872), and TKW via HI (0.14495). The highest negative indirect effect on yield was shown by SW via HI (-0.13889), followed by NGPS via SW (-0.12925), NGPS via HI (-0.11905), SL via SW (-0.1123), and NSPS via SW (-0.10129). The other indirect effects on yield had low values. Partial similar results were obtained by Kayastha, et al. [35].

4. Conclusion

The grain yield has a positive correlation with SPMS and harvest index, which also showed high direct effects through the path coefficient analysis. Therefore, selection should be done in favor of these yield parameters to increase the overall yield of the wheat crop in the given environment condition. Grain yield has a negative correlation with spike weight, plant height, number of grains per spike & spike length. The path coefficient analysis showed the highest negative direct effects on grain yield by spike weight. Therefore, it is suggested that we avoid selecting genotypes with higher value of SW during selection. The indirect effects on grain yield weren't profound in magnitude as the direct effects, however, the highest positive and negative indirect effects were shown by the number of grains per spike via number of spikelets per spike, and spike weight via harvest index.

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