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IMPROVING GRAIN YIELD AND NITROGEN USE EFFICIENCY IN TWO WHEAT CULTIVARS BY BIOCHAR AND NITROGEN APPLICATION TIMING

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ABSTRACT

Use of biochar and nitrogen application timing might be an effective strategy to improve soil properties and increase wheat yield, especially in sandy soils. Giza 171 cultivar exhibited uppermost grain yield, almost yield attributes, nitrogen uptake efficiency (total-NUpE) and nitrogen use efficiency (NUE) followed by Shandwel 1. Biochar application at 6 Mg ha^{-1} significantly increased grain yield and almost yield attributes, total-NUpE and NUE compared with the control treatment. Adding N fertilizer at T2 (10,25,40,55 and 70 days after sowing, DAS) or T3(10,30,50,70 and 90 DAS) had greatly improved grain yield and yield attributes and nitrogen use efficiencies comparing with T1(10,20,30,40 and 50 (DAS) treatment. The interaction between N application timing at T2 and application of 6 Mg biochar ha^{-1} produced the maximum grain yield (7.23 Mg ha^{-1}) and NUE (55.37 kg kg^{-1}) when Giza 171 was used. Path coefficient analysis showed that spike length and number of spikes m^{-2} had exerted positive and high direct effect on grain yield of wheat (0.343 and 0.436), while flag leaf area and number of fertile spikeletes spike^{-1} had positive but moderate direct effect on wheat grain yield (0.280 and 0.201).

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most vital cereal crop in the human life, because it is rich in mineral, gluten and fiber contents and one of the greatest strategic crops in Egypt, but Egypt became the largest wheat importing in the world **(Asseng *et al.*, 2018)**. In 2020-2021, Egypt imported about 12.85 million ton of wheat, and expected to rise to 12.9 million ton **(USDA, 2021)**. However, there is still a large gap between consumption and production, which reaches 9 million ton, due to the rapid population growth, so increasing wheat productivity is an essential national aim to fill the gap which increased to 16 million ton **(FAO Statistics Division 2019)**. Increasing wheat productivity can be achieved by breeding and cultivating the promising wheat cultivars, fertilizer use efficiency and increasing the newly reclaimed lands to expand the cultivated wheat area, **(FAO Statistics Division, 2019 and Niel, 2021)**. Sandy soils in Egypt are poor fertility. Therefore, sandy soil's unsuitable chemical and physical properties could be improved with applying soil amendments that retain soil moisture and recycle soil nutrients **(Mancy and Sheta, 2021)**.

Improve crop production and fertilizers use efficiency is a main strategy of sustainability. Biochar is a carbon rich product that is resulted from the pyrolysis of organic materials at high temperatures and under exiguous of oxygen **(Ronsse *et al.*, 2013)**. Various strategies are introduced by intensive study to reduction fertilizers

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losses and improve NUE by use organic sources as biochar **(El-Sobky and Abdo, 2021)**. Biochar has become a subject of scientific interest as an amendment for soil improvement **(Kraska *et al.,* 2016)**. **Kuppusamy *et al.* (2016)** showed that, biochar could potentially applications in ability to enhance crop production and soil properties. Therefore, the application of biochar positively influences many soil properties, *i.e*. reduces soil infiltration rate, improves soil structure, increase soil moisture content and increase the availability of nutrients, especially nitrogen (N) and phosphorous (P) **(Adekiya *et al.,* 2019; Farrar *et al.,* 2019)**. In this regard, **El-Naggar *et al.* (2019)** mentioned that the role of biochar in enhancement of crop production could be categorized to soil quality, nutrient cycling and N. Biochar increases activity of microbial, water retention, stimulate crop growth and availability of soil nutrient because of its great surface area and nature of porous **(Arabi *et al.,* 2018; Nie *et al.,* 2018; Razzaghi *et al.,* 2020; Li *et al.,* 2022)**.

Nitrogen (N) as essential element has conspicuous role in a plant metabolism and it also increases the formation of proteins, chlorophyll, as well as, grain yield. **Avlin *et al* (1999)** reported that nitrogen (N) application during grain fill is required to maximize grain yield. Applying excess nitrogen (N) than crop's requirement can result unavailable N to the crop through immobilization, leading to decrease recovery of nitrogen (N) fertilizer by a crop **(King *et al.,* 2001)**. Nitrogen (N) loses through gaseous emission, soil volatilization and leaching, so split nitrogen (N) application is necessary **(Gad *et al.,* 2018)**. Nitrogen (N) fertilizer application increased significantly growth attributes, grain and straw yields of wheat **(Gad *et al.,* 2018; Tian *et al.,* 2020; Marco *et al.,* 2021; Benchelali *et al.,* 2022)**.

On other hand, **Chaudhary and Joshi, (2005)** reported that, path analysis provides information about direction of direct and indirect effects of the grain yield attributes. Studies have reported that plant height, flag leaf area, number of spikes m^{-2}, spike length, number of spikelets/ spike, grain weight/ spike, biological yield, and harvest index "HI" had positive direct effect on grain yield indicating the relationship between these traits as good contributors to grain yield **(Mecha *et al.,* 2017; Sabit *et al.,* 2017; Baye *et al.,* 2020; Dayem *et al.,* 2021)**.

Therefore, the current study aimed to investigate the interactive impacts of biochar supply and N application timing on performance of two wheat cultivars and nitrogen use efficiencies as well as identify the relationship between grain yield and its relevant characters in sandy soil under semi-arid environmental conditions.

MATERIALS AND METHODS

Experimental Site and Agricultural Practices

Field experiment was conducted on the experimental farm of Faculty of Agriculture "El-Khattara", Zagazig University; 30°36′N, 32°16′E, Sharkia Governorate Egypt, during 2018-2019 and 2019-2020 growing seasons. Sowing took place on mid-November in the two growing seasons. Physical and chemical analyses of soil were carried according to **Black and Hartge (1968) and Jackson (1973)**. The soil was sandy throughout the profile (92.98% sand, 5.75% silt and 1.27% clay) with a slightly alkaline pH of 8.15. During the two seasons, the organic matter and EC were 0.42% and 0.6 dS m^{-1}, respectively. In addition, available nutrients were 6, 76 and 23 mg kg^{-1} soil for P, K and N, respectively. Temperature is around 15-25^{o}C with precipitation of 62 mm that was distributed during the study seasons from November to April. Potassium was applied at the rate of 115 kg K_2O ha^{-1} as potassium sulphate

(48% K_2O) in one dose with the first dose of N fertilizer. Phosphorus was added during seedbed preparation at rate of 75 kg P_2O_5 ha^{-1} as super-phosphate (15.5% P_2O_5), N was applied with rate of 240 kg N ha^{-1} as ammonium sulphate (20.5% N) which was added in five equal doses. The agronomic practices including weed control, pest and disease and sprinkler irrigation were applied as recommended for wheat production in the region.

Plant Material and Experimental Design

The design of the experimental was split-split plot in three replicates. The main plots were randomly occupied by the two wheat cultivars (Giza 171 and Shandwel 1). The sub-plots were assigned for the two biochar treatments *i.e.* (i) check (without-adding) and (ii) 6.0 Mg ha^{-1}. Sub-sub plots were devoted for the three N application splitting regimes, *i.e.*, T_1 (10, 20, 30, 40 and 50 days after sowing (DAS), T_2 (10, 25, 40, 55 and 70 DAS and T_3 (10, 30, 50, 70 and 90 DAS. Each plot included 10 rows, each of 0.15 m apart and 4-m long and seeding rate was 400 grains m^{-2} for the two cultivars. Biochar was prepared using rice straw, dried and pyrolized at 450°C for 4 hr (**Jindo *et al.*, 2014**). Biochar was incorporated in soil before sowing wheat. Biochar analysis carried according to **Gai *et al.* (2014) and Malav *et al.* (2015)** total carbon (79.3%), pH (8.4), total N (0.7%), P_2O_5 (1.1%) and K_2O (5.3%).

Measured Traits

At heading, random samples of 10 plants were taken from each plot to determine the following traits; plant height (cm) "the distance in centimeters from ground to the top of spike", chlorophyll content (SPAD value) was estimated using SPAD-502 chlorophyll meter **(Castelli *et al.*, 1996)** and flag leaf area (cm^2) was determined according to **Voldeng and Simpson (1967)**.

At physiological maturity on end of April. Number of spikes was counted in 1.0 m^2. Spike length (cm), number of grains spike^{-1}, number of fertile spikeletes spike^{-1}, 1000-grain weight and grain weight spike^{-1} (g) were measured from 10 randomly spikes in each plot. Grain, straw and total yields (Mg; "ton") were estimated by harvesting 2.0 m^2 from each plot and then converted per hectare. HI (%) *i.e.*, grain to total yield in percentage was estimated. Grain yield was adjusted to 13.0% moisture content.

Samples of grain and straw were dried at 70°C for 72 h until constant weight and total N was determined according to **Jackson (1973)**, using micro-Kjeldahl method. Crude protein yield (kg ha^{-1}) was estimated by multiplying grain yield by grain protein content. Total N accumulation (TNA; kg N ha^{-1}) was considered as straw N uptake plus grains N uptake. N utilization efficiency (grain-NUtE; kg kg^{-1}) was estimated as the ratio of grain yield to TNA (**Moll *et al.*, 1982**). N uptake efficiency (total-NUpE; kg kg^{-1}) was calculated as the ratio of TNA to amount of total N (available N from the soil and applied fertilizer). N use efficiency (NUE; kg kg^{-1}) was estimated as the ratio of grain yield to total N.

Statistical Analysis

Data were analyzed according to **Gomez and Gomez (1984)**. Treatment means were compared using Least Significant Differences (LSD) test at 0.05 level of probability (**Waller and Duncan, 1969**). Statistical analysis was performed by using analysis of variance technique using MSTAT-C statistical package (**Freed, 1991**). The error mean squares of split-split plot design were homogenous (Bartlett's test), therefore the combined analysis was calculated for all the studied characters in both seasons.

RESULTS AND DISCUSSION

Yield and its Attributes

Analysis of variance displayed highly significant effects of cultivars, biochar rates, N application timing and their interaction on yield and its attributes of wheat (Tables 1 and 2). Results outlined in Tables 1 and 2 clear that cultivars differed significantly in all yield traits and its attributes, Giza 171 cultivar significantly surpassed Shandwel1 cultivar in most traits, plant height (114.8 cm), flag leaf area (35.54 cm), chlorophyll content (44.88), spike length (12.88 cm), number of fertile spikelets spike^{-1} (20.91) number of spikes m^{-2} (468.9), grain weight spike^{-1} (1.91 g), 1000-grain weight (37.19 g), grain yield (6.24 Mg ha^{-1}), straw yield (10.48 Mg ha^{-1}), total yield (16.72 Mg ha^{-1}), HI (38.21%) and crude protein yield (720.9 kg ha^{-1}). Whereas, Shandwel 1 cultivar outnumber significantly Giza 171 in grains spike^{-1} (54.81). The variation between the tested wheat cultivars may be ascribed to the slight differences in their genetic makeup and their response to the environment. Varietal differences in grain yield, total yield and protein yield were also corroborated by **Gomaa *et al.* (2018) and Ibrahim *et al.* (2022)**. Similar results have been reported by **Shaalan *et al.* (2019) and Moustafa *et al.* (2021)**. Effective and significant impact of biochar rate on yield and its attributes of bread wheat in combined analysis noted in the two seasons (Tables 1 and 2). Results indicated that application biochar at 6 Mg ha^{-1}, significantly increased the studied traits of wheat yield compared with the check treatment (untreated). Where, application biochar caused operative increment in plant height (110.2 cm), flag leaf area (35.67 cm), chlorophyll content (45.02), number of fertile spikelets spike^{-1} (20.71), number of spikes/m^{2} (430.2) and number of grains spike^{-1} (54.81). On the contrary, non-application of biochar exiguously affected the six traits previously mentioned, the shortest plants (109.3 cm) and smaller flag leaf area (33.65 cm) except spike length was the highest (12.22 cm), fewer chlorophyll content (42.6), number of fertile spikelets spike^{-1} (20.15), number of spikes m^{-2} (399.6) and number of grains spike^{-1} (52.87). Likewise, addition of biochar increased each of grain weight spike^{-1} and 1000-grain weight, grain yield, straw yield and total yield, HI and crude protein yield, with values of (13.09, 8.76, 6.68, 6.67, 6.67, 1.58 and 9.27%, respectively). The beneficial impacts of biochar addition on yield and its attributes may be determined by improves in soil fertility and its properties **(Chan *et al.*, 2007; Sohi *et al.*, 2010)**.

Also, **Hogan (2011)** quoted that biochar improved the soil properties and photosynthetic rate. Also, **Joba *et al.* (2022)** avouched that, biochar amendment affected soil nutrient. Furthermore, biochar application enhances crop growth, improve soil fertility because of its great surface area **(Arabi *et al.*, 2018; Nie *et al.*, 2018; Razzaghi *et al.*, 2020; Li *et al.*, 2022)**. The results revealed that N application timing significantly affected on grain yield and most of its attributes (Tables 1 and 2). The T3 treatment gave the highest plant height (112.4 cm), flag leaf area (41.39 cm^{2}), chlorophyll content (48.11), spike length (12.44 cm), grain weight spike^{-1} (1.92g) and HI (39.86%) followed by T2 and T1 treatments. While, the maximum number of fertile spikeletes spike^{-1} (20.70), number of spikes m^{-2} (461.1), number of grains spike^{-1} (56.42), 1000-grain weight (37.75 g), straw yield (10.96 Mg ha^{-1}), total yield (17.02 Mg ha^{-1}) and crude protein yield (680.3 kg ha^{-1}) values were obtained under T2 treatments. N application at T2 or T3 had analogues intrinsically effect on improving grain yield (6.06 and 6.07 Mg ha^{-1}) comparing with T1 treatment (4.37 Mg ha^{-1}).

Table 1. Influence of biochar rate and nitrogen application timing on plant height, flag leaf area, chlorophyll content, spike length and number of fertile spikeletes spike^{-1} of two wheat cultivars (combined analysis of two seasons)

Study factor		Plant height (cm)	Flag leaf area (cm^2)	Chlorophyll content (SPAD value)	Spike length (cm)	Number of fertile spikeletes spike^{-1}
Cultivar (C)						
Giza 171		114.8 A	35.54 A	44.88 A	12.88A	20.91 A
Shandwel 1		104.6 B	33.78 B	42.74 B	11.47 B	19.95 B
Biochar rate (B)						
Check		109.3 B	33.65 B	42.60 B	12.22 A	20.15 B
6 Mg ha^{-1}		110.2 A	35.67 A	45.02 A	12.13 B	20.71 A
Nitrogen application timing (N)						
T1		106.5 C	26.58 C	38.92 C	11.91 C	20.07 C
T2		110.3 B	36.01 B	44.40 B	12.17 B	20.70 A
T3		112.4 A	41.39 A	48.11 A	12.44 A	20.51 B
ANOVA	**df**			***p*-value**		
C	1	0.0414	<0.001	<0.001	<0.001	0.0100
B	1	<0.001	<0.001	<0.001	<0.001	<0.001
N	2	<0.001	<0.001	<0.001	<0.001	<0.001
C×B	1	<0.001	0.0025	<0.001	<0.001	<0.001
C×N	2	<0.001	<0.001	<0.001	<0.001	<0.001
B×N	2	<0.001	<0.001	<0.001	<0.001	<0.001
C×B×N	2	<0.001	<0.001	<0.001	<0.001	<0.001

T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. Means followed by different letters under the same factor differ significantly by LSD ($p \leq 0.05$).

Table 2. Influence of biochar rate and nitrogen application timing on yield, yield components, harvest index and crude protein yield of two wheat cultivars **(combined analysis of two seasons)**

Study factor		Number of spikes m^{-2}	Number of grains spike^{-1}	Grain weight spike^{-1} (g)	1000-grain weight (g)	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	Total yield (Mg ha^{-1})	Harvest index (%)	Crude protein yield (kg ha^{-1})
Cultivar (C)										
Giza 171		468.9 A	52.87 B	1.91 A	37.19 A	6.24 A	10.48 A	16.72 A	38.21 A	720.9 A
Shandwel 1		360.9 B	54.81 A	1.66 B	30.05 B	4.76 B	9.51 B	14.27 B	33.30 B	480.5 B
Biochar rates (B)										
Check		399.6 B	52.87 B	1.66 B	32.08 B	5.31 B	9.65 B	14.96 B	35.47 B	571.5 B
6 Mg ha^{-1}		430.2 A	54.81 A	1.91 A	35.16 A	5.69 A	10.34 A	16.03 A	36.04 A	629.9 A
Nitrogen application timing (N)										
T1		351.2 C	49.08 C	1.69 C	29.56 C	4.37 B	9.39 B	13.76 C	31.93 C	476.0 C
T2		461.1 A	56.42 A	1.74 B	37.75 A	6.06 A	10.96 A	17.02 A	35.48 B	680.3 A
T3		432.4 B	56.03 B	1.92 A	33.55 B	6.07 A	9.64 B	15.71 B	39.86 A	645.7 B
ANOVA	**df**					***p*-value**				
C	1	<0.001	0.0037	0.0126	0.0019	<0.001	<0.001	<0.001	<0.001	<0.001
B	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0187	<0.001
N	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C×B	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	--
C×N	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1895	<0.001
B×N	2	0.2655	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C×B×N	2	0.2283	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. Means followed by different letters under the same factor differ significantly by LSD ($p \leq 0.05$).

The appropriate nitrogen dose varies, depending on soil properties and environmental conditions. This can be attributed to the role that N as an important macronutrient plays in plant growth and dry matter production, as well as promoting photosynthesis, which helped to accumulate more biomass, and improved yield components, particularly number of spikes m^{-2}, 1000-grain weight, and number of fertile spikeletes spike^{-1}. These results are in agreement with those stated by **Gad *et al.* (2018) and Marco *et al.* (2021)**. Split N applying is shown to enhance leaf chlorophyll content, which flush growth and thus leads to an increase in dry matter **(Tian *et al.*, 2020; Zhen *et al.*, 2021)**.

Results under time of N application showed that the T2 treatment significantly enhanced grain yield, which was attributed to increase in grain yield components (number of spikes m^{-2}, number of grains spike^{-1} and 1000-grain weight). Such increase in grain yield may be due to sufficient supply of the photoassimlates (current and stored assimilate for grain at the grain filling stage. **Hiroshi *et al.* (2008)** showed that N applying at tillering stage is more effective than anthesis stage for improving grain yield due to N application at tillering stage increases number of active tillers and hence increase number of spikes m^{-2}.

The three-way interaction effect between factors under study in Fig. 1 detected that plant height, flag leaf area, chlorophyll content, spike length and number of fertile spikelets spike^{-1} were significantly affected by the interaction between wheat cultivars and both of N application time and biochar rate. It appears from Fig. 1-a that Giza 171 cultivar was the tallest (115.8 cm) when added N at T3 under the check biochar treatment. The higher values for flag leaf area, chlorophyll content, spike length and number of fertile spikelets/ spike were reported due to applying N at T3 combined with supplying 6 Mg biochar ha^{-1} under Giza 171 cultivar (Figs. 1-b, c, d and e).

Shandwel 1 wheat cultivar gave the highest number of grains/ spike (59.87) when added biochar with applying N at T3 (Fig. 2-a). While, Giza 171 gave the highest grain weight/ spike under application of N at T1 with added 6 Mg biochar ha^{-1} (Fig. 2-b). Moreover, the maximum 1000-grain weight (45.68g) and grain yield (7.23 Mg ha^{-1}) were reported when applied biochar by 6 Mg ha^{-1} combined with adding N at T2 under Giza 171 cultivar (Figs. 2-c and d). In addition, the highest straw yield (12.22 Mg ha^{-1}) and total yield (19.05 Mg ha^{-1}) each was obtained when Shandwel 1 cultivar supplied with 6 Mg biochar ha^{-1} combined with applied N at T3 treatment (Figs. 3-a and b). While, the maximum HI (49.40%) was reported when applied biochar by 6 Mg ha^{-1} combined with adding N at T3 under Giza 171 cultivar (Fig. 3-c). Moreover, the highest crude protein yield (874.1kg ha^{-1}) was given by application of N at T2 combined with applying biochar by 6 Mg ha^{-1} with sowing Giza 171 cultivar (Fig. 3-d). Contrariwise, straw yield, total yield and crude protein yield gave the minimum values when Shandwel 1 supplied with N at T1 under the check biochar treatment.

Nitrogen Use Efficiency and its Attributes

With respect to varietal differences, the results revealed highly significant differences. Despite that Giza 171 presented the highest total-NUpE and NUE (1.26 and 47.82 kg kg^{-1}) but it had the lowest grain-NUpE value (38.53 kg kg^{-1}). However, TNA was not significantly affected by varietal differences (Table 3). The possible explanation for the higher total-NUpE and NUE for sowing Giza 171 cultivar than Shandwel 1, was that the superiority genetic makeup of Giza 171 rather than Shandwel 1, as well as, genetically variation and interaction with environmental conditions (**Khattab, 2019**). Similar results regarding the significant variation between wheat genotypes in NUE parameters have been established by other researchers; **Barraclough *et al.* (2010),**

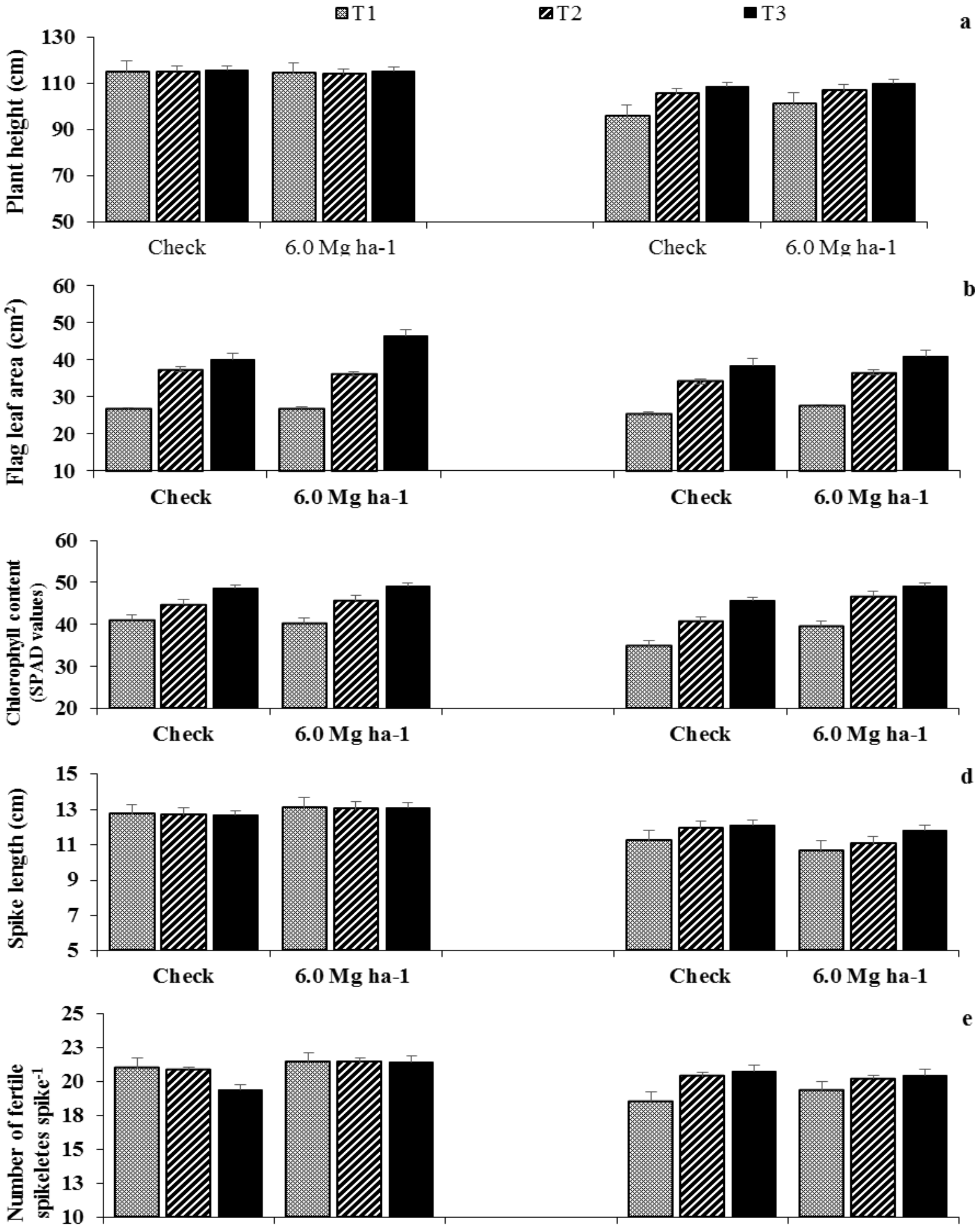

Fig. 1. Effect of nitrogen application timing on plant height (a), flag leaf area (b), chlorophyll content (c), spike length (d) and number of fertile spikeletes spike^{-1} (e) of two wheat cultivars under two biochar rates over two growing seasons. T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. The bars on the top of the columns correspond to LSD ($p \leq 0.05$)

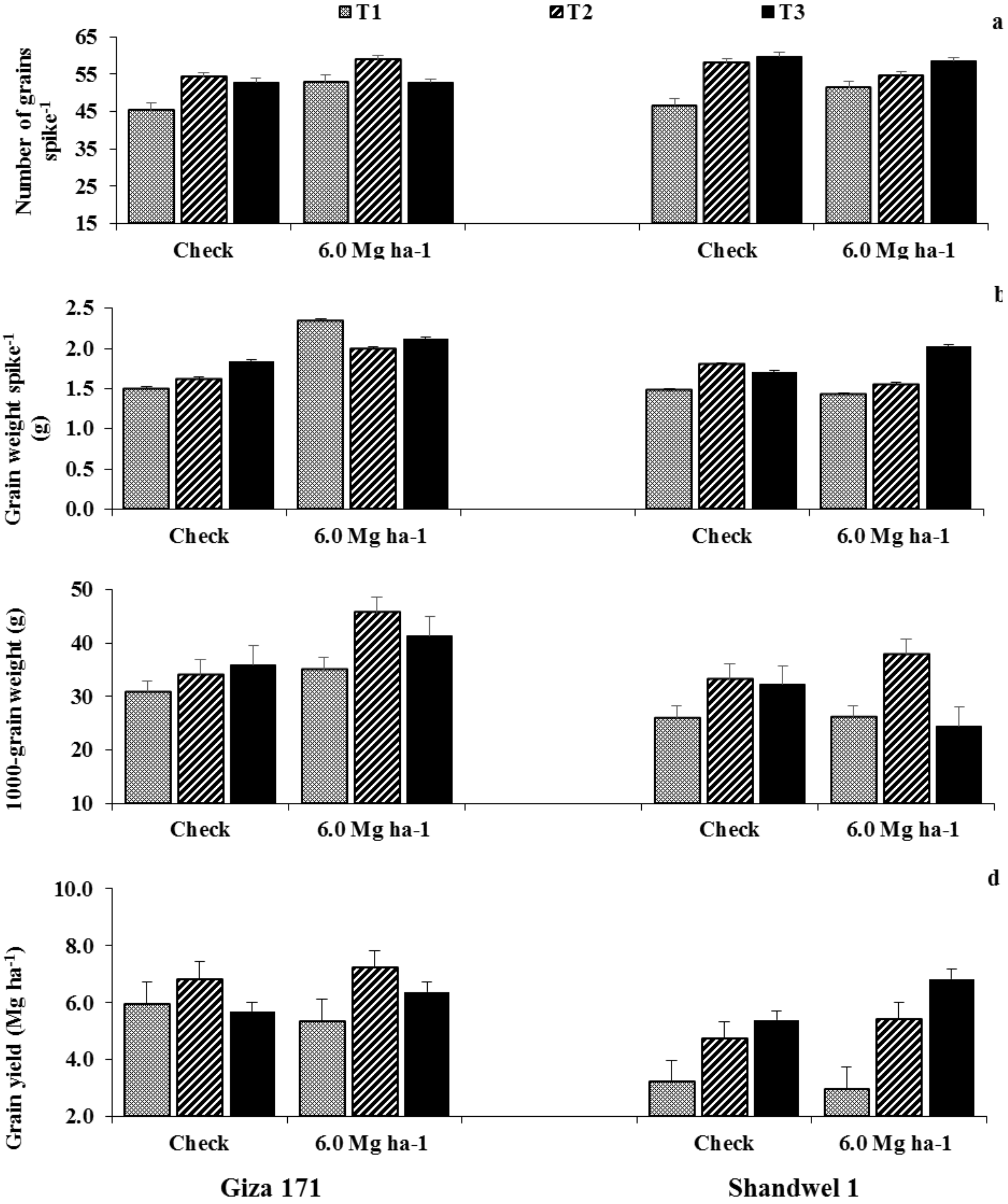

Fig. 2. **Effect of nitrogen application timing on number of grains spike^{-1} (a), grain weight spike^{-1} (g) (b), 1000-grain weight (g) (c) and grain yield (Mg ha^{-1}) (d) of two wheat cultivars under two biochar rates over two growing seasons. T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. The bars on the top of the columns correspond to LSD ($p \leq 0.05$)**

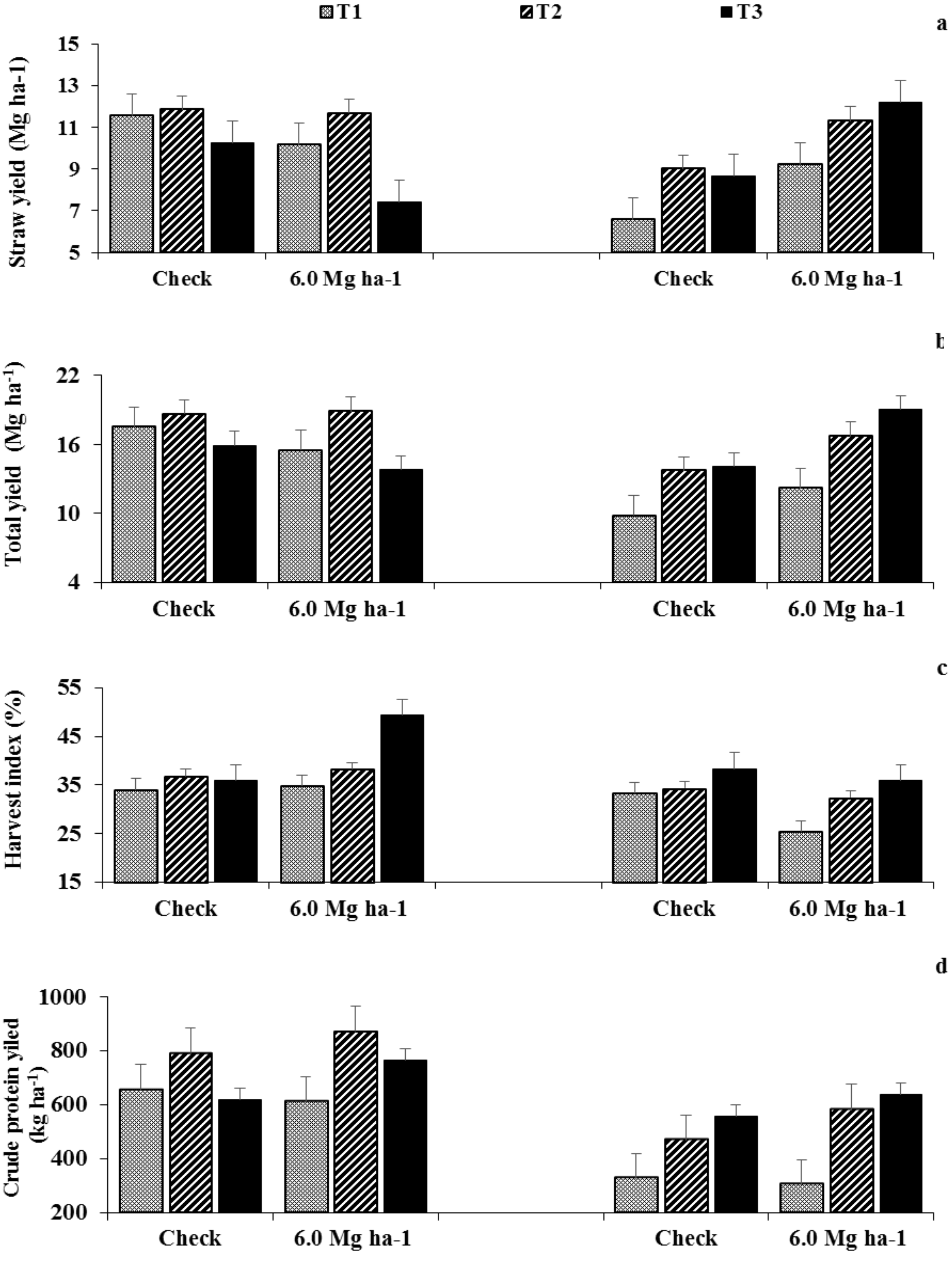

Fig. 3. Effect of nitrogen application timing on straw yield (Mg ha^{-1}) (a), total yield (Mg ha^{-1}) (b), harvest index (%) (c) and crude protein yield (kg ha^{-1}) (d) of two wheat cultivars under two biochar rates over two growing seasons. T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. The bars on the top of the columns correspond to LSD ($p \leq 0.05$)

Table 3. Influence of biochar rate and nitrogen application timing on total nitrogen accumulation (TNA; kg N ha^{-1}), nitrogen utilization efficiency (grain-NUtE; kg kg^{-1}), nitrogen uptake efficiency (total-NUpE; kg kg^{-1}) and nitrogen use efficiency (NUE; kg kg^{-1}) of two wheat cultivars (combined analysis of two seasons)

Study factor		TNA (kg N ha^{-1})	Grain-NUtE (kg kg^{-1})	Total-NUpE (kg kg^{-1})	NUE (kg kg^{-1})
Cultivar (C)					
Giza 171		132.5 A	38.53 B	1.26 A	47.82 A
Shandwel 1		132.9 A	40.34 A	0.92 B	36.46 B
Biochar rates (B)					
Check		144.3 A	40.72 A	1.03 B	40.65 B
6 Mg ha^{-1}		121.2 B	38.15 B	1.15 A	43.63 A
Nitrogen application timing (N)					
T1		107.6 B	39.82 AB	0.85 C	33.52 B
T2		147.3 A	37.94 B	1.25 A	46.41 A
T3		143.3 A	40.54 A	1.16 B	46.49 A
ANOVA	**df**		***p*-value**		
C	1	--	0.0018	<0.001	<0.001
B	1	0.0110	<0.001	<0.001	<0.001
N	2	<0.001	0.0083	<0.001	<0.001
C×B	1	--	<0.001	0.0014	<0.001
C×N	2	0.3722	0.1353	<0.001	<0.001
B×N	2	0.2165	0.0120	<0.001	<0.001
C×B×N	2	--	--	0.1347	<0.001

T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. Means followed by different letters under the same factor differ significantly by LSD ($p \leq 0.05$).

Sadras and Lawson (2013), Ruisi *et al.* (2015), Nguyen *et al.* (2016), Todeschini *et al.* (2016), Mansour *et al.* (2017) and Peng *et al.* (2022). Results in Table 3 reveal that biochar supply showed significant influences on TNA, grain-NUtE, total-NUpE and NUE. Biochar rate 6 Mg ha^{-1} had significant influences on TNA and grain-NUtE where, it was decreased by 16.01 and 6.31% comparing by control treatment. But biochar application at rate of 6 Mg ha^{-1} was more effective in increasing total-NUpE and NUE significantly by 11.65 and 7.33% comparing by control treatment.

This influence might attribute to improving soil properties and decreases nutrient leaching **(Vaccari *et al.* 2011 ; Hale *et al.* 2012)**. **Laird (2008)** reported that, when biochar applied to soil, its quality is enhanced as increased nutrients availability, sorption water retention capacity, plant growth and fewer leaching.

In addition, **Pan *et al.* (2009)** reported that great soil organic carbon because of biochar could improve NUE and enhancing the grain yield.

Nitrogen supply timing had a marked effect on N use efficiency and its attributes (Table 3). Delaying application of N (T3) caused significant increase in each of TNA, grain-NUtE, and NUE. However, Delaying application of N produced a significant decrease in total-NUpE. Such increase in N use efficiencies may be due to delaying N application until anthesis, caused a significant improvement in leaf area, leaf area duration and therefore increased assimilation capacity and current photosynthates as well as N uptake. **Peng *et al.* (2022)** showed that increase in NUE resulted from a significant increase in TNA.

The interaction among factors showed significant differences in NUE were detected as shown in Fig. 4, where this parameter reached their maximum value (55.37%) when applying 6 Mg ha^{-1} of biochar combined with N application at T2 and sowing Giza 171.

Correlations of Grain Yield with Other Traits

The phenotypic correlation coefficient among all possible pairs of important traits is presented in Table 4. Plant height was positively and significantly correlated with each of flag leaf area, chlorophyll content, spike length, number of fertile spikeletes $spike^{-1}$, number of spikes m^{-2}, number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000-grain weight, straw yield, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield but had negative and significant correlation with nitrogen utilization efficiency (-0.253^{*}) over the years. Positive and significant correlations associations were found between flag leaf area and each of chlorophyll content, number of spikes m^{-2}, number of grains $spike^{-1}$, 1000-grain weight, total yield, HI, crude protein yield, total nitrogen accumulation, nitrogen uptake efficiency, nitrogen use efficiency and grain yield. Moreover, chlorophyll content had positive and significant correlations with number of spikes m^{-2}, 1000- grain weight, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield. Furthermore, positive and highly significant associations correlations ($p < 0.01$) between spike length and number of fertile spikeletes $spike^{-1}$, number of spikes m^{-2}, number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000- grain weight, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield. Similarly, correlation was positive and highly significant ($p < 0.01$) between number of fertile spikeletes $spike^{-1}$ and each of number of spikes m^{-2}, number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000- grain weight, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield, but had negative and significant correlation with total nitrogen accumulation (-0.292^{*}).

Number of spikes m^{-2} appeared to be positively and significantly correlated with number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000- grain weight, straw yield, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield, otherwise negative and significant correlation with nitrogen utilization efficiency (-0.244^{*})was noted.

Positive and highly significant correlations ($p < 0.01$) between number of grains $spike^{-1}$ and grain weight $spike^{-1}$, 1000- grain weight, straw yield, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield and *vice versa* with nitrogen utilization efficiency (-0.240^{*}). Also, grain weight $spike^{-1}$ had positive and significant correlations with 1000- grain weight, total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield.

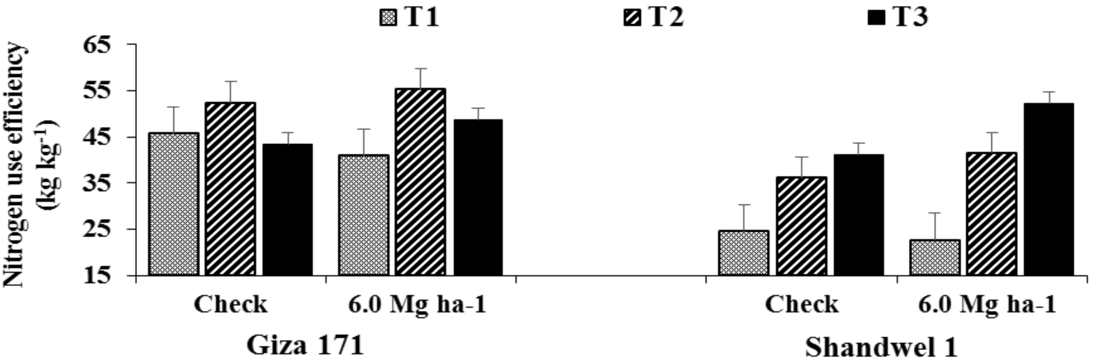

Fig. 4. Effect of nitrogen application timing on nitrogen use efficiency (kg kg^{-1}) of two wheat cultivars under two biochar rates over two growing seasons. T1: N application at 10, 20, 30, 40 and 50 days after sowing (DAS), T2: N application at 10, 25, 40, 55 and 70 DAS, T3: N application at 10, 30, 50, 70 and 90 DAS. The bars on the top of the columns correspond to LSD ($p \leq 0.05$)

Table 4. Correlations (Pearson correlation coefficient) among the study traits in wheat as calculated from the combined data across two season

Characters	FLA	CC	SL	FSNS^{-1}	NSm^{-2}	NGS^{-1}	GWS^{-1}	1000-GW	SY	TY	HI	CPY	TNA	Grain-NUtE	Total-NUpE	NUE	GY
PH	0.341**	0.384**	0.735**	0.658**	0.653**	0.273*	0.496**	0.524**	0.246*	0.416**	0.339**	0.673**	-0.103	-0.253*	0.616**	0.610**	0.610**
FLA		0.742**	.089	0.105	0.459**	0.250*	0.160	0.313**	0.101	0.277*	0.423**	0.481**	0.266*	-0.102	0.496**	0.524**	0.524**
CC			0.113	0.113	0.542**	0.144	0.116	0.322**	0.222	0.356**	0.258*	0.351**	0.196	0.017	0.422**	0.500**	0.500**
SL				0.717**	0.548**	0.497**	0.665**	0.580**	0.157	0.356**	0.473**	0.690**	-0.160	-0.146	0.578**	0.622**	0.621**
FSNS					0.483**	0.472**	0.533**	0.416**	0.142	0.331**	0.477**	0.624**	-0.292*	-0.048	0.522**	0.586**	0.586**
NS/m^2						0.288*	0.424**	0.573**	0.476**	0.641**	0.280*	0.725**	0.083	-0.244*	0.732**	0.754**	0.754**
NG/S							0.534**	0.384**	0.316**	0.414**	0.129	0.429**	-0.038	-0.240*	0.463**	0.470**	0.470**
GW/S								0.471**	0.116	0.263*	0.368**	0.481**	-0.119	-0.173	0.434**	0.459**	0.459**
1000-GW									0.117	0.280*	0.403**	0.626**	0.049	-0.309**	0.557**	0.501**	0.501**
SY										0.947**	-0.461**	0.439**	-0.082	-0.367**	0.612**	0.553**	0.553**
TY											-0.162	0.678**	-0.024	-0.339**	0.810**	0.792**	0.792**
HI												0.479**	0.168	0.247*	0.305**	0.455**	0.455**
CPY													0.038	-0.396**	0.947**	0.920**	0.920**
TNA														0.244*	-0.004	0.093	0.094
Grain-NUtE															-0.493**	-0.182	-0.182
Total-NUpE																0.935**	0.935**
NUE																	1.000**

*,** Significant at P=0.05 and P= 0.01, respectively. PH is plant height (cm), FLA is flag leaf area (cm^2), CC is chlorophyll content (SPAD values), SL is spike length (cm), FSNS^{-1} is number of fertile spikeletes spike^{-1}, NSm^{-2} is number of spikes m^{-2}, NGS^{-1} is number of grains spike^{-1}, GWS^{-1} is grain weight spike^{-1} (g), 1000-GW is 1000- grain weight (g), SY is straw yield (Mg ha^{-1}), TY is total yield (Mg ha^{-1}), HI is harvest index (%), CPY is crude protein yield (kg ha^{-1}), TNA is total nitrogen accumulation (kg N ha^{-1}), Grain-NUtE is nitrogen utilization efficiency (kg/kg), Total-NUpE is nitrogen uptake efficiency (kg/kg), NUE is nitrogen use efficiency (kg/kg) and GY is grain yield (Mg ha^{-1}).

1000-grain weight had positive and significant correlations with total yield, HI, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield, but had negative and highly significant correlation ($p<0.01$) with nitrogen utilization efficiency (-0.309**). Positive and highly significant correlations ($p < 0.01$) between straw yield and each of total yield, crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield, but had negative and highly significant correlation with HI (-0.461**) and nitrogen utilization efficiency (-0.367**). Positive and highly significant correlations ($p<0.01$) were registered between total yield and each of crude protein yield, nitrogen uptake efficiency, nitrogen use efficiency and grain yield, but had negative and highly significant correlation ($p < 0.01$) with nitrogen utilization efficiency (-0.339**). HI exhibited positive and significant correlations with crude protein yield, nitrogen utilization efficiency, nitrogen uptake efficiency, nitrogen use efficiency and grain yield. Negative and highly significant correlations ($p < 0.01$) between crude protein yield and nitrogen utilization efficiency (-0.396**) but had positive and highly significant correlation with nitrogen uptake efficiency, nitrogen use efficiency and grain yield. Total nitrogen accumulation showed positive and significant relationship with nitrogen utilization efficiency. However, negative and highly significant correlation ($p < 0.01$) was recorded between nitrogen utilization efficiency and nitrogen uptake efficiency. Nitrogen uptake efficiency had positive and highly significant correlations ($p < 0.01$) with nitrogen use efficiency (0.935**) and grain yield (0.935**). Furthermore, nitrogen use efficiency exhibited positive and highly significant correlations with grain yield. The results suggested that enhancement of wheat grain yield is related with the improve of these traits. Likewise, **Sabit *et al.* (2017), Alan *et al.* (2020), Maurya *et al.* (2020), and Dayem *et al.* (2021)** reported a significant positive association among wheat grain yield and yield components and NUE.

Path Coefficient

The maximum direct effect on wheat grain yield was accounted for number of spikes m^{-2} followed by spike length, flag leaf area and then number of fertile spikeletes/spike with values of 0.436, 0.343, 0.280 and 0.201, respectively. Whereas, negligible direct effects were recorded by both number of grains spike^{-1} and chlorophyll content as exhibited 0.101 and 0.064 respectively (Table 5).

For indirect effects, plant height showed negligible positive indirect effect *via* flag leaf area, chlorophyll content, number of grains spike^{-1} moderate positive indirect effect *via* spike length and number of spikes m^{-2}, low positive indirect effect *via* number of fertile spikeletes spike^{-1}. Flag leaf area showed negligible positive indirect effect *via* chlorophyll content, spike length, number of fertile spikeletes spike^{-1}, number of grains spike^{-1} and moderate positive indirect effect *via* number of spikes m^{-2}. Chlorophyll content showed moderate positive indirect effect *via* flag leaf area, number of spikes m^{-2}, negligible positive indirect effect *via* spike length, number of fertile spikeletes spike^{-1}and number of grains spike^{-1}. Spike length showed negligible positive indirect effect *via* flag leaf area, chlorophyll content, number of grains spike^{-1}, low positive indirect effect *via* number of fertile spikeletes spike^{-1}and moderate positive indirect effect *via* number of spikes m^{-2}. Number of fertile spikeletes spike^{-1} showed negligible positive indirect effect *via* flag leaf area, chlorophyll content, number of grains spike^{-1}, moderate positive indirect effect *via* spike length and number of spikes m^{-2}. Number of spikes m^{-2} showed low positive indirect effect *via* flag leaf area, spike length, negligible positive indirect effect *via* chlorophyll content, number of fertile spikeletes spike^{-1} and number of grains spike^{-1}.

Number of grains spike^{-1} showed negligible positive indirect effect *via* flag leaf area, chlorophyll content, number of fertile spikeletes spike^{-1} and low positive indirect effect *via* spike length and number of spikes m^{-2}. These results clearly indicate that flag leaf area, spike length, number of fertile spikeletes spike^{-1}, number of spikes m^{-2} considered the major yield contributing traits that the wheat breeder should take into account for improving yield of wheat genotypes. Effective Similar results were reported by several investigators **(Mecha *et al.*, 2017, Sabit *et al.*, 2017, Baye *et al.*, 2020 ; Dayem *et al.*, 2021)**.

Table 5. Direct (Diagonal) and indirect effect of yield components on wheat grain yield across two seasons relative to correlation

Characters	PH	FLA	CC	SL	FSNS	NS/m2	NG/S	GW/S	1000-GW	Correlation with grain yield (Mg ha^{-1})
PH	**-0.135**	0.096	0.025	0.252	0.132	0.285	0.028	-0.032	-0.040	0.610
FLA	-0.046	**0.280**	0.048	0.031	0.021	0.200	0.025	-0.010	-0.024	0.524
CC	-0.052	0.208	**0.064**	0.039	0.023	0.236	0.015	-0.007	-0.025	0.500
SL	-0.099	0.025	0.007	**0.343**	0.144	0.239	0.050	-0.043	-0.045	0.621
FSNS	-0.089	0.029	0.007	0.246	**0.201**	0.211	0.048	-0.034	-0.032	0.586
NS/m^2	-0.088	0.129	0.035	0.188	0.097	**0.436**	0.029	-0.027	-0.044	0.754
NG/S	-0.037	0.070	0.009	0.170	0.095	0.126	**0.101**	-0.035	-0.030	0.470
GW/S	-0.067	0.045	0.007	0.228	0.107	0.185	0.054	**-0.065**	-0.036	0.459
1000-GW	-0.071	0.088	0.021	0.199	0.084	0.250	0.039	-0.030	**-0.077**	0.501

Bold and italic refers to direct effects of yield components on wheat grain yield. PH is plant height (cm), FLA is flag leaf area (cm^2), CC is chlorophyll content (SPAD values), SL is spike length (cm), FSNS^{-1} is number of fertile spikeletes spike^{-1}, NSm^{-2} is number of spikes m^{-2}, NGS^{-1} is number of grains spike^{-1}, GWS^{-1} is grain weight spike^{-1} (g), 1000-GW is 1000- grain weight (g).

Conclusions

The results of the current study focus the importance of some agronomic practices that secure improve wheat yield and NUE. The findings reveal that, Giza 171 cultivar exhibited high grain yield, yield attributes, as well as, nitrogen uptake efficiency and nitrogen use efficiency followed by Shandwel 1. Biochar application at 6 Mg ha^{-1} significantly increased grain yield, yield attributes, crude protein yield, as well as, total-NUpE and NUE compared with check treatment. N adding timing at T2 or T3 had greatly improved grain yield (6.06 and 6.07 Mg ha^{-1}) comparing with T1 treatment (4.37 Mg ha^{-1}). Delaying application of N (T3) caused significant increase in each of TNA, grain-NUtE, and NUE. Path coefficient analysis revealed that flag leaf area, spike length, number of fertile spikeletes spike^{-1}, number of spikes m^{-2} had exerted positive and direct effect on wheat grain yield of wheat. According to the study apt to recommend combining N application timing at T2 with application of 6 Mg biochar ha^{-1} to attain the maximum grain yield and NUE for wheat when Giza 171 cultivar was cultivated.

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الملخص العربي

تحسين محصول الحبوب وكفاءات استخدام النيتروجين في صنفين من القمح من خلال البيوشار وميعاد إضافة النيتروجين

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استخدام البيوشار وميعاد إضافة النيتروجين قد تكون استراتيجية فعالة لتحسين خصوبة التربة وزيادة محصول القمح، خاصة في التربة الرملية. وفي هذا الصدد، فقد أجريت تجربة حقلية خلال الموسمين الزراعيين 2019/2018 – 2020/2019 بالمزرعة التجريبية التابعة لكلية الزراعة جامعة الزقازيق (أرض رملية) بهدف دراسة تأثير كل من البيوشار (بدون إضافة و6 ميجاجرام/هكتار) وكذلك ثلاثة نظم لمواعيد إضافة النيتروجين (النظام الأول عند 10، 20، 30، 40 و50 يوم من الزراعة، النظام الثاني عند 10، 25، 40، 55 و70 يوم من الزراعة والنظام الثالث عند 10، 30، 50، 70 و90 يوم من الزراعة) على الصفات المحصولية لصنفين من القمح (جيزة 171 وشندويل 1) وكفاءة استخدام النيتروجين. ويمكن تلخيص النتائج المتحصل عليها على النحو التالي: تفوق الصنف جيزة 171 في محصول الحبوب ومعظم مؤشرات المحصول، بالإضافة الي زيادة كفاءة امتصاص النيتروجين وكفاءة استخدام النيتروجين. أدت إضافة البيوشار بمعدل 6 ميجاجرام/ هكتار إلي زيادة معنوية في كل من محصول الحبوب ومعظم مؤشرات المحصول، بالإضافة الي زيادة كفاءة امتصاص النيتروجين وكفاءة استخدام النيتروجين مقارنة بمعاملة الكنترول (عدم الإضافة). مواعيد التسميد النيتروجيني التي تنتهي عند 70 أو 90 يوم من الزراعة كان لها تأثيراً معنوياً في تحسين محصول الحبوب ومؤشرات المحصول، بالإضافة الي زيادة كفاءات استخدام النيتروجين مقارنة بميعاد التسميد الذي ينتهي عند 50 يوم من الزراعة. تشير نتائج تداخل الفعل إلى إمكانية معظمة إنتاجية محصول الحبوب (7.23 ميجاجرام/ هكتار) وكفاءة استخدام النيتروجين (55.37 كجم/ كجم) من خلال زراعة الصنف جيزة 171 وإضافة البيوشار بمعدل 6 ميجاجرام/ هكتار مع إضافة السماد النيتروجين على دفعات حتى 70 يوم من الزراعة. أظهرت نتائج تحليل معامل المرور إلى أن عدد السنابل/ م^2 وطول السنبلة كان له تأثيراً مباشراً إيجابياً ومرتفعاً (0.436 و0.343) على محصول الحبوب، بينما كان لمساحة ورقة العلم وعدد السنيبلات الخصبة/ السنبلة تأثيراً مباشراً إيجابياً ومتوسطاً على محصول الحبوب (0.280 و0.201).

الكلمات الاسترشادية: القمح، النيتروجين، الفحم الحيوي، كفاءة امتصاص النيتروجين، تحليل المرور.

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