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Research Article

Testing the feasibility of sunflower and cotton intercropping systems in irrigated conditions of arid climatic zone

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ABSTRACT

Intercropping is an important component in cropping system research. It can improve crop productivity by utilizing a piece of land efficiently. It also strengthens the farmer's capability towards growing crops to adapt to climate change impacts. Hence, a field experiment to identify the advantages of sunflower-cotton intercropping over solitary cropping through agronomic interactions in arid irrigated conditions was conducted in the crop season of year 2016 and 2017. The experiment was designed in RCBD with four replications. The experiment comprised four treatments; 75 cm sole planting of sunflower (P1), 75 cm sole planting of cotton (P2), 75 cm single row of sunflower with cotton (P3), and 112.50 cm double rows strip of sunflower with cotton (P4). Evaluations of planting patterns were performed based on several crop competition indices. Agronomic interactions revealed that sunflower-cotton single-row intercropping (P3) had advantages over solitary planting, due to its better yield of cotton (2444, 2383 kg ha-1) and sunflower (3055, 2752 kg ha-1), Land Equivalent Ratio (1.76, 1.73), Competitive Ratio (2.03, 2.01), significant Relative Crowding Coefficient (32.73, 15.37) and lower Aggressivity (0.16, -0.16; 0.10, -0.10) in year 2015 and 2016, respectively. The sunflower crop was more competitive than the cotton crop in planned planting patterns. Although the yield of intercrops was low compared to pure stands, the results obtained from competition indices attributed to better land use efficiency when the intercrops were sown in 75 cm spaced single rows with limited use of external inputs. Hence, it is concluded that this practice is economical and feasible for application at the farmer's field for higher productivity of the cropping system.

Keywords: Climate-smart practices; competition indices; agronomic interactions; sunflower; cotton.

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INTRODUCTION

Current food insecurity and higher demand for food under changing climate scenarios with, an increasing population in the world, demand much attention from the agricultural research community. This food insecurity compels us to carefully examine the research agenda suitable for devising new technologies that increase crop productivity. In such a scenario, we are unable to meet the food/feed demand with a horizontal increase in yields of crops. While vertical increase in yields can also be possible through growing two or more crops in proximity with each other in the same growing season (Ullah et al., 2007; Zhou et al., 2011), which is termed as intercropping. Intercropping is an important aspect of cropping system research. Generally, it / this system produces more yield as compared to a sole crop (Yu et al., 2015) and reduces the crop failure risks (Zhang et al., 2019). It can improve crop productivity by utilizing a piece of land efficiently. It also strengthens the farmer's capability towards growing crops as a business. Intercropping is a widespread practice in all cereals (Ofori and Stern, 1987; Amanullah, 2015), legumes (Tusubo et al., 2003), oilseed crops (Naeem et al., 2013; Anas et al., 2017), and up to some extent in cotton crop (Kandhro et al., 2014). Among several mechanisms that bring higher yields, intercropping is one of the most widespread systems that can use environmental resources in a better way (Bhatti et al., 2006; Lithourgidis et al., 2011; Martin-Guay et al., 2018). Agricultural sustainability and productivity are increasingly important in the face of rising global food and fiber demands, climate change, and resource limitations. Intercropping, the practice of growing two or more crops simultaneously on the same piece of land, is a time-tested strategy that promotes efficient use of available resources while enhancing ecological stability. In recent years, intercropping has gained renewed interest among researchers and farmers due to its potential to improve land use efficiency, reduce input costs, and support environmental conservation. Among various intercropping combinations, the integration of oilseed and fiber crops holds significant promise, especially in regions where maximizing output from limited arable land is essential

Intercropping is usually adopted as climate-smart practice and to diversify the cropping systems and judicious use of resources. This practice enhances the chances of higher land utilization and helps the farmers to meet their food needs. The practice of growing crops in proximity with other crops is usually designed for small land holders to to take advantage of more than one crop in unit area. (Ullah et al., 2007; Wahla et al., 2009). Rather, this cropping system captures more light, hence resulting in higher yield due to high light interception over the season (Gou et al., 2017a, b; Hong et al., 2017). Intercropping sunflower with sunn hemp with a 1:1 ratio resulted in better sunflower growth and yield (Chappa et al., 2023). Kandhro et al. (2014) reported the highest productivity under intercropping of sorghum and sunflower in cotton. The cotton crop is ideal for growing with other crops due to its longer growing period and slow growth during the initial stages of the crop. The conventional cotton cultivation is not convenient to get higher profit (Khan and Khaliq, 2004), either due to environmental stress to cotton lint or market crisis (low market prices), especially in Pakistan. Therefore, the new planting pattern of early cotton, facilitating the intercropping of sunflower, is quite helpful to overcome many problems. While early planting of cotton is much familiar in all over Punjab-Pakistan that compete the season of sunflower. Sunflower (*Helianthus annuus* L.) and cotton (*Gossypium hirsutum* L.) are two economically important crops with complementary growth characteristics that make them suitable for intercropping. Cotton is a long-duration crop with a bushy growth habit, whereas sunflower is a relatively short-duration crop with an upright growth pattern and a deep root system. These morphological differences allow for better spatial and temporal resource partitioning, minimizing competition and enhancing the overall productivity of the system. Moreover, sunflowers' ability to improve soil aeration and structure can be beneficial for cotton development, while its presence may also contribute to pest management by attracting pollinators and natural predators of cotton pests.

It is documented that cotton-sunflower intercropping primarily yielded better cotton equivalent yields and ultimately maximum net income (Aladakatti et al., 2011). Several research workers designed intercropping of cotton with other plants to check the advantages of intercropping, such as cotton with sorghum and pigeon pea (Aiyer, 1949), with corn or sorghum (Baker, 1979; Rao, 1984; Mohamed et al., 1986; Kamel et al., 1990 and Abdel-Malak et al., 1991), with mungbean (Khan and Khaliq, 2004), with melons (Sankaranarayanan, 2016). Intercropping sunflower with cotton not only improves agronomic efficiency but also provides economic and ecological advantages. It offers farmers the opportunity to diversify their cropping system, guaranteeing a steadier income even if one component's crop fails or prices fluctuate. The practice also aligns with sustainable agriculture goals by reducing the need for chemical inputs and promoting biodiversity in the cropping system. Studies have reported increased land equivalent ratios (LER), better weed suppression, and improved soil fertility under sunflower-cotton intercropping systems compared to their respective sole crops. Despite these potential benefits, there is a need for region-specific research to determine optimal planting geometries, crop ratios, and management practices to maximize the benefits of sunflower-cotton intercropping. In such scenarios, intercropping cotton with different planting patterns is needed to further explore the feasibility, economics, and reliability of sunflower and cotton-based intercropping systems. Hence, a study with the objective to determine the agronomic competition parameters to find out suitable planting pattern with higher bio-economic efficiency was designed. It was hypothesized that a suitable planting pattern would enhance the bio-economic efficiency by improving Land equivalent ratio, competitive ratio, relative crowding coefficient, and lowering Aggressivity.

MATERIALS AND METHODS

Site Description

The field experiment as a living lab was established in year 2016 and 2017 in irrigated field conditions at Agronomic Research Station Karor Lal Eason-Layyah, Punjab-Pakistan (31˚ 13´10.97" N˚, 70˚ 58´31.88" E˚ with 158 m altitude)

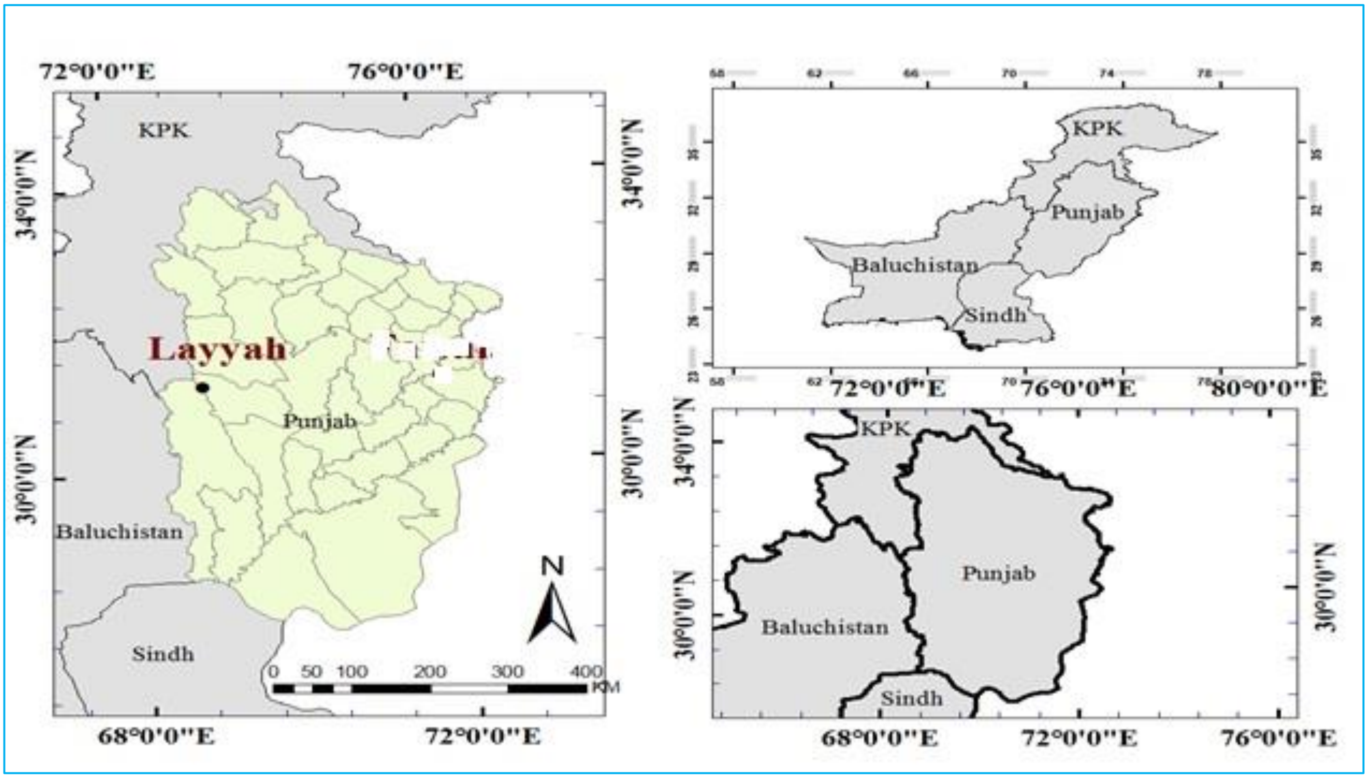

Figure 1. Geographical location study area (Karor Lal Eason, Layyah, Punjab Pakistan).

The soil was sandy loam in texture with low nutrients, the chemical properties were; organic matter Ct 0.051 %, K+ 160 ppm, P 12 ppm and soil pH 8.18. According to the classification of USDA, the soil series of location is Rangpur (Mixed, sandy, typic torripsamments, hyper-thermic) with an arid climatic zone.

Experimental Design

The experiment was designed using a Randomized Complete Block Design (RCBD) with four replications. The experimental treatments were comprised of four treatments; 75 cm sole planting of sunflower (P1), 75 cm sole planting of cotton (P2), 75 cm single row of sunflower with cotton (P3), and 112.50 cm double rows strip of sunflower with cotton (P4).

Cultural Practices

The net plot size in the case of each treatment was 8 m × 4.5 m. The hybrid sunflower (Hysun-33) was sown through a hand drill after seedbed preparation with row to row distance of 0.75 m. After sowing of sunflower crop, Bt. cotton (FH-142) was intercropped in different planting patterns (Fig. 2). The plant to plant distance in each case was maintained at 0.22 m. Phosphorus (P) and Potash (K) and Nitrogen (N) was applied at the rate of 137:59:62 NPK Kgha-1. Application of P and K was completed during the time of sowing, however, N were applied in different split at stages of both crops. The crops were sown during 1st week of March in both years. The field was irrigated at all critical stages of crops and weeds were controlled through hoeing practice.

Data Observations

Cotton and sunflower yield

Achene yield in case of sunflower was obtained through manual threshing of each plot and later, it was converted to kg ha-1. while three pickings in case of cotton crop were added in each plot which were later converted to kg ha-1.

(i) Agronomic Competitive Indices: The benefit ofan extra crop and competition between two crops was calculated using different indices. They were used to evaluate / find out the stability and relative advantage of intercropping over sole crop. The following key agronomic interactions were evaluated; Land Equivalent Ratio (LER)

(ii) Relative Crowding Coefficient (RCC) or (K)

(iii) Competitive Ration (CR)

(iv) Aggressivity (A)

Land equivalent ratio (LER)

LER, or the ratio of land needed by pure stands to provide the same yield as that of intercropping, was calculated using the relative land area under sole crops required to provide the same yield as under an intercropping approach at the same level of management (Mead and Willey, 1980).

$$LER\ (Total) = LER\ (Sunflower) + LER(Cotton) \quad (1)$$

$$LER(Sunflower) = Ys'/\ Ys \quad (2)$$

$$LER(Cotton) = Yc'/\ Yc \quad (3)$$

Figure 2. Layout plan and treatments showing different intercropping systems.

Where Y denotes yield in pure stand, Ys′ is the yield of intercropped sunflower; and Yc′, Yc represent the monocrop yield of cotton and intercropped yield of cotton, respectively. The critical value for LER is one. Intercropping promotes crop growth and yield when the value is higher than one. In contrast, the lower value shows negative growth and yield of crops.

Competitive ratio (CR)

Competition ratio (CR) is another important way to assess interference between crops. It gives a better competitive ability of crops as index over other indices like Aggressivity (A) and Relative Crowding Coefficient (RCC or K). It simply represents the ratio of LER(s) of components crops as sowing proportion of crops. It can be determined by formula given by Willey and Rao (1980).

$$CR = \frac{LERs}{LERc} \times \frac{Zcs}{Zsc} \quad (4)$$

Relative crowding coefficient (RCC or K)

RCC is the relative crowding coefficient used to measure relative dominance of one crop to other in intercropping. This coefficient was formulated by De Wit (1960) as following;

$$K = K(Sunflower) \times K\ (Cotton) \quad (5)$$

$$Ks = \frac{Ys'Zcs}{(Ys - Ys')Zsc} \quad (6)$$

$$Kc = \frac{Ys'Zsc}{(Yc - Yc')Zcs} \quad (7)$$

where Zcs denotes the sown proportion of cotton in the combination and Zsc represents the sown proportion of sunflower in the mixture with cotton. There is a yield advantage when the total coefficient (Ks × Kc) is larger than one, a yield disadvantage when K is less than one, and no yield benefit when K is equal to one.

Aggressivity (A)

Aggressivity is an important indice and is commonly used to indicate a relative increase in yield in one crop in comparison with other in an intercropping strategy as described earlier by McGilchrist (1965).

$$A(Sunflower) = \frac{Ys'}{YsZcs} - \frac{Yc'}{YcZsc} \quad (8)$$

$$A(Cotton) = \frac{Yc'}{YcZcs} - \frac{Ys'}{YsZsc} \quad (9)$$

RESULTS AND DISCUSSION

The sowing of one crop in proximity to another is a useful technique and helpful in testing the feasibility of the cropping system. The effective utilization of land and resources can be made possible through intercropping.

Effect of Weather on Crops: The weather conditions during crop season 2016 and 2017 are depicted in Fig. 3, which shows that 359 mm of rainfall was received in the first year of crop season as compared to the second year of the experiment (160 mm). The maximum monthly mean temperature in season 2017 was relatively higher than 2016, hence, the year 2017 was observed to be warmer than 2016 (Figure 2).

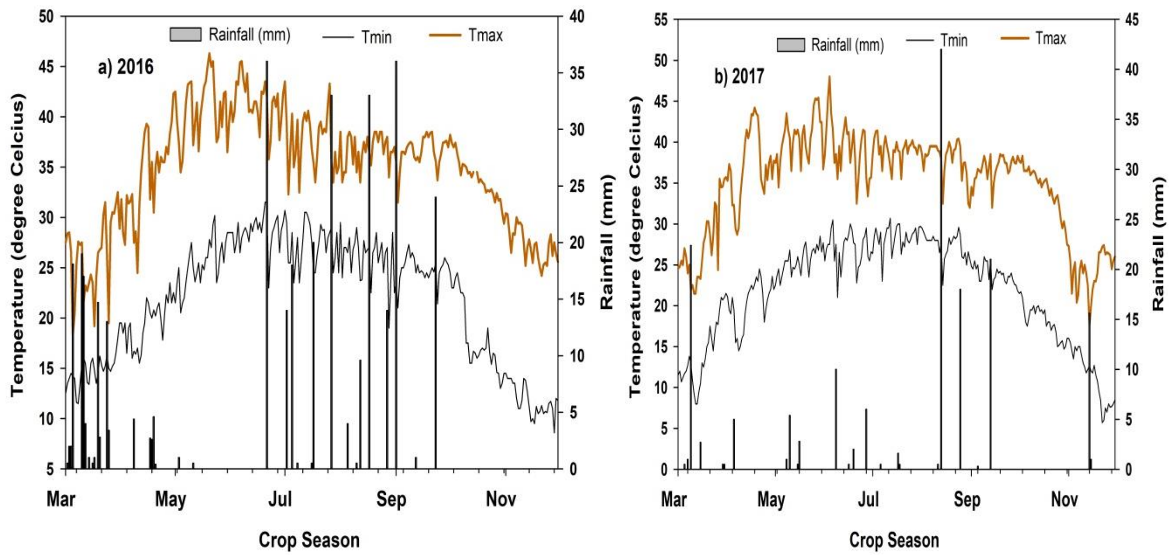

Figure 3. Crop season weather condition.

Achene and Cotton Yield (kg ha-1)

In the intercropping systems, the sole crop stand are maintained to determine different agronomic indices. In this study, each crop was sown in a pure stand in both seasons of the study. The results showed that cotton alone produced 3063 kg ha-1 in 2016 and 2928 kg ha-1 in season 2017. While as intercrops they gave lower yields as compared to a sole crop (Table 1).

Land Equivalent Ratio (LER)

Assessment of crop yield in a sole cropping system is much easier and output per unit area is expressed as yield in pure stand. In an intercropping system, direct comparison became difficult due to different yields due to the sowing of more than two crops on a single piece of land (Beets, 1982; Ullah et al., 2007). LER was selected to show how resource-efficient intercropping is in comparison to sole crops. Partial LER of sunflower [0.97, 0.83 (2013); 0.92, 0.77 (2017)] was observed to be higher in both seasons as compared with partial LER of cotton [0.80, 0.56 (2016); 0.81, 0.60 (2016)], Table 1. The total LER shows a greater combined yield advantage (1.76) in case of sunflower + cotton sown with 75 cm single row (P3) followed by P4 (sunflower intercropped with cotton at 112.5 cm double rows) at 1.39. This depicts that 76% (0.76 ha) and 39% (0.39 ha) more area would be necessary for pure stand crop to equate the yield of intercropping strategy. The results are in line with the findings of Aladakatti et al. (2011) and Kandhro et al. (2014) that cotton intercropped with sunflower gave a higher yield advantage as compared with sole cotton and sunflower crop. Buriro et al. (2018) got significantly higher cotton yield in intercropping systems.

Table 1. Competition Indices in sunflower-cotton intercropping systems.

Treatments	Cotton Yield (kg ha^{-1})	Achene Yield (kg ha^{-1})	LER_S S.flower	LER_C Cotton	LER_T Total	CR_S S.flower	CR_C Cotton	CR_T Total	K_S S.flower	K_C Cotton	K_T Total	A_S S.flower	A_C Cotton
Crop Season 2016													
Cotton Alone (P_1)	3064	0	0	1.00	1.00	0	0	0	0	1.00	1.00	0	0
S.flower Alone (P_2)	0	3161	1.00	0	1.00	0	0	0	1.00	0	1.00	0	0
S.flower + Cotton (P_3)	2444	3056	0.97	0.80	1.76	1.21	0.82	2.03	28.79	3.94	32.73	0.16	-0.16
S.flower + Cotton (P_4)	1708	2639	0.83	0.56	1.39	1.48	0.67	2.15	5.04	1.26	6.3	0.28	-0.28
Crop Season 2017													
Cotton Alone (P_1)	2928	0	0	1.00	1.00	0	0	0	0	1.00	1.00	0	0
S.flower Alone (P_2)	0	3002	1.00	0	1.00	0	0	0	1.00	0	1.00	0	0
S.flower + Cotton (P_3)	2383	2752	0.92	0.81	1.73	1.13	0.89	2.01	11.00	4.37	15.37	0.10	-0.10
S.flower + Cotton (P_4)	1758	2308	0.77	0.60	1.37	1.28	0.78	2.06	3.32	1.50	4.82	0.17	-0.17

Relative Crowding Coefficient (RCC or K)

RCC shows if a crop cultivated in a mixed population has yielded more than what would have been predicted in a pure stand. (Panda, 2006). The results indicated that relative crowding coefficient of sunflower is higher (28.79, 11.00) in both intercropping seasons when intercropped in a 75 cm spaced single row. The results showed (Table 1) that sunflower is more competitive than cotton in this study. However, partial and KTotal were above one in all intercropping systems in both seasons, demonstrating a clear production advantage due to growing crops in proximity with each other under specific planting patterns (Banik, 2000). A yield disadvantage was indicated by a K value less than one (Willey and Rao, 1980; Gosh, 2004). The K value pattern and the LER value pattern were fairly comparable.

Competitive Ratio (CR)

CR is determined to measure interspecific competition. CR of sunflower and cotton was influenced by the intercropping system (Trydeman et al., 2004). The results showed that intercropped sunflower depicted a higher competitive ratio which indicated that sunflower is more competitive (CR>1) in both season (2016 and 2017). In both the seasons of experimentation, sunflowers intercropped with cotton at 112.5 cm spaced double rows showed more competitiveness (1.48, 1.28), followed by sunflowers sown with cotton in 75 cm spaced single row (1.21, 1.13). It illustrates the dominance of sunflower over cotton (Table 1) and the less competitiveness of cotton (CR<1) in the intercropping system. The fast growth of sunflower might create shade over cotton and utilize the growth-limiting nutrient resource (Berntsen et al., 2004). The results of the contemporary study are in line with the findings of Narwal (2004) and Oliveira et al. (2011) that crop reciprocal effects and improved resource use are linked to yield advantage and competitiveness. This might also be attributed to higher uptake of nutirnts by sunflower than cotton which creates a suppressive microclimate for cotton, resulting in poor cotton growth and yield.

Aggressivity (A)

It indicates how much component a's relative yield increase is higher than component b's (Panda, 2006).(Panda, 2006). The results showed that the sunflower crop was dominant (ASunflower positive) and cotton was dominated (ACotton negative). In first year crop season (2016) the A values 0.16 (P3), 0.28 (P4) while in season 2017 the A values 0.10 (P3), 0.17 (P4) were observed in the sunflower-cotton intercropping system (Table 1). The higher value, either positive or negative, signifies a wide difference in competing abilities, except that the positive values indicate dominate and negative values means dominated. Similarly, the aggressivity was noted quite higher in mustard-legume intercropping (Beenik, 2000). The higher aggressivity might be attributed to the fast growth of sunflower than cotton which allows sunflower to dominate cotton crop in its vicinity.

CONCLUSION

It can be concluded from the field investigation that intercropping cotton in sunflower with different planting patterns affects the yields of intercrops and competition between the crops. However, intercropping of cotton in sunflower with 75 cm spaced single row had yield advantage of intercropping to exploit the environmental resources compared with other intercropping systems. Therefore, it is concluded that this practice can be used by the farmers of arid irrigated areas. The reduction in cotton crop areas and opt for other crops in the region is a threat to cotton crop. However, this study supports and facilitates farmers to not give up the cultivation of cotton. Instead, cotton crop can be sown as intercrop in sunflower to get maximum profitability. The results of this study regarding testing the feasibility of sunflower and cotton intercropping also support its wide spread use.

RESEARCH NEEDS AND LIMITATIONS

Further research is essential to include other combinations in sunflower-cotton intercropping system under different agro ecological zones including socio-economic aspects of intercropping. Usually, intercropping is conducted without proper machinery that limits its adaptation at large scale. Hence, there is urgent need to devise such type of machinery that can facilitate and encourage the farmers to adapt these types of practices for better external resource utilization and economic returns.

AUTHOR'S CONTRIBUTION

Asmat Ullah planned the idea of feasibility and supervised the experiment. Fiaz Hussain conducted the research trial and collected the data. Asmat Ullah performed the data analysis and figured out the intercropping indices. Siraj Ahmed, Sana Ullah, and Saba Iqbal prepared the initial draft of the manuscript. Hafiz Naveed Ramzan, Muhammad Idrees, Saeed ur Rehman, Naveed Akhtar, and Iqtidar Hussain critically revised the manuscript. All authors read and approved the final manuscript.

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There was no external source of funding for the study.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this published article in the form of tables and figures.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not required for this study, as it involved only crop research and did not include human or animal subjects.

CONSENT FOR PUBLICATION

Not applicable. This study does not involve any individual person's data in any form. All authors are agreed for its publication.

CONFLICT OF INTERESTS

Authors have no conflict of Interest regarding this publication.

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