

## EFFECT OF POTASSIUM AND FOLIAR NAPHTHALENE ACETIC ACID APPLICATION RATES FOR ENHANCING YIELD AND YIELD COMPONENTS OF MAIZE

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### Abstract

A study entitled “Effect of potassium and foliar naphthalene acetic acid application rates for enhancing yield and yield components of maize” was carried out at Agronomy Research Farm, The University of Agriculture Peshawar during summer 2024. The experiment was conducted in randomized complete block design with three replications. CS-220 maize hybrid was sown at the rate of 25 kg ha<sup>-1</sup>. There were two factors in this experiment, naphthalene acetic acid (0, 40, 80 and 120 ml ha<sup>-1</sup>) and potassium (0, 30, 60 and 90 kg ha<sup>-1</sup>). According to the results of experiment, naphthalene acetic acid and potassium had a significant effect on yield and its components of maize hybrid. Application of naphthalene acetic acid at the rate of 120 ml ha<sup>-1</sup> significantly increased days to tasseling (55), silking (65), physiological maturity (96), leaves plant<sup>-1</sup> (15), leaf area plant<sup>-1</sup> (3784 cm<sup>2</sup>), taller plants (176 cm), ears density (8), grains ear<sup>-1</sup> (340), thousand grain weight (230 g), biological yield (11549 kg ha<sup>-1</sup>), grain yield (4927 kg ha<sup>-1</sup>) and harvest index (43 %). While at the application of potassium levels, higher days to tasseling (55), silking (65), physiological maturity (96), leaves plant<sup>-1</sup> (14), leaf area plant<sup>-1</sup> (3853 cm<sup>2</sup>), taller plants (176 cm), ears density (8), grains ear<sup>-1</sup> (341), thousand grain weight (233 g), biological yield (12508 kg ha<sup>-1</sup>), grain yield (4730 kg ha<sup>-1</sup>) was recorded at 90 kg K ha<sup>-1</sup> while higher harvest index (38 %) was noted at 30 kg K ha<sup>-1</sup>. The application of naphthalene acetic acid at 120 ml ha<sup>-1</sup> applied as a foliar spray and potassium at 90 kg ha<sup>-1</sup> gave significantly high yield and yield components of CS-220 maize hybrid.

### Keywords:

*CS-220 hybrid, Naphthalene acetic acid (NAA), Potassium, Foliar application, phenological and yield components.*

## INTRODUCTION

Maize (*Zea mays* L.) is the third-largest cereal crop in the world, crucial for nutrition, livestock feed, and industry (Shah et al., 2016; Ramzani et al., 2017). It contains essential nutrients like protein, oil, sugar, fiber, and starch (Zilic et al., 2011). In Pakistan, especially in Khyber Pakhtunkhwa maize is the third most significant crop (Iqbal & Iqbal, 2015). To achieve food security, agricultural production in particular maize, needs to increase by 70 % to meet the world population (Pawlak and Kołodziejczak, 2020).

Crop growth regulators (CGRs) play a crucial role in increasing productivity by minimizing lodging and improving grain formation. Lodging hampers, the transport of water, nutrients, and photosynthetic enzymes, reducing maize production. Plant growth regulators (PGRs) raise the standard and productivity while making harvesting easier. They are complementary agricultural methods to genetic engineering for boosting crop yield and optimizing resource utilization. Plant growth regulators (PGRs) have been used in agriculture due to their relatively low adverse chemical effects, which are often limited to specific crops (Djanaguiraman and Ramesh, 2013). In field crops, they enhance the distribution and movement of nutrients from the source to the sink. Naphthalene acetic acid (NAA) enhances growth characteristics and stimulates reproductive growth by encouraging cell division, expansion, and elongation during vegetative growth. The green cob yield of baby corn is positively impacted by growth regulator sprays (Hussain et al., 2021).

A synthetic auxin called naphthalene acetic acid (NAA) improves plant growth potential by increasing quantities of sugars, proteins, carbs and antioxidant enzymes and facilitating nutrient transport. In addition, also increases crop yields by acting as a growth regulator (Khan et al., 2019). These solutes are ideal as osmoprotectants due to their non-toxic nature, low molecular weight, and high solubility even at elevated cellular concentrations. They effectively safeguard biological components from dehydration (Ullah et al., 2021). By facilitating the upward movement of nutrients, NAA enhances plant growth and physiological characteristics, including higher concentrations of proteins, carbohydrates, and sugars (Tůmová et al., 2018). NAA functions as a synthetic growth regulator that enhances plant growth, yield, and production, especially in tomatoes (Abou El-ghit, 2015).

According to Mallikarjuna et al. (2022), potassium (K) is a macronutrient that is vital for metabolism, crop growth, and other regulatory functions that have an immediate effect on yield and quality. K dramatically strengthens plant defense mechanisms by activating more than 60 enzymes that are involved in controlling stresses that plants experience, both biotic and abiotic (Wang et al., 2013; Pandey and Mahiwal, 2020). K deficiency in crops alters control of transcription factor (TF) and coding genes produced by stress (Yang et al., 2021; Wang et al., 2022; Wei et al., 2022). Phosphorus (P) and nitrogen (N) fertilizers in recent years has resulted in imbalanced fertilization and a lack of accessible K in soils used to grow maize (Zhu et al., 2021; Soumare et al., 2023). Only a portion of K in the soil (dissolved or exchangeable) is present to plants, and this is referred to as soil K (Wakeel and Ishfaq, 2022). Consequently, the lack of K has impeded crop yield (Li et al., 2017). K a major impact on crop quality, yield, absorption, and transport of nutrients as well as stress tolerance (Johnson et al., 2022 and Zhang et al., 2023). However, compared to N, K has received less attention for yield enhancement because its effects are slower, particularly in soils high in K (Qiu et al., 2014).

Growth parameters such as shoot length, leaf size along with corrinas, and leaf plant<sup>-1</sup> were measurably increased with the application of foliar sprays of NAA (naphthalene acetic acid) ranging from 50 mg L<sup>-1</sup> to 100 mg L<sup>-1</sup> and K nitrate 500 mg L<sup>-1</sup> to 1000 mg L<sup>-1</sup>. Specifically on leaves plant<sup>-1</sup> and branches plant<sup>-1</sup> all rose dramatically (Alotaibi et al., 2024). Meanwhile, a one year experiment showed that when 120 kg nitrogen ha<sup>-1</sup> and 40 ppm naphthalene acetic acid on baby corn yield increased by 25%. It proved efficient than the standard dosage (Rao et al., 2021).

The objectives of this study were to evaluate the effects of different concentrations of foliar-applied naphthalene acetic acid and soil-applied potassium on the productivity of a maize hybrid and to determine their interactive influence on maize hybrid yield.

## Materials and Methods

### Experimental Site and Treatment Details

Effect of potassium and foliar naphthalene acetic acid application rates for enhancing yield and yield components of maize was carried out at Agronomy Research Farm, The University of Agriculture Peshawar during summer 2024. To guarantee statistical reliability and reduce differences due to the site's layout, the experiment was conducted in three replications following the RCBD. In the experiment, the following factors were investigated: factor A was naphthalene acetic acid (NAA, ml ha<sup>-1</sup>) (0 (water spray), 40, 80 and 120) and factor B was potassium (K, kg ha<sup>-1</sup>) (Control, 30, 60 and 90). Plot size was 3.5m × 3m, while maintaining the spacing between plants and rows at 20 and 70 cm, respectively. The crop variety CS-220 was seeded at a rate of 25 kg per hectare, as advised by the recommended practices. Naphthalene acetic acid was applied at V<sub>3</sub> stage with the help of sprayer. To make 40, 80 and 120 ml ha<sup>-1</sup> naphthalene acetic acid solutions 0.042, 0.084 and 0.126 ml naphthalene acetic acid was added in 600 ml water per plot. For NAA, phytofix' (4.5 % w/v) was used. The weeds were tended to by hand. Standard agronomic practices were followed to maintain the field.

### Growth and Phonological Observation

Plants reached tasseling stage during the period from planting until 80 percent of plants in each plot produced tassels. The observation date for tasseling stage will be documented visually then averaged for each reading. The period from seed planting until when eighty percent of plants exhibited silking stages was recorded by counting the total days. A single reading obtained from visual observations provides the date information which gets averaged for one trial. Plants reached maturity when 80% of plants within a plot achieved maturity to determine the days to physiological maturity. After the plants were considered physiologically mature, five of them were chosen at random from every experimental unit to count their leaves. The leaf area plant<sup>-1</sup> calculation utilized the average leaf areas from five randomly chosen plants in each experimental unit through the following formula. Leaf area plant<sup>-1</sup> (cm<sup>2</sup>) = Leaf length x leaf width x Correction factor. Once plants matured, five plants per experimental group were measured for their height. With the graduated stick, we measured the height from the ground up to where the tassel started. After measuring all the plants, the mean plant height was found for each treatment using the collected data.

## Yield and Yield Components Observation

At three locations randomly chosen in a row of a meter length, ears  $m^{-2}$  was counted on each plot. The data was afterwards averaged and converted to ears  $m^{-2}$ . For each region, ten of ten ear cobs were randomly chosen and grains counted. Finally, the mean of the results was calculated. The seed lot from each plot was sampled by random weighing, tallying and averaging 1000 grains from each plot. At maturity, the main rows from every experimental unit were picked, bound and left out to dry for ten days in the sun. Each package was weighed on a digital balance to find out how much was produced biologically. After harvesting, the data was changed to kilograms per hectare using the plot area. The same formula as equation 1 was used for it. The three core rows were harvested with a sickle and were then placed in each plot. After dehusking, drying and shelling the maize seeds were weighed with an electronic scale. It was converted to  $kg\ ha^{-1}$  by the following equation 1. Grain yield ( $kg\ ha^{-1}$ ) = (Biological or grain yield/ Row length x No. of rows x R-R distance) x 10000. The harvest index (HI) was set as the amount of grain yield against the total yield produced above the ground (HI = grain yield divided by total biomass) for each unit. Both the grain yield and overall biomass was recorded from data taken in one area. After deriving ratios, the resulting number had to be multiplied by one hundred to convert it to a percentage value.

## Statistical analysis

Using a randomized complete block design (RCBD), the experimental data were analyzed with ANOVA. We applied Fisher's LSD test when the P value in the ANOVA treatment analysis was less than 0.05 (Steel & Torrie, 1997).

## Results

### Days to tasseling

Analysis of variance (ANOVA) exhibited that naphthalene acetic acid (NAA) and potassium (K) significantly affected days to tasseling (Table 1). The interaction between NAA and K was found non-significant. Mean data exhibited that higher day to tasseling (55) was noted in plots where 120 ml NAA  $ha^{-1}$  was applied followed by 80 ml NAA  $ha^{-1}$  (54) and less days to tasseling was noted in no application plots (53). While in potassium levels, longest tasseling period (55) was recorded in 90 kg K  $ha^{-1}$  followed by 60 and 30 kg K  $ha^{-1}$  (54) while earliest tasseling period was recorded in control plots (53).

### Days to silking

ANOVA showed that NAA and K significantly affected days to silking (Table 1). The interaction between NAA and K was found non-significant. Delayed silking (65) was noted in plots where 120 ml NAA  $ha^{-1}$  was applied followed by 80 and 40 ml NAA  $ha^{-1}$  (64) and early silking was noted in control plots (62). While in potassium levels, longest tasseling period (65) was recorded in 90 kg K  $ha^{-1}$  followed by 60 and 30 kg K  $ha^{-1}$  (64) while earliest silking was recorded in control plots (62).

### Days to physiological maturity

ANOVA showed that NAA and K significantly affected days to physiological maturity (Table 1). The interaction between NAA and K was found non-significant. Among the NAA levels, higher day to physiological maturity (96) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 and 40 ml NAA ha<sup>-1</sup> (95) and less days to physiological maturity was noted in control plots (94). While in potassium levels, higher days to physiological maturity (96) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 and 30 kg K ha<sup>-1</sup> (95) while less days to physiological maturity was recorded in control plots (93).

**Table 1: Days to tasseling, silking and maturity of maize hybrid as impacted by various naphthalene acetic acid and potassium rates.**

Treatments	Days to tasseling	Days to silking	Days to maturity
<b>Naphthalene Acetic Acid (NAA) (ml ha<sup>-1</sup>)</b>			
0	53 b	62 c	94 b
40	53 b	64 b	95 ab
80	54 b	64 ab	95 a
120	55 a	65 a	96 a
<b>LSD<sub>(0.05)</sub> for NAA</b>	1	1	1
<b>Potassium Rates (K) (kg ha<sup>-1</sup>)</b>			
0	53 b	62 b	93 c
30	54 b	64 a	95 b
60	54 ab	64 a	95 ab
90	55 a	65 a	96 a
<b>LSD<sub>(0.05)</sub> for K</b>	1	1	1
<b>Interaction (NAA × K)</b>	NS	NS	NS

There are notable differences between the means of the same category with different letters.

### Number of leaves plant<sup>-1</sup>

ANOVA showed that NAA and K significantly affected leaves plant<sup>-1</sup> (Table 2). The interaction between NAA and K was found non-significant. The mean data showed that more leaves plant<sup>-1</sup> (15) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 and 40 ml NAA ha<sup>-1</sup> (13) and few leaves plant<sup>-1</sup> was noted in control plots (12). While in potassium levels, more leaves plant<sup>-1</sup> (14) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 and 30 kg K ha<sup>-1</sup> (13) while few leaves plant<sup>-1</sup> were recorded in control plots (12).

### Leaf area plant<sup>-1</sup> (cm<sup>2</sup>)

ANOVA revealed that NAA and K significantly affected leaf area plant<sup>-1</sup> (Table 2). The interaction between NAA and K was found non-significant. Data analysis showed that higher leaf area of plant<sup>-1</sup> (3784) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (3574) and a smaller number of leaf area of plant<sup>-1</sup> was noted in control plots (3262). While in potassium levels,

higher number of leaf area of plant<sup>-1</sup> (3853) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> (3607) while a smaller number of leaf area of plant<sup>-1</sup> was recorded in control plots (3181).

### Plant height (cm)

ANOVA exhibited that NAA and K significantly affected number of plant height (Table 2). The interaction between NAA and K was found non-significant. Mean table of data indicated that higher plant height (176 cm) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (171 cm) and a smaller number of plant height was noted in control plots (160 cm). While in potassium levels, higher number of plant height (176 cm) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> (171 cm) while a smaller number of plant height was recorded in control plots (161 cm).

**Table 2. Number of leaves plant<sup>-1</sup>, leaf area plant<sup>-1</sup> (cm<sup>2</sup>) and plant height (cm) of maize hybrid as impacted by various naphthalene acetic acid and potassium rates.**

Treatments	Number of leaves plant <sup>-1</sup>	Leaf area plant <sup>-1</sup> (cm <sup>2</sup> )	Plant height (cm)
<b>Naphthalene Acetic Acid (NAA) (ml ha<sup>-1</sup>)</b>			
0	12 c	3262 c	160 b
40	13 b	3499 b	166 ab
80	13 b	3574 ab	171 a
120	15 a	3784 a	176 a
LSD <sub>(0.05)</sub> for NAA	1	211	11
<b>Potassium Rates (K) (kg ha<sup>-1</sup>)</b>			
0	12 c	3181 c	161 a
30	13 b	3478 b	166 b
60	13 b	3607 b	171 ab
90	14 a	3853 a	176 a
LSD <sub>(0.05)</sub> for K	1	211	11
<b>Interaction (NAA × K)</b>	NS	NS	NS

There are notable differences between the means of the same category with different letters.

### Number of ears m<sup>-2</sup>

ANOVA exhibited that NAA and K significantly affected number of ears m<sup>-2</sup> (Table 3). The interaction between NAA and K was found non-significant. Mean data show that higher number of ears m<sup>-2</sup> (8) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (7) and a smaller number of ears m<sup>-2</sup> was noted in control plots (7). While in potassium levels, higher number of ears m<sup>-2</sup> (8) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> which is also (8) while a smaller number of ears m<sup>-2</sup> was recorded in control plots (7).

### Number of grains ear<sup>-1</sup>

ANOVA exhibited that NAA and K significantly affected number of grains ear<sup>-1</sup> (Table 3). The interaction between NAA and K was found non-significant. Among NAA levels, higher number of grains ear<sup>-1</sup> (340) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (324) and a smaller number of grains ear<sup>-1</sup> was noted in control plots (301). While in potassium levels, higher number of grains ear<sup>-1</sup> (341) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> (325) while a smaller number of grains ear<sup>-1</sup> was recorded in control plots (300).

### Thousand grain weight (g)

ANOVA showed NAA and K significantly affected thousand grain weight (Table 3). The interaction between NAA and K was found non-significant. Mean data indicated that higher thousand grain weight (230 g) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (224 g) and a smaller number of thousand grain weight was noted in control plots (214 g). While in potassium levels, higher thousand grain weight (233 g) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> (226 g) while a smaller number of thousand grain weight was recorded in control plots (212 g).

**Table 3. Number of ears m<sup>-2</sup>, grains ear<sup>-1</sup> and thousand grain weight (g) of maize hybrid as impacted by various naphthalene acetic acid and potassium rates.**

Treatments	Ears m <sup>-2</sup>	Grains ear <sup>-1</sup>	Thousand grain weight (g)
<b>Naphthalene Acetic Acid (NAA) (ml ha<sup>-1</sup>)</b>			
0	7 c	301 c	214 d
40	7 b	319 b	219 c
80	7 b	324 b	224 b
120	8 a	340 a	230 a
LSD <sub>(0.05)</sub> for NAA	0.4	15	5
<b>Potassium Rates (K) (kg ha<sup>-1</sup>)</b>			
0	7 c	300 c	212 d
30	7 b	317 b	218 c
60	8 ab	325 b	226 b
90	8 a	341 a	233 a
LSD <sub>(0.05)</sub> for K	0.4	15	5
<b>Interaction (NAA × K)</b>	NS	NS	NS

There are notable differences between the means of the same category with different letters.

### Biological yield (kg ha<sup>-1</sup>)

ANOVA showed that NAA and K significantly affected biological yield (Table 4). The interaction between NAA and K was found non-significant. Mean data indicated that higher biological yield (11549 kg ha<sup>-1</sup>) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (11217 kg ha<sup>-1</sup>) and a smaller number of biological yield was noted in control plots (10224 kg ha<sup>-1</sup>). While in potassium levels, higher number of biological yield (12508 kg ha<sup>-1</sup>) was recorded in 90 kg K ha<sup>-1</sup>

followed by 60 kg K ha<sup>-1</sup> (11070 kg ha<sup>-1</sup>) while a smaller number of biological yield was recorded in control plots (9745 kg ha<sup>-1</sup>).

### Grain yield (kg ha<sup>-1</sup>)

ANOVA showed that NAA and K significantly affected grain yield (Table 4). The interaction between NAA and K was found non-significant. Among NAA levels, higher number of grain yield (4927 kg ha<sup>-1</sup>) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (4295 kg ha<sup>-1</sup>) and a smaller number of grain yield was noted in control plots (3517 kg ha<sup>-1</sup>). While in potassium levels, higher number of grain yield (4730 kg ha<sup>-1</sup>) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> (4187 kg ha<sup>-1</sup>) while a smaller number of grain yield was recorded in control plots (3695 kg ha<sup>-1</sup>).

### Harvest index (%)

ANOVA showed that NAA and K significantly affected harvest index (Table 4). The interaction between NAA and K was found non-significant. Mean data show that higher harvest index (43%) was noted in plots where 120 ml NAA ha<sup>-1</sup> was applied followed by 80 ml NAA ha<sup>-1</sup> (38 %) and a smaller number of harvest index was noted in control plots (34 %). While in potassium levels, higher number of harvest index (38%) was recorded in 90 kg K ha<sup>-1</sup> followed by 60 kg K ha<sup>-1</sup> which is also (38%) while a smaller number of harvest index was also same which is recorded in control plots (38%).

**Table 4. Biological yield (kg ha<sup>-1</sup>), grain yield (kg ha<sup>-1</sup>) and harvest index (%) of maize hybrid as impacted by various naphthalene acetic acid and potassium rates.**

Treatments	Biological yield (kg ha <sup>-1</sup> )	Grain yield (kg ha <sup>-1</sup> )	Harvest index (%)
<b>Naphthalene Acetic Acid (NAA) (ml ha<sup>-1</sup>)</b>			
0	10224 c	3517 d	34 c
40	10759 b	3883 c	36 bc
80	11217 a	4295 b	38 b
120	11549 a	4927 a	43 a
LSD(0.05) for NAA	409	245	3
<b>Potassium Rates (K) (kg ha<sup>-1</sup>)</b>			
0	9745 d	3695 c	38
30	10425 c	4011 b	38
60	11070 b	4187 b	38
90	12508 a	4730 a	38
LSD(0.05) for K	409	245	NS
Interaction (NAA × K)	NS	NS	NS

There are notable differences between the means of the same category with different letters.

### Principal component analysis (PCA)

Principal component analysis (PCA) was performed to evaluate the contribution of morphological and yield-related traits of hybrid maize under varying levels of naphthalene acetic acid (NAA) and

potassium (K). The first two principal components (PC1 and PC2) explained 70.72% of the total variability, with PC1 accounting for 61.11% and PC2 contributing 9.61% of the variance (Fig. 1).

PC1 was strongly and positively associated with grain yield (GY), biological yield (BY), thousand grain weight (TGW), number of leaves plant<sup>-1</sup> (NLP), leaf area plant<sup>-1</sup> (LAP), ears m<sup>-2</sup> (EM2), grains ear<sup>-1</sup> (GPE), and plant height (PH). This indicates that these parameters are the main contributors to yield improvement under the influence of NAA and potassium application. Conversely, PC1 exhibited weak loadings for phenological traits such as days to tasseling (DTT), days to silking (DTS) and days to maturity (DTM), suggesting that these traits contributed less to the variability explained.

PC2 was mainly explained by harvest index (HI), which loaded positively and separately from the other traits, suggesting that HI had a distinct contribution compared to yield and growth-related parameters.

The distribution of treatments showed that higher doses of NAA (120 ml ha<sup>-1</sup>) combined with increasing potassium levels (30–90 kg ha<sup>-1</sup>) clustered in the positive quadrant of PC1, closely associated with grain yield and yield-contributing traits. In contrast, control treatments (0 ml ha<sup>-1</sup> NAA with low or no potassium) were positioned on the negative side of PC1, indicating their weaker association with yield performance.

Overall, the PCA biplot revealed that the synergistic application of NAA and potassium had a strong influence on yield-related attributes, while phenological traits had less influence on variability under the given experimental conditions.

### Correlation Analysis

The correlation analysis revealed significant positive associations among most of the morphological and yield-related traits of hybrid maize (Fig. 2). Grain yield (GY) showed strong positive correlations with biological yield (BY,  $r = 0.77$ ), thousand grain weight (TGW,  $r = 0.77$ ), number of leaves per plant (NLP,  $r = 0.75$ ) and days to silking (DTS,  $r = 0.76$ ). This indicates that higher grain yield is closely linked with greater vegetative growth, assimilates partitioning, and improved grain development.

Similarly, BY exhibited significant correlations with TGW ( $r = 0.75$ ), leaf area per plant (LAP,  $r = 0.71$ ) and days to maturity (DTM,  $r = 0.72$ ), highlighting its dependence on both physiological duration and assimilatory surface area. LAP was strongly correlated with TGW ( $r = 0.78$ ), suggesting that enhanced photosynthetic area contributes directly to grain filling and seed weight.

Phenological traits such as DTS and DTM also showed positive correlations with GY ( $r = 0.76$  and  $r = 0.68$ , respectively), implying that extended crop duration favoured yield accumulation. However, harvest index (HI) exhibited weak or negligible correlations with BY ( $r = 0.14$ ), LAP ( $r = 0.31$ ) and PH ( $r = 0.30$ ), suggesting its independence from biomass accumulation and morphological traits.

Overall, the results indicate that yield improvement in hybrid maize is mainly driven by TGW, BY, NLP and LAP, whereas HI contributed independently and had weaker linkages with growth-related parameters.

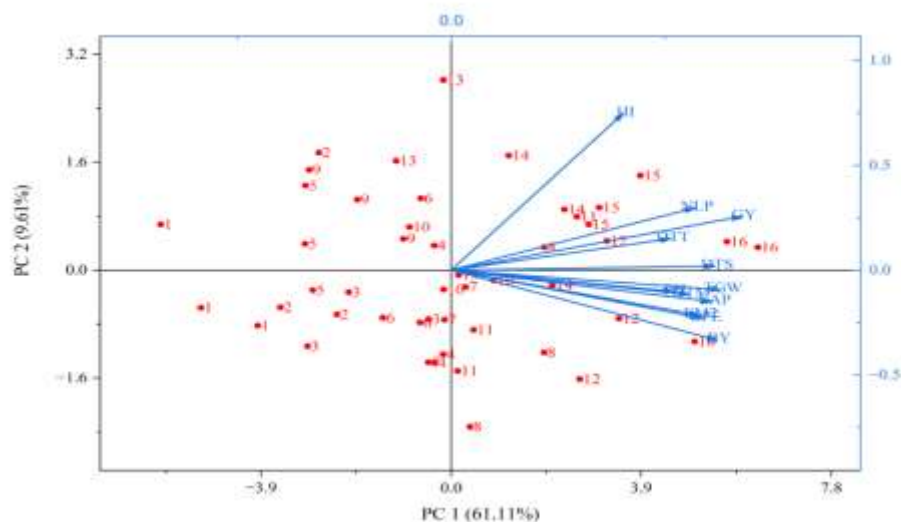


Figure 1. Principal component analysis for the maize

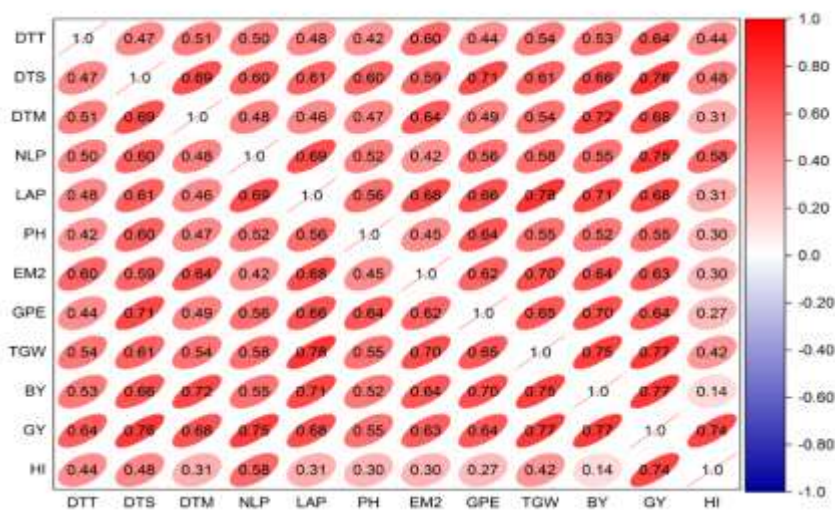


Figure 2. Correlation analysis for the studied traits of hybrid maize.

DTT= Days to tasseling, DTS = Days to silking, DTM = Days to maturity, NLP = number of leaves plant<sup>-1</sup>, LAP = Leaf area plant<sup>-1</sup> (cm<sup>2</sup>), PH = Plant height (cm), EM2 = Ears m<sup>-2</sup>, GPE = Grains ear<sup>-1</sup>, TGW = Thousand grain weight (g), BY = Biological yield (kg ha<sup>-1</sup>), GY = Grain yield (kg ha<sup>-1</sup>), HI = Harvest index (%)

1 = (0 ml ha<sup>-1</sup> NAA + 0 kg ha<sup>-1</sup> K), 2 = (0 ml ha<sup>-1</sup> NAA + 30 kg ha<sup>-1</sup> K), 3 = (0 ml ha<sup>-1</sup> NAA + 60 kg ha<sup>-1</sup> K), 4 = (0 ml ha<sup>-1</sup> NAA + 90 kg ha<sup>-1</sup> K), 5 = (40 ml ha<sup>-1</sup> NAA + 0 kg ha<sup>-1</sup> K), 6 = (40 ml ha<sup>-1</sup> NAA + 30 kg ha<sup>-1</sup> K), 7 = (40 ml ha<sup>-1</sup> NAA + 60 kg ha<sup>-1</sup> K), 8 = (40 ml ha<sup>-1</sup> NAA + 90 kg ha<sup>-1</sup> K), 9 = (80 ml ha<sup>-1</sup> NAA + 0 kg ha<sup>-1</sup> K), 10 = (80 ml ha<sup>-1</sup> NAA + 30 kg ha<sup>-1</sup> K), 11 = (80 ml ha<sup>-1</sup> NAA + 60 kg ha<sup>-1</sup> K), 12 = (80 ml ha<sup>-1</sup> NAA + 90 kg ha<sup>-1</sup> K), 13 = (120 ml ha<sup>-1</sup> NAA + 0 kg ha<sup>-1</sup> K), 14 = (120 ml ha<sup>-1</sup> NAA + 30 kg ha<sup>-1</sup> K), 15 = (120 ml ha<sup>-1</sup> NAA + 60 kg ha<sup>-1</sup> K), 16 = (120 ml ha<sup>-1</sup> NAA + 90 kg ha<sup>-1</sup> K)

## Discussion

Mean data demonstrated that application of potassium and naphthalene acetic acid had delayed the tasseling stage of maize hybrid. These results are similar with Shah et al. (2017) that the role of potassium in photosynthetic activity delayed the tasseling of highest K. Our findings are in line with Zamir et al. (2015) who reported that applying higher K can delay the tasseling stage of maize.

The analysis of data revealed delayed silking in plots having 120 ml NAA ha<sup>-1</sup>, while in 90 kg K ha<sup>-1</sup> plots was observed with more days to silking as compare to control plots. As Aslam et al. (2014) reported, increasing the potassium supply by 1 to 5 grams delayed maize silking for 2 to 3 days. Our results suggest that the delay was caused by K in the soil promoting a longer active period in plant cells. According to Shah et al. (2018), proper potassium levels (80-100 kg ha<sup>-1</sup>) boost the amount of chlorophyll, allowing photosynthesis to continue longer and delaying the start of reproduction. The similar pattern in both NAA and K treatments suggests that moderately controlling plant growth, through either hormones or fertilizer, manipulates maize growth in a similar way. Similar results were given by Akter (2010), who observed that NAA affects some growth parameters in maize including vegetative phase extension and delay reproductive events (tasseling). It might be due to the fact that NAA facilitates cell division and elongation, thereby increasing the duration of vegetative growth periods.

Mean data exhibited delayed maturity in plots having NAA at the rate of 120 ml ha<sup>-1</sup>, while potassium at the rate of 90 kg ha<sup>-1</sup>. According to Bukhsh et al. (2009) stated that applying K increased the nitrogen uptake which delayed the physiological maturity of maize crop. Our results were similar with Asif et al. (2007), who reported that applying K in soil can delayed the physiological maturity of the maize crop. These results were supported by Iqbal et al. (2016), who reported that physiological maturity delayed with increasing the K levels.

The application of NAA and potassium @ 120 ml ha<sup>-1</sup> and 90 kg ha<sup>-1</sup> was increased the number of leaves plant<sup>-1</sup> of maize hybrid. The results were in line with Hussain et al. (2021) who stated that maximum number of leaves plant<sup>-1</sup> of sorghum crop was recorded at 160 ml NAA ha<sup>-1</sup>.

Statistical analysis revealed significant effects ( $p < 0.05$ ) of naphthalene acetic acid (NAA) and potassium (K) application rates on leaf area per plant in maize hybrids. Khan et al. (2021) reported that maximum leaf area plant<sup>-1</sup> was observed at 120 kg K ha<sup>-1</sup> which was at par with 90 kg K ha<sup>-1</sup>. Aslam et al. (2013) observed that applying 100 mg kg<sup>-1</sup> K in soil was increased the leaf area of maize. Our results were contrasting with Gong et al. (2021) reported that leaf area was decreased with the use of plant growth regulators (EDAH which contain 27% ethephon and 3% DA-6).

Mean data of plant height demonstrated that NAA 120 ml ha<sup>-1</sup> and K 90 kg ha<sup>-1</sup> observed maximum plant height of maize hybrid. According to Sankadiya and Sanodiya (2021), who observed that applying 70 kg phosphorus ha<sup>-1</sup> with the combination of 60 kg potassium ha<sup>-1</sup> produced the tallest plants of maize crop. Applying Azotobacter + KSB + potassium 50 kg ha<sup>-1</sup> produced the maximum plant height of maize as observed by Kumar and Mehera (2022). Similar results were given by Waqas et al. (2017),

who observed that plant growth regulator at tasseling stage was significantly increased the plant height of maize.

The data analysis revealed that NAA and K had positively influenced the number of ears  $m^{-2}$  of maize hybrid. The results were accordance with Ortas (2018) reported that increasing the level of K will produce the higher number of ears  $m^{-2}$ . Maximum number of cobs  $plant^{-1}$  was observed when 50 kg K + 15 kg Zinc was applied (Sravan et al., 2021).

Mean data demonstrated that NAA applied at the rate of 120 ml  $ha^{-1}$  and 90 kg K  $ha^{-1}$  produced higher grains  $ear^{-1}$  of maize hybrid. It was likely that the K application increased in the water use efficiency of crops under water limited conditions that led to overall dry matter production and hence partitioned to the reproductive part of the plant and increased the grains  $ear^{-1}$  (Iqbal et al., 2016). The results were also confirmed by Salimi et al. (2013) revealed that highest K level produced the higher grains  $ear^{-1}$  which was accordance with our findings.

Data analysis showed that thousand grain weight was the highest when 90 kg K  $ha^{-1}$  and 120 ml NAA  $ha^{-1}$  were used. According to Ali et al. (2016), who reported that foliar application of 3 % potassium source of  $K_2SO_4$  was significantly increased thousand grain weight of maize. The findings are also best sustained by Ertiftik and Zengin (2017), stated that increasing the dosage of K fertilizer can increase the thousand grain weight of maize. The results are contradicting with Xu et al. (2024), found that applying fresh water recorded maximum thousand grain weight as compared to application of other plant regulators. When NAA was applied at rate of 25 mg  $l^{-1}$  has significantly increased the thousand grain weight of wheat crop (Jahan et al., 2019).

Mean data reveals that applying NAA at 120 ml  $ha^{-1}$  and K at 90 kg  $ha^{-1}$  produces a better biological yield of maize. Research found that the use of nano-potassium resulted in the most significant harvest of maize (Kandil et al., 2020). Shah et al. (2018) also found that 160 kg K  $ha^{-1}$  was similar to the maximum production of 120 kg K  $ha^{-1}$ . Ren et al. (2024) found that applying both ethephon and cycocel during V14 can increase maize yields by about 8.1%. Jiang and colleagues discovered that using NAA nearly doubled maize biomass in their study.

Mean data of grain yield demonstrated that NAA and K had significantly affected the grain yield of maize hybrid. Maize yield increased by 1.3 kg  $ha^{-1}$  in two splits of 90 kg  $ha^{-1}$  of soil K (Amanullah et al. 2016). According to Ravindra et al. (2016), using 100 kg K  $ha^{-1}$  on the soil resulted in a significant improvement in grain yield compared to the control. The results agreed with Huang et al. (2021), who noticed that DHEAP therapy increased the amount of maize grain by 22.28%. Applying EDAH increased maize's grain yield by 7.8% to 8% (Zhang et al., 2014).

Analyzed data exhibited that NAA had positively affected harvest index of maize hybrid while effect of K was found non-significant. Higher harvest index of maize hybrid was recorded when applying NAA at the rate of 120 ml  $ha^{-1}$ . Our results were contradicting with Sadiq et al. (2017), stated that soil K significantly affected harvest index, who also reported that increase of 15 % over control was seen when soil K was applied at the rate of 120 kg  $ha^{-1}$ . Maurya et al. (2021) revealed a HI of 35.37 %,

corresponding to the highest grain yield of 5,015.33 kg ha<sup>-1</sup> and stover yield of 9,162.07 kg ha<sup>-1</sup> achieved through the use of 40 ppm NAA and 120 kg ha<sup>-1</sup> of nitrogen.

The biplot also indicated that there were significant relationships between GY, BY, TGW and LAP, which were close together on the same quadrant. This indicates that hybrids that have larger assimilatory surface area and seed weight are more likely to have high yields. Nzuve et al. (2013) also reported similar clustering of yield-related traits in maize, which underscores the universal nature of the traits in the improvement of crop productivity. The dominance of harvest index (HI) over other traits in PC2 (rather than vice versa) suggests that in this experimental environment partitioning efficiency (ratio of grain to total biomass) has a relatively independent behavior with respect to biomass accretion as well as morphological characteristics. The same lack of dependence of harvest index on biomass characteristics has been reported in the literature where HI was found to have a different structure of variance than growth traits (Long et al., 2024).

The positive relationship between BY and TGW ( $r = 0.75$ ), leaf area per plant (LAP,  $r = 0.71$ ) and days to maturity (DTM,  $r = 0.72$ ) further indicate that an extended growing season and increased surface area of photosynthesis contribute to the accumulation of biomass and grain filling. This is in line with the general agronomic principles and past reports that indicate that the longer the plant can develop, and the bigger the area of the foliage, the greater yield and yield stability (Ren et al. 2022). Interestingly, the harvest index (HI) showed weak or no correlation with BY, LAP and PH, which suggests that it was relatively independent of morphological parameters. This corresponds to Akinwale et al. (2014) who have determined that HI is frequently independent of vegetative biomass, and represents a more genotype-specific partitioning efficiency than overall growth.

## CONCLUSION AND RECOMMENDATION

This research showed that the naphthalene acetic acid (NAA) solution (120 mL/ha<sup>-1</sup>) remarkably increased the important growth and yield characteristics of maize such as leaves per plant, leaf area, plant height, ears m<sup>-2</sup>, grains ear<sup>-1</sup>, thousand-grain weight, biological yield, grain yield and harvest index. On the same, potassium fertilization of 90 kg ha<sup>-1</sup> significantly increased leaf area, plant height, ears m<sup>-2</sup>, grains ear<sup>-1</sup>, thousand-grain weight, biological yield and grain yield of the CS-220 hybrid maize. These findings demonstrate that NAA and potassium application is a critical element in the optimization of the physiological and agronomic performance of maize in the evaluated circumstances. According to the results of this experiment, a mixture of 120 mL ha<sup>-1</sup> of NAA and 90 kg ha<sup>-1</sup> of potassium is advisable to produce better growth, yield, and yield constituents of CS-220 maize hybrid. These findings should be confirmed in other environments and under varying soil fertility regimes in future research to enhance their relevance to other maize production systems.

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