Research Article

Comparative Analysis of Grain Yield and Filling Pattern in Maize Genotypes Under Irrigated and Rainfed Conditions in the Old Brahmaputra Floodplain, Bangladesh

Md. Azihullah[1], Ahmed Khairul Hasan[1*], Md. Abdul Kader[1], Md. Liton Mia[1], Md. Rakibul Hasan Sanet[2], Md. Atikur Rahman[3], Md. Shafiqul Islam[1*]

[1]Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh: [2]Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh: [3]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.

Abstract |In water-scarce locations, creative and sustainable methods are consequently necessary for the efficient management of water for agricultural production. An experiment was conducted at Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. Aim of the study was to investigate the yield and yield contributing characters for grain filling pattern of inbred and hybrid maize varieties under irrigated (Irricon) and rainfed condition (Raincon). A split plot arrangement using a randomized complete block design was used to set up three replications of the experiment. Four maize varieties namely Khoi Bhutta, BHM-09, C-1921, P-3396 were grown under raincon and Irricon. Among varieties, maize GY ranged between 4.42 t ha^{-1} (Khoi Bhutta) and 11.85 t ha^{-1} (C-1921) under raincon and between 6.73 t ha^{-1} (Khoi Bhutta) and 13.82 t ha^{-1} (C-1921) under Irricon. Raincon inflicted relative yield losses ranged from 14.24% to 34.32% among varieties. C-1921 allowed the least yield penalty (14.24%) while Khoi Bhutta had the maximum yield penalty (34.32%) due to raincon. On the other hand, C-1921 appeared as the most water deficit resistant variety (only 14.24% relative yield loss) with productivity of 13.82 t ha^{-1}. The highest value of individual grain weight of hybrid maize variety was P-3396 (308.1 mg) found under Irricon and second highest value of individual grain weight observed in C-1921 (356.2 mg). The highest value of maximum grain water content of hybrid maize variety was P-3396 (193.9 mg) under Irricon. Grain filling rate of P-3396 and C-1921 was statistically similar. Based on experimental results, it may be concluded that hybrid maize C-1921 can be cultivated under Irricon. Maximum grain water content and grain filling rate explained the individual grain weight variation irrespective of variety and irrigation level.

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***Correspondence** | Ahmed Khairul Hasan and Md. Shafiqul Islam, Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh. **Email:** akhasan@bau.edu.bd
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Introduction

Maize (*Zea mays L.*), an annual grass native to Mexico and Central America, is the only species in the genus *Zea* of the family Gramineae. It is one of the most important food grains in the world and ranks second in output to wheat (Asaduzzaman *et al*., 2023). The wild species collectively referred to as *teosinte* (*Zea* ssp.) and domesticated maize or corn (*Zea mays L.* ssp. mays) are both members of the genus *Zea* (Hossain *et al*., 2016). *Zea mays* is an annual, monoecious, determinate plant that can reach a height of 4 m. The broad, lanceolate leaves have a noticeable midrib and can reach a length of 100 cm. At every node, broad leaf sheaths alternate and overlap around the stalk. There are two stages of maize development: vegetative and reproductive (Strable, 2021).

Worldwide, maize is grown for food, animal feed, and industrial raw materials. Up to 70-75% of kernel's weight is made up of starch, which is the main chemical component. Protein makes 8-10% while oil makes 4-5% (Amanjyoti *et al*., 2024). Minerals, dietary fiber, water- and fat-soluble vitamins are abundant in maize kernels. However, shortages in certain key amino acids, primarily lysine and tryptophan, limit the quality of maize protein (Garcia-Lara *et al*., 2019; Xu *et al*., 2019; Zarei *et al*., 2022).

Over the past ten years, average amount of maize produced has climbed significantly. It was grown in more than 145.43 million ha with a production of 984.45 million metric tons (2013), compared to 137.43 million ha with production of 788.11 million metric tons (FAOSTAT, 2007). According to FAO production, the United States (USA) produces 371 million metric tons maize, followed by China (259 m metric t), Brazil (97.7 m metric t), and Argentina (49.5 m metric t). Mexico, India, Indonesia, and Ukraine are major producers, with an average annual production of 27–28 million metric tons. The total annual production of maize in Bangladesh is 40.15 lac tons from 11.65lac acres of land in the fiscal year 2019-2020 and the production is increasing year by year (12.5% yield was increased during2019-2020 fiscal year) (BBS, 2021). In Bangladesh, maize is increasingly playing a significant role in the rice-based farming system. In the nation, maize production and area are growing daily. At an average annual growth rate of 20%, maize is still growing quickly (CIMMYT, 2009). Bangladesh's north-western and south-western districts are where maize is primarily grown and produced. Gradually, the demand for maize is growing. Approximately 2.8 million hectares of land in the nation might be used for the production of maize (Moslehuddin *et al*., 2015). In Bangladesh, maize may be farmed all year round. In Bangladesh, maize cultivation helps with food insecurity, enhance health of cattle and poultry, and promote agro-based industrial application (Khatun *et al*., 2024; Rahman and Islam, 2014).

Despite the fact that world's food consumption is increasing, climate change has significantly reduced both water shortages and rising food demand. "During Rabi season, maize is farmed in Bangladesh under water-limited conditions (Halder *et al*., 2024a; Timsina *et al*., 2018). The amount of water available in soil for crop use has a major impact on maize yield because there is little to no rainfall throughout this cropping season or during dry seasons (Bodner *et al*., 2015). In this case, irrigation would be necessary to provide more or all of the water in order to prevent crop loss.

Water stress usually has a detrimental effect on several aspects of maize growth and physiological metabolism, including as pH, photosynthesis, dry matter production, leaf area, final yield, and nutritional content (Zhao *et al*., 2010; Zaidi *et al*., 2004; Younis *et al*., 2000). Increasing productivity, while concentrating on natural resource management, is probably the best method to stop poverty, reverse deterioration, and increase food and economic security, particularly for the resource. Poor farmers' and maize's vulnerability to moisture stress fluctuates over the course of its growth cycle, and as the water supply increases, the sub surface's drainage conditions deteriorate (Akter *et al*., 2022). Yang *et al*. (2008) observed genotype on maize yield from the different inbred and hybrid varieties. It is said that yield of early maturing maize can be achieved by selecting lines that are early maturing but have longer grain filling duration and a higher grain filling rate (Teng *et al*., 2022). The ability to normalize genotypic variance in kernel development and forecast environmental impacts on kernel growth has been demonstrated by a number of experiments conducted on commercial maize varieties. Different genotype showed different variation on kernel development in normal as well as in stressed environment (Saini and Westgate, 1999). The objective of this study was undertaken to find out the yield and yield contributing characters of inbred and hybrid maize varieties, determining variations in GY and yield contributing characters of inbred and hybrid maize under Raincon and Irricon and to observe the grain filling pattern and grain morphology of inbred and hybrid maize.

Materials and Methods

Experimental location

At Bangladesh Agricultural University's Agronomy Field Laboratory in Mymensingh, an experiment was carried out. The area being studied is situated at an angle of 18 m above the sea level, with latitudes 24°75` N and longitudes 90°50` E (Mia *et al*., 2023). The medium-high land used for experiment was part of the Sonatola Soil Series of Grey Flood zone soil, which sits in the Old Brahmaputra Floodplain's agro-ecological zone (AEZ-9). The region is made up of a sizable section of Brahmaputra sediments that were deposited down approximately 200 years ago before the river moved into its current Jamuna Channel (FAO and UNDP, 1988).

Experimental soil

The terrain was silty-loam in texture, medium high, and well-drained. The pH of 6.82, soil in the experimental field was essentially neutral in reactivity. It also had a low organic matter content (1.19%) and a poor overall fertility level. The physical attributes of top soil (0–15 cm depth) and morphological features of the soil are given (Table 1).

Climate

The experimental region was situated in a sub-tropical environment, which is characterized by high temperatures and heavy rainfall during kharif season (April–September) and somewhat low rainfall and low temperatures during rabi season (October–March).

Experimental factors and treatments

The factors and treatments included in the experiment were 4 variety namely Khoi Bhutta (Inbred, T_1), BARI Hybrid Maize-9 (hybrid, T_2), C-1921 (hybrid, T_3), P-3396 (hybrid, T_4) and irrigation level i.e. Irricon (I-1) - Irrigation at 20, 35, 70 and 85 DAS, as well as Raincon (I-2)-no irrigation during the growing period but received 39.37mm rainfall throughout the crop growth season.

Description of the varieties

Khoi bhutta

In 1986, BARI introduced this cultivar. The height of the khoi bhutta maize plant is medium. This cultivar weighs (140-150 g per 1000 grains). It has medium-sized, slender cobs. The cobs' apexes are typically empty of grain (BARI, 1986). It has a lifespan 130–140 d. The yellow and flint-colored grains can be used for popping. It can withstand insects. About 3.5-4 t of khoi bhutta are produced each hectare.

BARI hybrid maize-9

The International Maize and Wheat Improvement Center (CIMMYT) in Mexico provided a selected genetic line from which the Bangladesh Agriculture Research Institute (BARI) developed BARI hybrid maize 9, which was introduced in Bangladesh as a single line in 2007 (CIMMYT, 2007). It is a composite variety with a high yield. Plants develop robustly and quickly. Plants are hard, weighty, and powerful. Ear height is 100-115 cm, Plant height 208-239 cm and 1000 orange-yellow flint kernels weigh 340-360 g. Rabi season crops last 133–141 days with an average yield 11–13 t ha^{-1}.

C-1921

Zuari Seed India Ltd., located in Hyderabad, India, released the variety. Syngenta (Bangladesh) Limited introduced it a hybrid variety with a very high yield (Syngenta Bangladesh Ltd, 2010). It may be grown in both rabi and kharif seasons due to its distinct plant structure, it may adjust to larger populations. Plant is

Table 1: *Soil properties of the experimental field*

Physical							Chemical						
Sand (%)	Silt (%)	Clay (%)	PD (g/cc)	BD (g/cc)	Textured	Porosity (%)	pH	OM	N (%)	S (ppm)	P (ppm)	K (me%)	Zn (ppm)
32	60	8	2.60	1.35	Silt loam	46.67	6.5	1.29	0.10	14.12	16.72	0.12	2.5

**Result obtain from the mechanical analysis of the initial soil sample were done in the Soil Science Division, BINA, Mymensingh. PD= Particle density, BD= Bulk density, OM= Organic matter, N= Nitrogen, S= Sulphur, P= Phosphorus, K= potassium, Zn= Zinc*

165–180 cm with a rabi season average yield of 6–8 t ha^{-1}.

P-3396

It is an extremely productive hybrid of the rabi and kharif seasons, with distinct plant structure enables to respond a larger population. Additionally, it has excellent standability, which is necessary in the marketplace. Because of its distinct plant structure, P-3396 can produce more plants per acre. Pioneer HI Seeds Ltd., located in Hyderabad, India, released the cultivar (Pioneer Hi-Bred Seeds India Pvt. Ltd, 2010). It is a hybrid variety with a very high yield. This cultivar grows to a height of 170-185 cm. During rabi seasons, average yield of P-3396 is between 7.0 and 9.5 t ha^{-1}.

Experimental design

Three replications of the experiment were set up in a split plot arrangements in randomized complete block design, where variety in subplots and irrigation level in main plots. Two sets of treatments were used. Three duplicates of each treatment set were made. Twelve-unit plots were created from each block, and treatment combinations were assigned at split. Consequently, there were 24- experimental unit in total. Each unit plot had a 6.25 m^2 (2.5 m × 2.5 m) area.

Preparation of experimental plot

To plant seeds, a plot of high ground was chosen at Bangladesh Agricultural University's Agronomy Field Laboratory in Mymensingh. The field was thoroughly prepared using a power tiller to till once, then run a country plough three times, and finally a ladder. The field layout was created in accordance with the experimental specifications right after the last stage of site preparation. Plots were leveled using a ladder and cleaned by pulling weeds and stubble. Lastly, in accordance with the experimental treatments, individual plots were leveled and prepared with a spade prior to seeding.

Planting method

The spacing between rows was maintained 20 cm, while gap between seeds was 60 cm. To reduce number of missed germination failures per hill, two seeds were planted in each hill. At a depth of 4-5 cm below the soil's surface, two seeds were deposited in each spot.

Application of fertilizers

The experiment plots were fertilized with Urea, TSP, MoP, Gypsum and $ZnSO_4$ as per the rates shown in Table 2. Urea 104 g, the full doses of TSP, MoP, gypsum and zinc sulphate was applied during final land preparation. Urea was applied in two instalments i.e. 104 g was applied 20 days after sowing and another 104 g was applied 35 days after sowing.

Table 2: *Does of manures of fertilizers*

Manure/ Fertilizer	Dose (kg ha^{-1})	Dose (g $plot^{-1}$) (6.25 m^2)
Urea	500	312
TSP	240	150
MOP	180	113
Gypsum	240	150
$ZnSO_4$	10	6

Intercultural operations

Thinning and gap Filling

Where seedlings did not germinate, pre-soaked seeds at the rate of 1 seed per hole were sown. Thinning was done by ensuring one plant per hill.

Weeding and irrigation

The crop was found to be infested with weeds, such as, durba *(Cynodon dactylon)*, mutha *(Cyperus rotundus)*, bishkatali etc. which were controlled by uprooting and removing by hands and spade as and when needed. The first weeding and irrigation was done after 20 DAS, second one was done at 35 DAS, the third one was given after 70 DAS and the final weeding and irrigation was done 85 DAS. Excess water was drained out from the plots.

Plant protection measures

Plants were infested with cut worm which was successfully controlled by flood irrigation.

Weeding and earthing-up

On 30th day after seeding, weeding was done. In order for the plants to grow directly on top of the newly formed ridges, earthing-up was done. The plants gained more anchoring as a result.

Acronym and abbreviations

We used acronyms and abbreviations throughout the manuscript to reduce similarity of the manuscript as follows: PH= Plant height, CPP= Cobs per plant, CL= Cob length, CD= Cob diameter, KRPC= Kernel rows cob^{-1}, KPR= Number of kernels row^{-1}, CW= Cob weight, TGW = 1000-grain weight, GY = Grain yield, SY = Straw yield, BY = Biological yield, HI = Harvest index, Raincon = Rainfed condition, Irricon = Irrigated condition.

Data collection procedure

Three plant randomly harvested from each plot in a week was weighed to determine grain yield per plot at 3 days after silking and continues up to physiological maturity was later converted to g plant^{-1} after adjusting to 12% moisture content. 1000-grain samples were collected from each plot at harvest for the determination of moisture. The samples were first weighed to obtain initial weight followed by drying to a constant weight in the oven at 80°C in the laboratory and the difference between the two weights provided as moisture at harvest. Additional data were also collected on yield components viz., plant height, cobs plant^{-1}, cob length, cob diameter, kernel rows cob^{-1}, number of kernels row^{-1}, cob weight, 1000-grain weight, grain yield, straw yield, biological yield, harvest index.

Morphological data

Morphological parameters such as PH, days to silking, days to tasseling, days to anthesis and days to physiological maturity etc. were collected.

Plant Height (PH) was measured in cm with the tallest leaf started from the base of the plant.

Crop phenology

Crop phenology refers to the different growth stages of a crop. In maize, different growth stages such as emergence to silking, tasselling, anthesis, physiological maturity etc. are referred to as maize phenology. Maize growth stages are measured in the duration of days.

Grain fresh weight, dry weight and water content during grain filling period

Grain fresh weight, dry weight and maximum water content of individual grain of maize during grain filling period were measured in mg.

Grain filling duration and grain filling rate

Grain filling duration of different inbred and hybrid maize varieties under Raincon and Irricon were measured in days. Grain filling rate of these varieties under these conditions measured in mg d^{-1}.

Yield and yield contributing characters

Plant Height

During harvesting PH was measured in cm.

Cobs plant^{-1}

Cobs containing white or brownish sheath were counted. Total CPP was counted during the harvesting period.

Cob length

CL was measured from the base of the rachis to the apex of each rachis. Each observation was an average of two cobs. CL was measured in cm.

Cob diameter

CD was measured at the base, middle and tip portion of the rachis. Each observation was an average of two cobs. The diameter of cob was measured in cm.

Kernel rows cob^{-1}

Numbers of rows were counted from the base of the rachis. It included effective grains.

Number of kernels row^{-1}

Presence of any food material in the grain was considered as filled grain and total numbers of grains present on each cob were counted.

1000-grain weight

Following sun drying, thousands of grains were randomly selected from each plot and weighed on an electric balance. Grams were used to measure TGW.

Grain yield

After being sun-dried at 12% moisture content, the grains from six plants in each plot were meticulously weighed to determine the GY per plant, which was subsequently translated to grams per plant. The unit of GY was t ha^{-1}.

Straw yield

After being sun-dried at the ideal moisture content, the straw from six plants in each plot was meticulously weighed to determine the GY per plant, which was subsequently translated to grams per plant. In t ha^{-1}, SY was measured.

Biological yield

BY is the weight of above ground plant's part. BY was measured in t ha^{-1}.

Harvest index(%)

The economic yield to BY ratio, or HI, was computed using the following formula and is shown as a percentage:

$$HI = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Harvesting and processing

The crop was deemed mature when 80–90% grains turned golden yellow. To collect the required data, five hills aside from boundary hills were chosen at random from each experimental plot. When plots matured, they were collected. Each plot's harvested produce was appropriately marked and packaged separately. Hands were used to thresh the crop. Using a moisture meter, the grains were washed, weighed, and their moisture content measured. GY was then transformed to have a moisture content of 12%. Straw was carefully sun-dried before being weighed. Lastly, GY plot^{-1} and straw were measured and converted to t ha^{-1}.

Statistical analysis

Following proper compilation and tabulation, the gathered data underwent statistical analysis. With the aid of the computer program MSTAT-C (MSTAT-C Version 2.10, Michigan State University, East Lansing, MI, USA), data were evaluated using the analysis of variance (ANOVA) technique, and Duncan's Multiple Range Test was used to determine mean differences (Gomez and Gomez, 1984) and multivariate analysis, viz. principal component analysis (PCA), correlation and heatmap conducted using R version 4.2.0 (R Core Team, 2022).

Results

Occurrence (d) of different growth stages of maize varieties under raincon and irricon Occurrence of different growth stages (in days) and total growth duration (TGD) of maize varieties under Raincon and Irricon are presented in Table 3. Inbred maize variety khoi bhutta and hybrid maize varieties namely BHM-09, C-1921 and P-3396 showed little variations in phenology both under Raincon and Irricon. All of the varieties emerged at the similar day under both Irricon and Raincon. A little bit variation on emergence to tasseling period among the varieties. Only hybrid maize variety P-3396 required 72 days from emergence to tasselling under both Irricon and Raincon. Without P-3396, all of the varieties required 74 days from emergence to tasseling under Raincon and Irricon. There is a little variation from emergence to anthesis period among the varieties under Irricon and Raincon. Lowest time was required (74 days) from emergence to anthesis period for inbred maize variety khoi bhutta under Raincon. Highest time (77 days) was needed from emergence to anthesis period in two hybrid maize varieties namely BHM-09 under Raincon and C-1921 under Irricon. 75 days, 76 days, 76 days, 75 days and 75 days were required for khoi bhutta under Irricon, BHM-09 under Irricon, C-1921 under Raincon, P-3396 under Raincon and P-3396 under Irricon, respectively. Anthesis to silking period is almost similar among the varieties under Raincon and Irricon. All varieties required 1 day to silking from anthesis except khoi bhutta under Raincon. It required 2 days to silking from anthesis period.

Table 3: *Duration of growth stages of maize varieties from sowing to emergence (So-Em), emergence to tasseling (Em- Ts), emergence to anthesis (Em-At), anthesis to silking (At- Sk), anthesis to physiological maturity (At-PM) and total growth duration (TGD).*

Variety	Irrigation level	Duration of growth stages (Days)					
		So-Em	Em-Ts	Em-At	At-SK	At-PM	TGD
Khoi bhutta	Rainfed	9	74	74	2	34	108
	Irrigated	9	74	75	1	36	111
BHM-09	Rainfed	9	74	77	1	42	119
	Irrigated	9	74	76	1	45	121
C-1921	Rainfed	9	74	76	1	47	123
	Irrigated	9	74	77	1	49	126
P-3396	Rainfed	9	72	75	1	49	124
	Irrigated	9	72	75	1	51	126

Variation observed in the physiological maturity stage from anthesis among the varieties under Irricon and Raincon. Among the varieties khoi bhutta under Raincon need shortest time (34 days) to physiological maturity stage from anthesis period and P-3396 under Irricon required longest time (51 days) to physiological maturity stage from the anthesis period. Khoi bhutta under Raincon, BHM-09 under Irricon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon required 35 days, 42 days, 45 days, 47 days, 49 days and 49 days, respectively to physiological maturity from the anthesis period. All the varieties reached the phonological stages almost at the same time. Clear Variation observed in the total growth duration of the inbred and hybrid varieties under Irricon and Raincon. Among the varieties khoi bhutta under Raincon needed the shortest time (108 days) to complete its life cycle and P-3396 under Irricon required the longest time (126 days) to complete its life cycle. Khoi bhutta under Raincon, BHM-09 under Irricon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon required 111 days, 119 days, 121 days, 123 days, 126 days and 124 days, respectively to complete their life cycle.

Effect of variety on yield and yield contributing characters of maize

Plant Height

Variation in PH was found among the maize varieties. The tallest plant (238.40 cm) was obtained in the hybrid variety P-3396 which was statistically significant with 1% level of probability. The shortest plant (202.90 cm) was shown in inbred variety khoi bhutta. The PH was around 15% higher in P-3396 than Khoi Bhutta. The PH of hybrid maize C-1921 was 219.45 cm and P-3396 was 229.00 cm (Table 4).

Cob length

CL was significantly affected by the varietal differences. CL of BARI hybrid maize-9 and P-3396 were statistically similar. Numerically the CL of BHM-09 was 19.85 cm and P-3396 was 19.70 cm (Table 4). CL of BHM-09 was around 17% higher than Khoi Bhutta. The CL of other hybrid maize variety C-1921 was 17.30 cm.

Cob diameter

CD was significantly affected by the varietal differences of maize. CD of hybrid maize C-1921 was 4.97 cm and P-3396 was 4.94 cm (Table 4) which were statistically identical. From which the highest CD was found in hybrid maize C-1921 (4.97 cm). Lowest CD found in inbred maize variety khoi bhutta containing 3.36 cm. CD of hybrid maize C-1921 was 32% greater than inbred maize Khoi Bhutta. CD of another hybrid maize variety BHM-09 was 14.00 cm.

Kernel rows cob^{-1}

KRPC was greatly affected by the variety. The

Table 4: *Effect of variety on yield and yield contributing characters of maize*

Variety	Plant height (cm)	Cob plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows cob^{-1}	No. of kernels row^{-1}	Cob weight (g)	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield(t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Khoi bhutta	202.90 d±4.76	1.00	16.45 c±0.53	3.36 c±0.07	14.00 c±0.46	33.87 c±0.8	128.97 d±6.16	164.57 d±7.98	5.58 d±0.09	18.01 c±0.41	23.58 c±0.51	23.48 c±0.58
BHM-09	229.00 b±4.76	1.00	19.85 a±0.53	4.52 b±0.07	16.00 a±0.46	37.17 a±0.8	248.70 b±6.16	261.85 c±7.98	11.24 c±0.09	30.15 b±0.41	41.39 b±0.51	27.13 ab±0.58
C-1921	219.45 c±4.76	1.00	17.30 b±0.53	4.97 a±0.07	15.00 b±0.46	35.20 b±0.8	238.00 c±6.16	294.50 b±7.98	12.84 a±0.09	33.85 a±0.41	46.69 a±0.51	27.50 a±0.58
P-3396	238.40 a±4.76	1.00	19.70 a±0.53	4.94 a±0.07	15.00 b±0.46	36.87 a±0.8	260.34 a±6.16	308.39 a±7.98	12.24 b±0.09	34.07 a±0.41	46.30 a±0.51	26.41 b±0.58
$LSD_{0.05}$	7.33	-	0.822	0.113	0.704	1.23	9.50	12.29	0.138	0.633	0.781	0.898
Sx	2.38	-	0.267	0.037	0.228	0.399	3.08	3.99	0.045	0.205	0.253	0.291
Level of significance	**	-	**	**	**	**	**	**	**	**	**	**
CV (%)	2.62	-	3.57	2.01	3.73	2.74	3.45	3.80	1.05	1.73	1.57	2.73

Maximum KRPC were found in both in C-1921 and P-3396 (Table 4). KRPC was statistically identical in hybrid maize variety C-1921 (15.00) and P-3396 (15.00). Minimum KRPC observed in the inbred maize variety khoi bhutta (14.00). KRPC in hybrid maize variety C-1921 was about 7% greater than inbred maize variety khoi Bhutta.

Number of kernels row^{-1}

KPR was significantly affected by the varietal differences. KPR of BARI hybrid maize-9 (37.17) and P-3396 (36.87) were statistically similar. KPR of BHM-09 was and P-3396 was (Table 4). The maximum KPR found in BHM-09 (37.17) and the minimum KPR found in inbred maize variety khoi bhutta (33.87). KPR in BHM-09 and P-3396 were about 11% and 9% higher than the Khoi bhutta, respectively.

Cob weight

Variation in CW was found in significant due to the varietal difference. The highest CW (260.34 g) was found in hybrid maize variety P-3396 which. The lowest CW (128.97) was observed in inbred maize variety khoi bhutta (Table 4). CW in hybrid maize variety P-3396 was 50% higher than the inbred maize variety Khoi Bhutta. The CW of hybrid maize variety BHM-09 and C-1921 was found in 248.70 g and 238.00 g, respectively.

1000-grain weight

TGW was greatly affected by the varietal difference. The highest TGW (308.39 g) was observed in hybrid maize variety P-3396. The lowest CW (164.57 g) found in khoi bhutta (Table 4). TGW of P-3396 was 46.64% higher than Khoi Bhutta. TGW of hybrid maize variety BHM-09 and C-1921 was observed in 261.85g and 294.50g, respectively.

Grain yield

GY showed a significant variation in different inbred and hybrid maize varieties with 1% level of probability. The highest GY observed in the hybrid maize variety C-1921 (12.84 tha^{-1}) and the lowest GY found in khoi bhutta (5.58 tha^{-1}) (Table 4). The amount of GY was around 57% higher in C-1921 than khoi bhutta (Figure 1a). GY of hybrid maize variety BHM-09 and P-3396 11.24 t ha^{-1} and 12.24 t ha^{-1}, respectively.

Straw yield

SY was significantly affected by the varietal differences of maize. SY of hybrid maize variety C-1921 was 33.85 t ha^{-1} and P-3396 was 34.05 t ha^{-1} (Table 4. Lowest SY found in khoi bhutta which value was 18.01 t ha^{-1}. The amount of SY was around 47% higher in P-3396 than khoi bhutta (Figure 1b). The SY of hybrid maize variety BHM-09 and C-1921 was observed in 30.15 t ha^{-1} and 33.85 t ha^{-1}, respectively.

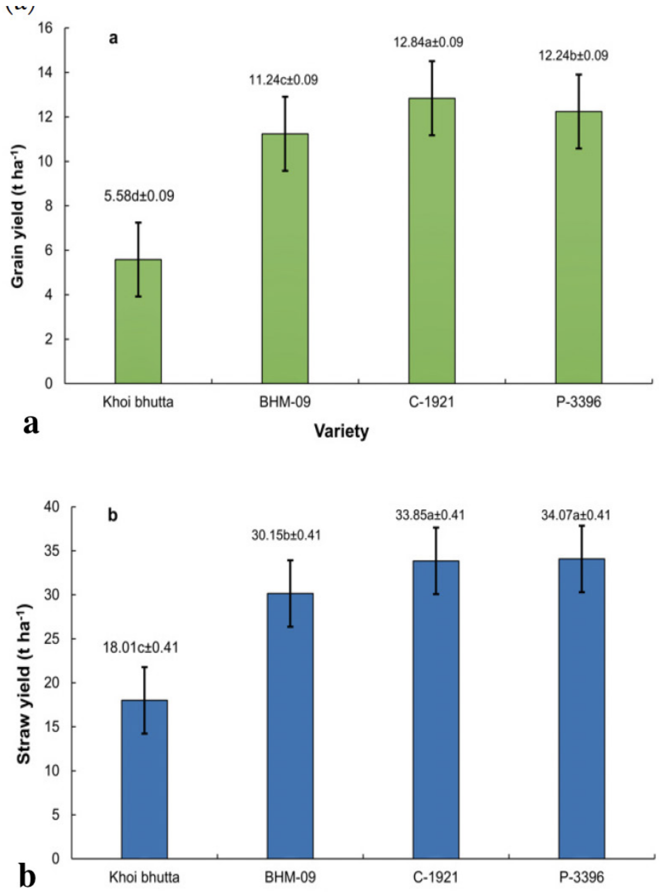

Figure 1: *GY and SY of inbred and hybrid varieties of maize*

Biological yield

BY was significantly affected by the varietal differences of maize. BY of hybrid maize variety C-1921 was 46.69 t ha^{-1} and P-3396 was 46-30 t ha^{-1} (Table 4) which were statistically similar with each other. Numerically lowest BY was found in inbred maize variety khoi bhutta which value was 23.58 t ha^{-1}. BY was around 50% higher in C-1921 than khoi bhutta among the varieties. BY of hybrid maize variety BHM-09 and P-3396 was observed 41.39 t ha^{-1} and 46.30 t ha^{-1}.

Harvest index (%)

HI showed a significant variation for different maize varieties with 1% level of probability. Highest HI observed in C-1921 (27.50%) and the lowest HI found in khoi bhutta (23.48%) (Table 4). HI of hybrid maize variety BHM-09 and C-1921, BHM-09 and P-3396 are similar.

Effect of yield and yield contributing characters of maize under raincon and irricon.

Plant Height

The PH was significantly affected under Raincon and Irricon. The lowest PH observed under Raincon was 214.23 cm and the highest PH under Irricon was 230.65 cm (Table 5). The PH was about 7% higher in Irricon than the Raincon.

Cob length

CL was significantly affected by Irricon in terms of Raincon. Under Irricon the highest CL was 19.68 cm and under Raincon it was 16.98 cm (Table 5). The CL was about 13.7% higher in Irricon than Raincon.

Cob diameter

From the **Table 5** it is observed that the lowest and highest CD were 4.17 cm and 4.72 cm under Raincon and Irricon, respectively. From the above findings, it is shown that CD was greatly affected by Raincon and Irricon.

Kernel rows cob^{-1}

KRPC was varied significantly from Raincon and Irricon. The lowest and highest KRPC under Raincon and Irricon was 13.50 and 16.50, respectively (Table 5). The kernel rows per cob was about 18% greater in Irricon than Raincon.

Number of kernels row^{-1}

KPR was also significantly affected by Raincon and Irricon. From the Table 5, it is found that KPR was higher (38.57) under Irricon than Raincon (32.98). The quantity of KPR is one of the most important bases of yielding components and is directly related to the general function; the more grains row^{-1}, the better the function grain. Therefore, the main effect of irrigation level was a highly significant difference in the number of grains per row at ($P \leq 0.05$).

Cob weight

CW was also varied significantly due to Raincon and Irricon. Under Raincon CW was 188.54 g and Irricon it was 249.47g (Table 5). The CW was about 24.4% higher in Irricon than Raincon.

1000-grain weight

TGW showed significant influence due to Raincon and Irricon. From the Table 5 it is seen that TGW under Raincon (232.11 g) was lower than the Irricon (282.54 g). About 17.84% higher TGW was observed under Irricon than the Raincon.

Grain yield

GY showed a significant variation for different Irricon. From the Table 5, under Irricon and Raincon the GY was 11.57 t ha^{-1} and 9.37 t ha^{-1}, respectively. GY of Irricon maize (11.57 t ha^{-1}) was 19% higher than the Raincon maize (9.37 t ha^{-1}) (Figure 2a).

Straw yield

SY under Raincon and Irricon were statistically significant. Under Irricon SY was 30.87 t ha^{-1} and Raincon. It was 27.17 t ha^{-1}. SY was about 12% higher in Irricon than Raincon. The production of

Table 5: *Effect of variety on yield and yield contributing characters of maize*

Irrigation level	Plant height (cm)	Cob plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows cob^{-1}	No. of kernels row^{-1}	Cob weight (g)	1000 grain weight (g)	Grain yield(t ha^{-1})	Straw yield(t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Rainfed	214.23 b±1.95	1.00	16.98 b±0.20	4.17 b±0.03	13.50 b±0.14	32.98 b±0.27	188.54 b±1.7	232.11 b±2.84	9.37 b±0.41	27.17 b±0.21	36.54 b±0.26	25.22 b±0.30
Irrigated	230.65 a±1.95	1.00	19.68 a±0.20	4.72 a±0.03	16.50 a±0.14	38.57 a±0.27	249.47 a±0.1.7	282.54 a±2.84	11.57 a±0.41	30.87 a±0.21	42.44 a±0.26	27.04 a±0.30
$LSD_{0.05}$	8.41	-	0.853	0.124	0.620	1.15	7.19	12.22	0.176	0.904	1.11	1.27
Sx	1.38	-	0.140	0.020	0.102	0.189	1.18	2.01	0.0289	0.148	0.182	0.209
Level of significance	**	-	**	**	**	**	**	**	**	**	**	*
CV (%)	2.15	-	2.65	1.59	2.36	1.83	1.87	2.70	0.96	1.77	1.60	2.77

*** = Significant at 1% level of probability, * = Significant at 5% level of probability* highest SY was (30.87 t ha^{-1}) under Irricon (Figure 2b) might be due to the fact that irrigation tends primarily to encourage vegetative growth. On the other hand, irrigation has also the most pronounced effect on plant growth. The lowest SY (27.17 t ha^{-1}) was obtained from the Raincon.

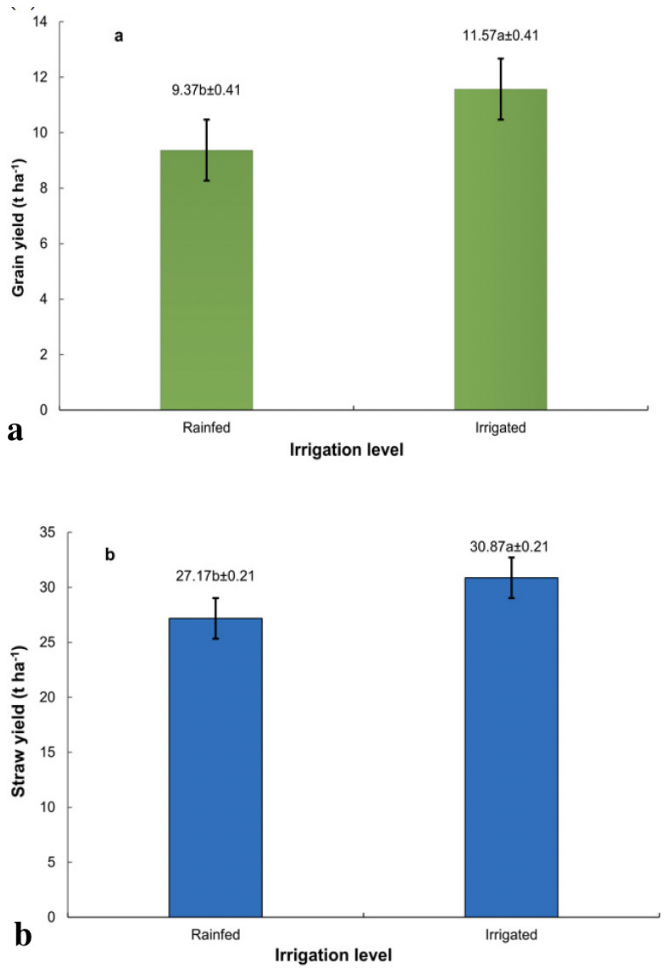

Figure 2: *GY and SY of inbred and hybrid varieties of maize under Raincon and Irricon*

Biological yield

BY is statistically influenced by different Irricon. Irricon affect the BY of maize. Under Raincon and Irricon the BY was 36.54 t ha^{-1} and 42.44 t ha^{-1} respectively (Table 5). BY was around 14% higher in Irricon than Raincon.

Harvest index (%)

Results presented in the Table 5 revealed that Raincon and Irricon was showed significant effect on HI. The highest HI (27.04%) was observed under Irricon and the lowest (25.22%) from the Raincon. HI was maximum under Irricon because of increasing the economic part of the maize varieties.

Yield and yield contributing characters of maize varieties under raincon and irricon

Plant Height

Crop response to Irricon and varietal interaction for PH is presented in Table 6. It can be observed that the interaction of irrigation level and different maize varieties showed no significant effect on PH. However, numerically the tallest plant was found in P-3396 (247.40 cm) variety with Irricon and the shortest plant was obtained in khoi bhutta (195.30 cm) under Raincon. PH of hybrid maize variety BHM-09 and C-1921 observed under Raincon and Irricon 220.40 cm, 211.80 cm, 237.60 cm, 227.10cm, respectively.

Cob length

Results presented in Table 6 showed that interaction effect on CL was not significant. However, among the treatments Irricon with BHM-09 variety gave numerically the tallest cob (21.30 cm) and the shortest (14.90 cm) was on khoi bhutta with Raincon.

Cob diameter

The interaction of conditions and variety levels showed significant effect on the CD. The highest value of CD was (5.18 cm) produced by hybrid maize variety P-3396 with irrigation. C-1921 with irrigation produced the second highest which was statistically similar to P-3396 with irrigation. Khoi bhutta with Raincon produced the lowest (3.04 cm) CD. Therefore, it was observed that best performance in respect of Irricon with C-1921 variety. CL of khoi bhutta under Irricon, BHM-09 under Raincon, C-1921 under Raincon and P-3396 under Raincon was obtained 3.67 cm, 4.17 cm, 4.78 cm, 5.15 cm, respectively (Table 6). It can be seen that around 41% higher CD was produced from C-1921 under Irricon than khoi bhutta which was under Raincon due to interaction effect.

Kernel rows cob^{-1}

Interaction effect of conditions and variety showed significant variation on kernel row cob^{-1} (Table 6). The number of kernel rows per cob^{-1} varied from 12.00 to 18.00 depending on the various treatments used. The treatment BHM-09 with irrigation produced the highest KRPC (18.00) and the lowest (12.00) was obtained from inbred maize variety khoi bhutta which was under Raincon. Hybrid maize variety C-1921 under Irricon and P-3396 under Irricon were produced second highest (16.00) KRPC which is statistically similar to the C-1921 variety.

Table 6: *Yield and yield Contributing characters of maize varieties under rainfed and irrigated conditio*

Irrigation level	Variety	Plant height (cm)	Cob plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows cob^{-1}	No. of kernels row^{-1}	Cob weight (g)	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Rainfed	Khoi bhutta	195.30	1.00	14.90	3.04 f±0.15	12.00 d±0.91	30.33 e±1.60	112.13 f±12.33	150.49 e±15.95	4.42 h±0.18	15.54 e±0.82	19.96 e±1.01	22.18
	BHM-09	220.40	1.00	18.40	4.17 d±0.15	14.00 c±0.91	33.73 d±1.60	201.07 d±12.33	241.53 d±15.95	10.06 f±0.18	28.30 c±0.82	38.36 c±1.01	26.26
	C-1921	211.80	1.00	16.30	4.78 bc±0.15	14.00 c±0.91	33.20 d±1.60	212.87 d±12.33	265.17 c±15.95	11.85 d±0.18	32.32 b±0.82	44.17 b±1.01	26.86
	P-3396	229.40	1.00	18.30	4.69 c±0.15	14.00 c±0.91	34.67 d±1.60	228.07 c±12.33	271.23 c±15.95	11.15 e±0.18	32.51 b±0.82	43.66 b±1.01	25.57
Irrigated	Khoi bhutta	210.50	1.00	18.00	3.67 e±0.15	16.00 b±0.91	37.40 bc±1.60	145.80 e±12.33	178.64 e±15.95	6.73 g±0.18	20.47 d±0.82	27.20 d±1.01	24.78
	BHM-09	237.60	1.00	21.30	4.87 b±0.15	18.00 a±0.91	40.60 a±1.60	296.33 a±12.33	282.17 c±15.95	12.42 c±0.18	31.99 b±0.82	44.41 b±1.01	28.00
	C-1921	227.10	1.00	18.30	5.15 a±0.15	16.00 b±0.91	37.20 c±1.60	263.13 b±12.33	323.82 b±15.95	13.82 a±0.18	35.38 a±0.82	49.20 a±1.01	28.13
	P-3396	247.40	1.00	21.10	5.18 a±0.15	16.00 b±0.91	39.07 ab±1.60	292.60 a±12.33	345.54 a±15.95	13.32 b±0.18	35.62 a±0.82	48.94 a±1.01	27.25
$LSD_{0.05}$		10.37	-	1.16	0.159	0.995	1.74	13.44	17.38	0.194	0.895	1.10	1.27
Sx		3.37	-	0.377	0.052	0.323	0.565	4.36	5.64	0.063	0.290	0.358	0.412
Level of sig.		NS	-	NS	*	**	*	**	**	*	*	*	NS
CV (%)		2.62	-	3.57	2.01	3.73	2.74	3.45	3.80	1.05	1.73	1.57	2.73

*** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant*

Number of kernels row^{-1}

Interaction effect of conditions and variety showed significant variation on the KPR (Table 6). The KPR varied from 30.33 to 40.60 depending on the various treatments used. The treatment BHM-09 with irrigation produced the highest KPR (40.60) and the lowest (30.33) was obtained from khoi bhutta with Raincon. Irricon with P-3396 produced second highest (39.07) KPR which was statistically similar to the BHM-09 under Irricon. KPR of khoi bhutta under Irricon, BHM-09 under Raincon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 37.40, 33.73, 33.20, 37.20, 34.67, respectively. It is seen that around 25% higher KPR was produced from BHM-09 under Irricon than khoi bhutta which was under Raincon due to interaction effect.

Cob weight

Crop response to Irricon and varietal interaction for CW is presented in Table 6. It can be observed that the interaction of irrigation level and maize varieties showed significant effect on CW. Numerically the highest CW produced in BHM-09 (296.33 g) was found when the crop was Irricon and the lowest CW produced in inbred maize variety khoi bhutta (112.13 g) was from Raincon. The second highest CW produced in P-3396 (292.60g) under Irricon which is statistically similar to the first type (BHM-09). Present results indicate that irrigation and varietal quality increased PH. Around 62% higher CW was produced from BHM-09 under Irricon than khoi bhutta which was under Raincon due to interaction effect. CW of khoi bhutta under Irricon, BHM-09 under Raincon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 145.80 g, 201.07 g, 212.87 g, 296.33 g, 228.07 g, respectively.

1000-grain weight

TGW of maize showed significant effect due to interaction of Raincon and Irricon and variety (Table 6). The highest TGW (345.54 g) was produced by the combination of hybrid maize variety P-3396 under Irricon. Lowest TGW (150.49 g) was achieved by the production of inbred maize variety khoi bhutta under Raincon. There was second lowest production (178.64 g) of TGW of khoi bhutta under Irricon which was statistically similar to the weight of khoi bhutta under Raincon. It is seen that around 48% higher TGW was produced from P-3396 under Irricon than khoi bhutta which was under Raincon due to interaction effect. TGW of BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 241.53 g, 282.17 g, 265.17 g, 323.82 g, 271.23 g, respectively.

Grain yield

Interaction effect of irrigation level and inbrd and hybrid maize varieties were significant regarding GY (Table 6). The maximum GY (13.82 t ha^{-1}) was recorded in hybrid maize variety C-1921 under Irricon and the lowest (4.42 t ha^{-1}) was found from inbred maize variety khoi bhutta under Raincon. It is seen that around 68% higher GY was produced from hybrid maize variety C-1921 under Irricon than khoi bhutta which was under Raincon due to interaction effect. It is clear from the trail that Irricon and variety produce higher GY. GY of khoi bhutta under Irricon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon and P-3396 under Raincon was 38.36 t ha^{-1}, 11.85 t ha^{-1}, 12.42 t ha^{-1}, 11.15 t ha^{-1}, 11.15 t ha^{-1}, respectively.

Straw yield

Interaction effect of Irricon and variety was significant regarding SY (Table 6). Numerically the highest SY (35.62 t ha^{-1}) was recorded in the hybrid maize variety P-3396 under Irricon and the second highest SY (35.38 t ha^{-1}) was produced from hybrid maize variety C-1921 under Irricon which is statistically similar to the first type (P-3396). The lowest (15.54 t ha^{-1}) was found from inbred maize variety khoi bhutta under Raincon. We can see that around 56% higher SY was produced from P-3396 under Irricon than khoi bhutta which was under Raincon due to interaction effect. It is clear from the trail that Irricon and variety produce higher SY. SY of khoi bhutta under Raincon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 20.47 t ha^{-1}, 28.30 t ha^{-1}, 31.99 t ha^{-1}, 32.32 t ha^{-1}, 35.38 t ha^{-1}, 32.51 t ha^{-1} respectively.

Biological yield

BY of maize showed significant effect due to interaction of Irricon and variety (Table 6). Numerically the highest BY (49.20 t ha^{-1}) was recorded in C-1921 under Irricon and the second highest BY (48.94 t ha^{-1}) was produced from P-3396 under Irricon which is statistically similar to the first type (C-1921). The lowest (19.96 t ha^{-1}) was found from khoi bhutta under Raincon. Around 59% higher BY was produced from C-1921 under Irricon than khoi bhutta which was under Raincon due to interaction effect. It is clear from the trail that Irricon and variety produce higher BY. BY of khoi bhutta under Raincon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, and P-3396 under Raincon, P-3396 under Irricon was 27.20 t ha^{-1}, 38.36 t ha^{-1}, 44.44 t ha^{-1}, 43.66 t ha^{-1}, 43.66 t ha-1, 48.94 t ha^{-1}, respectively.

Harvest index (%)

The interaction effect of Irricon and varieties was not significant for HI (Table 6). However, numerically the highest HI (28.13%) was obtained from C-1921 under Irricon. The lowest HI (22.185) was found from khoi bhutta under Raincon. HI of khoi bhutta under Raincon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, and P-3396 under Raincon, P-3396 under Irricon was 24.78%, 26.26%, 28.00%, 26.86%, 25.57%, 27.25%, respectively.

Grain morphology and grain filling pattern of maize as influenced inbred and hybrid maize varieties

Individual grain weight

Individual grain weight of inbred and hybrid maize varieties differed at 1% level of probability. Maximum individual grain weight was observed in hybrid maize varieties C-1921(323.9 mg) which was statistically similar to P-3396(339.2 mg) (Table 7). The lowest individual grain weight was observed in the inbred maize variety khoi bhutta (181.0 mg). P-3396 maize variety obtained the 46.62% higher individual grain weight than the khoi bhutta. The average individual grain weight observed in the hybrid maize variety BHM-09 was 288.0 mg (Table 5). Individual grain weight was maximum in hybrid maize variety C-1921 because of its better resource uptaking capability and its physiology than the other maize varieties.

Table 7: *Effect of variety on yield and yield contributing characters of maize*

Variety	Individual grain weight(mg)	Maximum Grain water content (mg)	Grain filling rate (GFR) (mgd^{-1})
Khoi bhutta	181.0 c±10.92	95.98c±4.6	5.163 b±0.16
BHM-09	288.0 b±10.92	164.1 b±4.6	6.615 a±0.16
C-1921	323.9 a±10.92	165.6 b±4.6	6.740 a±0.16
P-3396	339.2 a±10.92	188.6 a±4.6	6.772 a±0.16
$LSD_{0.05}$	16.85	7.09	0.248
Sx	5.46	2.30	0.081
Level of significance	**	**	**
CV (%)	4.73	3.67	**3.12**

*** =Significant at 1% level of probability*

Maximum grain water content

Maximum grain water content showed variation due to inbred and hybrid maize varieties at 1% level of probability. Highest individual grain weight was observed in hybrid maize variety P-3396 was (188.6 mg) (Table 7). Lowest maximum grain water content was observed in the inbred maize variety khoi bhutta (95.98 mg). P-3396 maize variety obtained the 49.12% higher individual grain weight than khoi bhutta. Maximum grain water content varied from variety to variety. Highest maximum grain water content observed in hybrid maize variety P-3396 due to the vigourisity of crop during growth stages and higher economic partitioning in its sink.

Grain filling rate

Grain filling rate of hybrid maize P-3396 (6.742 mgd^{-1}) was the highest which was statistically similar to (6.740 mgd^{-1}) and BHM-09 (6.615 mg d^{-1}). The lowest grain filling rate was observed in the inbred maize variety khoi bhutta which was 5.163 mg d^{-1}, (Table 7). Hybrid maize variety P-3396 showed 23.78% higher grain filling rate than inbred maize variety khoi bhutta.

Grain dry weight and water content during grain filling period

Individual grain weight

Individual grain weight varied significantly due to Irricon and Raincon. In the Irricon, individual grain weight was maximum (310.8 mg) (Table 8). The minimum individual grain weight was found in under Raincon (253.2 mg). Around 18.53% higher individual grain weight was found under Irricon than Raincon.

Maximum grain water content

It was found that the maximum grain water content differed significantly due to irrigation level (Table 8). Highest maximum grain water content (161.0 mg) was observed under Irricon. Lowest maximum grain water content (146.2 mg) was found under Raincon. The maximum grain water content was 9.19% higher in Irricon than the Raincon. When moisture concentrations were between 700 and 800 g kg^{-1} for all genotypes, the expected ultimate kernel weight was calculated.

Grain filling rate

Grain filling rate affected significantly due to Irricon and Raincon. Under Irricon the highest grain filling rate was 6.771 mg d^{-1} (Table 8) and the lowest one (5.874 mgd^{-1}) was observed in Raincon. About 13.25% more grain filling rate was observed under Irricon than Raincon.

Table 8: *Effect of rainfed and irrigated condition on yield and yield contributing characters of maize*

Irrigation level	Individual grain weight(mg)	Maximum Grain water content (mg)	Grain filling rate (mgd^{-1})
Rainfed	255.3b±10.65	146.2b±1.84	5.874b±0.09
Irrigated	310.8a±10.65	161.0a±1.84	6.771a±0.09
$LSD_{0.05}$	45.85	7.88	0.380
Sx	7.53	1.30	0.063
Level of significance	*	**	**
CV (%)	9.22	2.92	**3.43**

*** = Significant at 1% level of probability, * = Significant at 5% level of probability*

Grain morphology and grain filling pattern of maize variety under Irricon and Raincon

Individual grain weight

The highest value of individual grain weight of hybrid maize variety was P-3396 (308.1 mg) found under Irricon. The lowest weight was found in the inbred maize variety khoi bhutta (165.5 mg) with Raincon. About 46.28% higher weight was found in hybrid maize variety P-3396 under Irricon than inbred maize variety khoi bhutta. Individual grain weight of khoi bhutta under Irricon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 196.5 mg, 265.7 mg, 310.4 mg, 291.7 mg, 356.2 mg, 298.4 mg, respectively (Table 9). From the above findings, it is shown that individual grain weight was greatly affected by interaction of hybrid and inbred maize varieties under Raincon and Irricon. Importantly, grain weight variation in maize varieties under both Irricon and Raincon can be explained by its highly positive relationship (Figure 3) with maximum grain water content (R^2=0.86) during post anthesis period and with grain filling rate (R^2=0.93).

Maximum grain water content

The highest value of maximum grain water content of hybrid maize variety was P-3396 (193.9 mg) under Irricon. The lowest one was found in the inbred maize variety khoi bhutta (79.16 mg) under Raincon. About 59.40% higher interaction effect found in hybrid

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maize variety P-3396 under Irricon than inbred maize variety khoi bhutta. Maximum grain water content of khoi bhutta under Irricon, BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon, C-1921 under Irricon and P-3396 under Raincon was 112.8 mg, 160.6 mg, 167.6 mg, 161.6 mg, 169.7 mg, 183.3 mg, respectively (Table 9). From the above findings, it is shown that individual grain weight was greatly affected by interaction of hybrid and inbred maize varieties under Raincon and Irricon. Due to the availability of water in Irricon of maize, maximum grain water content was more in P-3396 than the khoi bhutta.

Grain filling rate

Grain filling rate is greatly affected by irrigation level and inbred and hybrid varieties of maize. The highest rate was found in P-3396 under irrigation (7.453 mgd^{-1}) which was statistically similar to hybrid maize variety C-1921 under Irricon (7.270 mg d^{-1}). The second highest grain filling rate was found in BHM-09 under Irricon. The lowest grain filling rate was observed in khoi bhutta under Raincon (4.867 mgd^{-1}). Around 34.7% more grain filling rate obtained inP-3396 under Irricon than khoi bhutta under Raincon. The grain filling rate of khoi bhutta under Irricon,

Table 9: *Interaction effects of irrigation level and variety on yield and yield contributing characters of maize*

Irrigation level	Variety	Individual grain weight(mg)	Maximum Grain water content (mg)	Grain-filling rate(mgd^{-1})
Rainfed	Khoi bhutta	165.5 f±21.86	79.16 e±9.19	4.867 e±0.32
	BHM-09	265.7 d±21.86	160.6 c±9.19	6.330 c±0.32
	C-1921	291.7 c±21.86	161.6 c±9.19	6.210 c±0.32
	P-3396	298.4 c±21.86	183.3 b±9.19	6.090 c±0.32
Irrigated	Khoi bhutta	196.5 e±21.86	112.8 d±9.19	5.460 d±0.32
	BHM-09	310.4 c±21.86	167.6 c±9.19	6.900 b±0.32
	C-1921	356.2 b±21.86	169.7 c±9.19	7.270 a±0.32
	P-3396	380.1 a±21.86	193.9 a±9.19	7.453 a±0.32
$LSD_{0.05}$		23.83	10.04	0.351
Sx		7.73	3.25	0.114
Level of sig.		*	**	**
CV (%)		4.73	3.67	**3.12**

*** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not-significant*

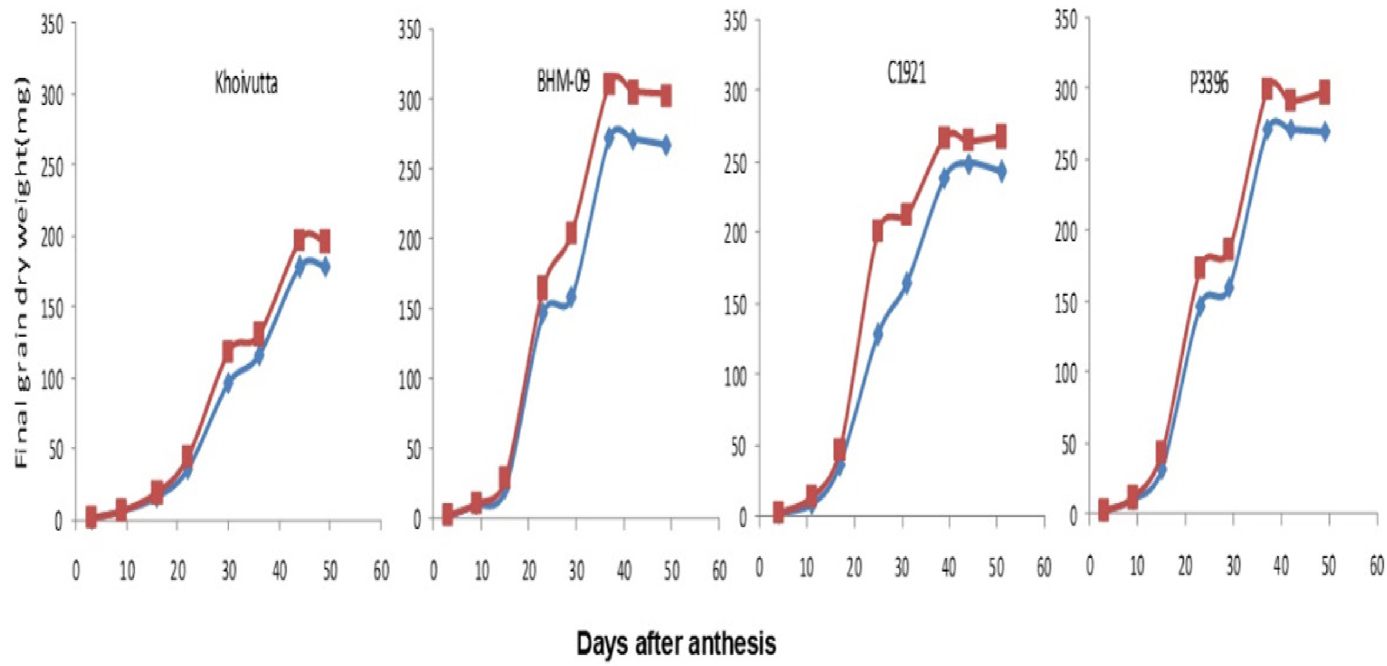

Figure 3: *GY growth dynamics of four maize varieties under raincon (blue color line) and irricon (red color line)*

BHM-09 under Raincon, BHM-09 under Irricon, C-1921 under Raincon was 5.460 mgd-1, 6.330 mgd-1, 6.900 mgd-1, 6.210 mgd-1, respectively (Table 9). From the Figures 4a & 4b it is also confirmed that grain weight variation was due to the variation of grain filling rate as grain filling duration did not vary between the Raincon and Irricon.

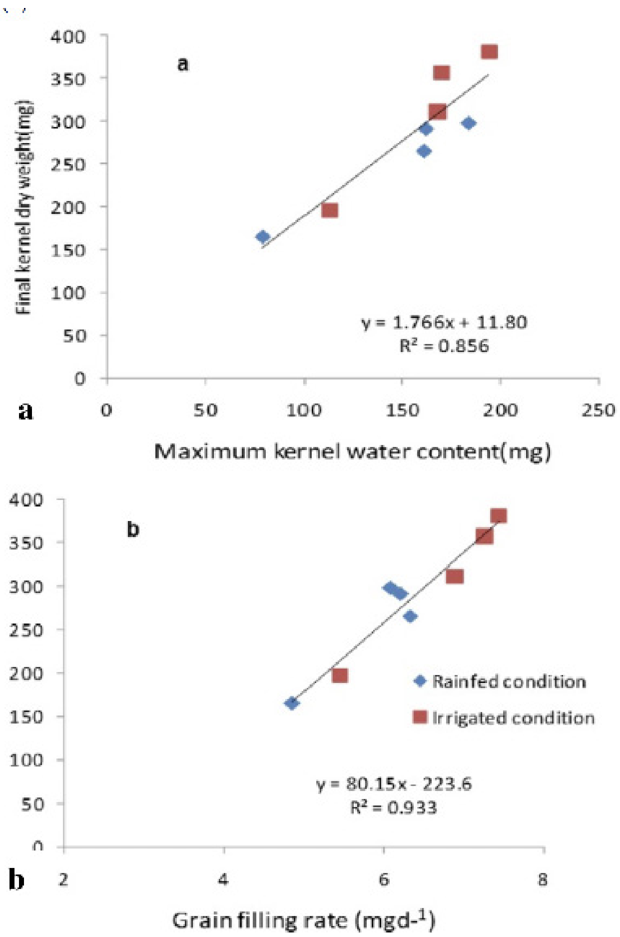

Figure 4: *Relationship between final grain weight and (left) maximum kernel water content and (right) grain filling rate*

PC, correlation and heatmap analysis

Principal Component Analysis was used to determine the GY and grain filling pattern of inbred and hybrid maize under Irricon. In Figure 5, the loadings of variables and the bi-plot of the first two principal components are displayed.

(PC1), represented by the x-axis, and 20.8% by thesecond principal component (PC2), represented by With 53.5% of the variation explained by the first principal component the y-axis. A high positive association exists between PC1 and the following variables: PH, CW, HI, CD, GY, SY, BY, and TGW. KPR and KRPC is more aligned with PC2.The CL is closer to origin. The PH, CW, HI, CD, GY, SY, BY, and TGW variables are closely aligned, indicating a strong positive correlation with each other. In addition to having a negative association with PH, CW, HI, CD, GY, SY, BY, and TGW, the KPR and KRPC cluster together, indicating a significant positive association between them. Treatment 1 and 4 is strongly influenced by PC1 and is distinct from other observations and treatments 2 and 3 are strongly influenced by PC2 and is distinct from other observations.

Principal Component Analysis was used to determine the GY and grain filling pattern of inbred and hybrid maize under Raincon. In Figure 6, the loadings of variables and the bi-plot of the first two principal components are displayed. With 53.5% of the variation explained by the first principal component (PC1), represented by the x-axis, and 20.8% by the second principal component (PC2), represented by the y-axis. The CW, HI, CD, GY, SY, KPR, KRPC, BY, and TGW variables have a strong positive correlation with PC1. CL is more aligned with PC2.The PH is closer to origin. The CW, HI, CD, GY, SY, KPR, KRPC, BY variables are closely aligned, indicating a strong positive correlation with each other. The CL has negative correlation with CW, HI, CD, GY, SY, KPR, KRPC, BY, and TGW. While treatment 2 is closer to the origin, suggesting it has more average values for the main components, treatments 1 and 4 are substantially influenced by PC1 and stand out from other observations, while treatment 3 is strongly influenced by PC2.

A correlation was performed to identify the interrelationship between the GY and grain filling pattern of inbred and hybrid maize under Irricon (Figure 7). According to the analysis, CD and BY had a substantial positive connection (<0.001). Additionally, SY and CD and BY showed a high positive association. GY has a moderate connection ($P<0.01$) with SY, BY, and CD. The GY, SY, BY, and CD showed a positive connection with TGW ($P<0.05$).

A correlation was performed to identify the interrelationship between the GY and grain filling pattern of inbred and hybrid maize under Raincon (Figure 8). The analysis revealed that SY had a strong positive correlation (<0.001) with BY and moderately corelated with the CW ($P<0.01$) while with the KRPC, it was corelated at $P<0.05$. KPRC also had a

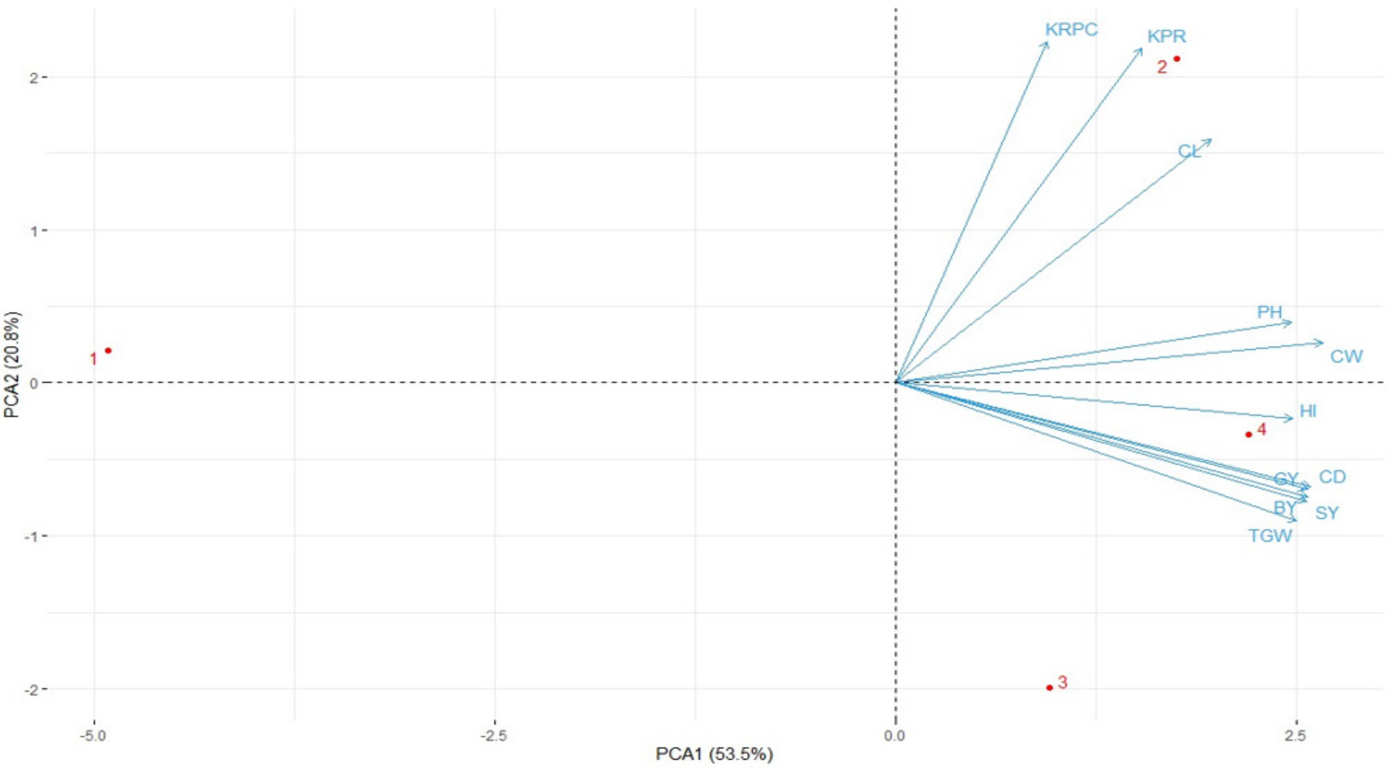

Figure 5: *Bi-plot of principal component analysis (PCA) showing the first two principal components (PC 1 and PC 2)*

For PCA, data on the GY and grain filling pattern of inbred and hybrid maize under Irricon. The red dots are indicating four treatments, like 1 = T_1 (Khoi bhutta), 2 = T_2 (BHM-09), 3 = T_3 (C-1921) and 4= T_4 (P-3396). Acronyms and abbreviations in materials and methods provide more specifics.

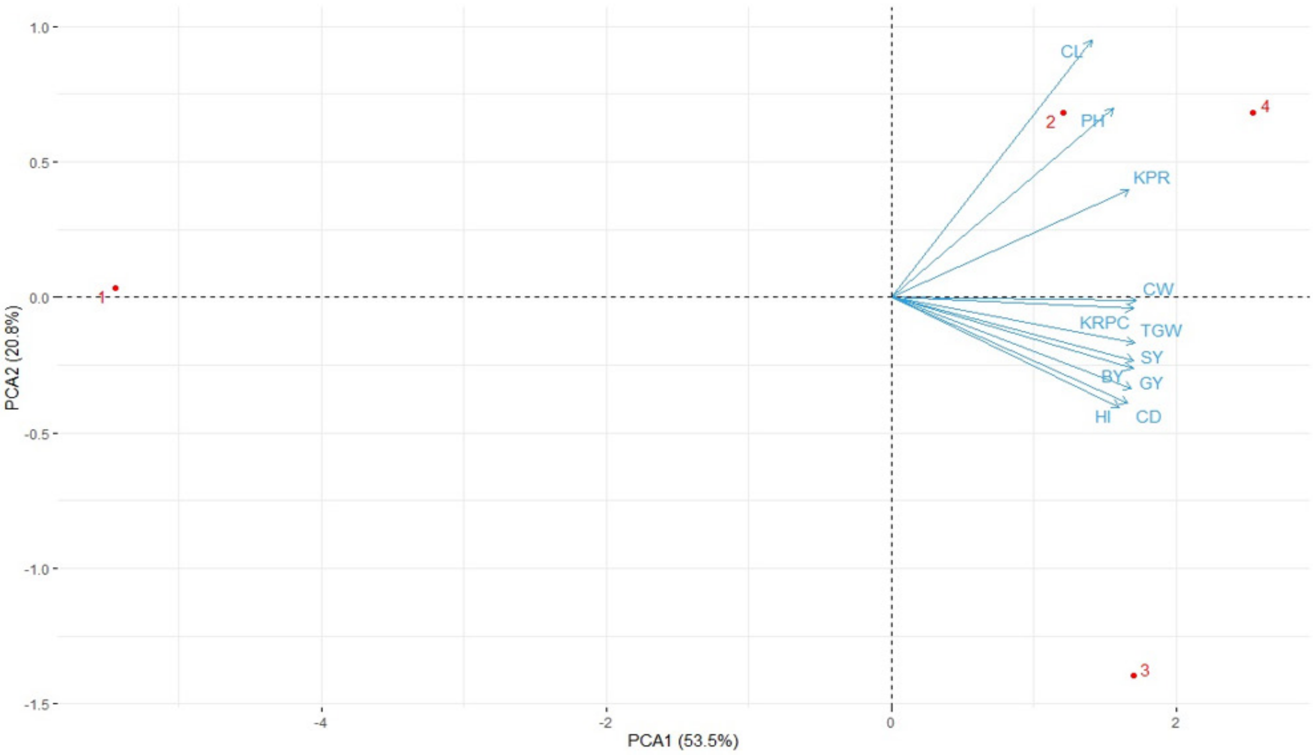

Figure 6: *Bi-plot of principal component analysis (PCA) showing the first two principal components (PC 1 and PC 2)*

For PCA, data on the GY and grain filling pattern of inbred and hybrid maize under Raincon. Acronyms and abbreviations in materials and methods provide more specifics.

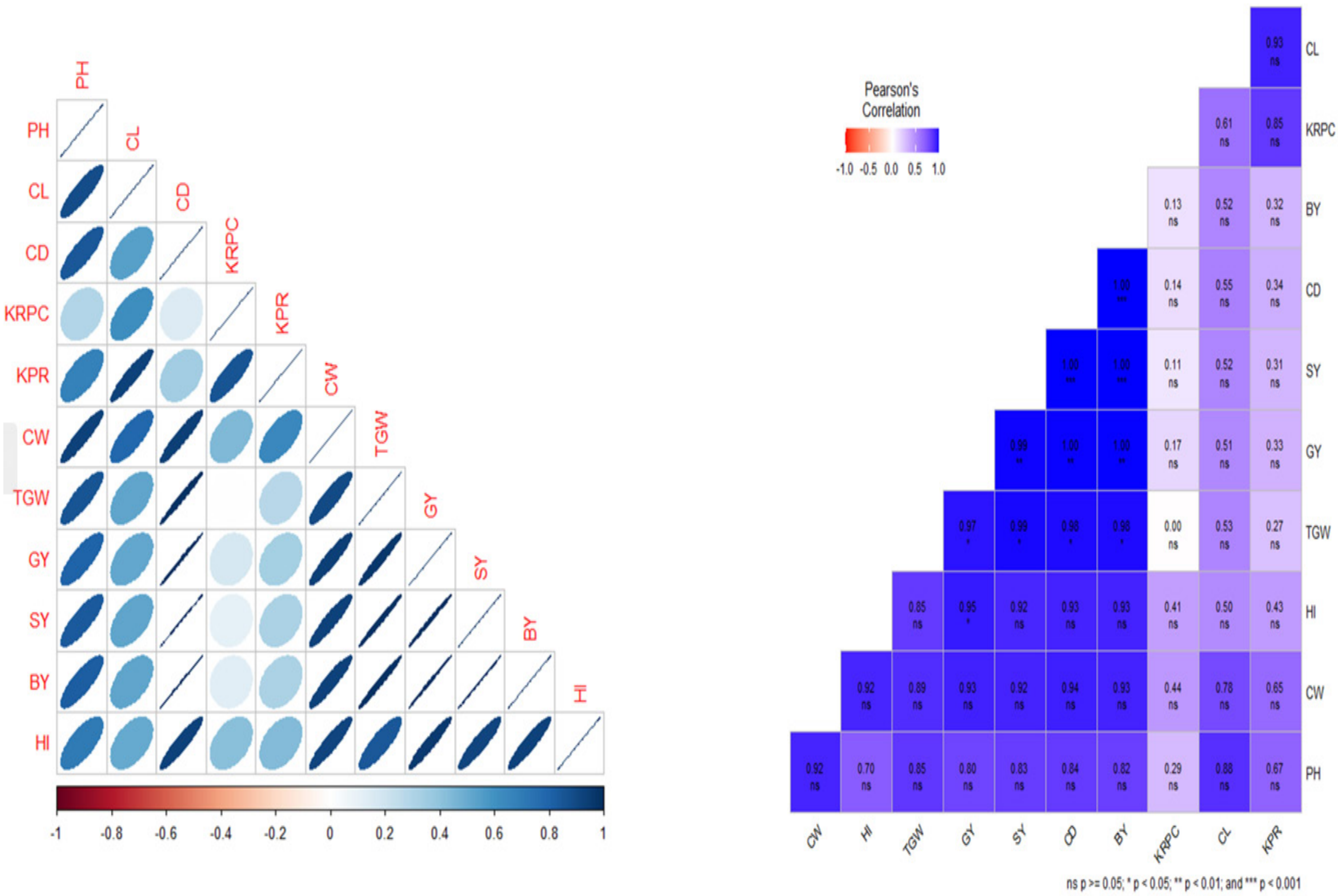

Figure 7: *Pearson correlation analysis of the GY and grain filling pattern of inbred and hybrid maize under Irricon. Acronyms and abbreviations in materials and methods provide more specifics, ***, **, * and NS (Not Significant) represent probability of ≤0.001, ≤0.01, ≤0.05 and >0.05, respectively.*

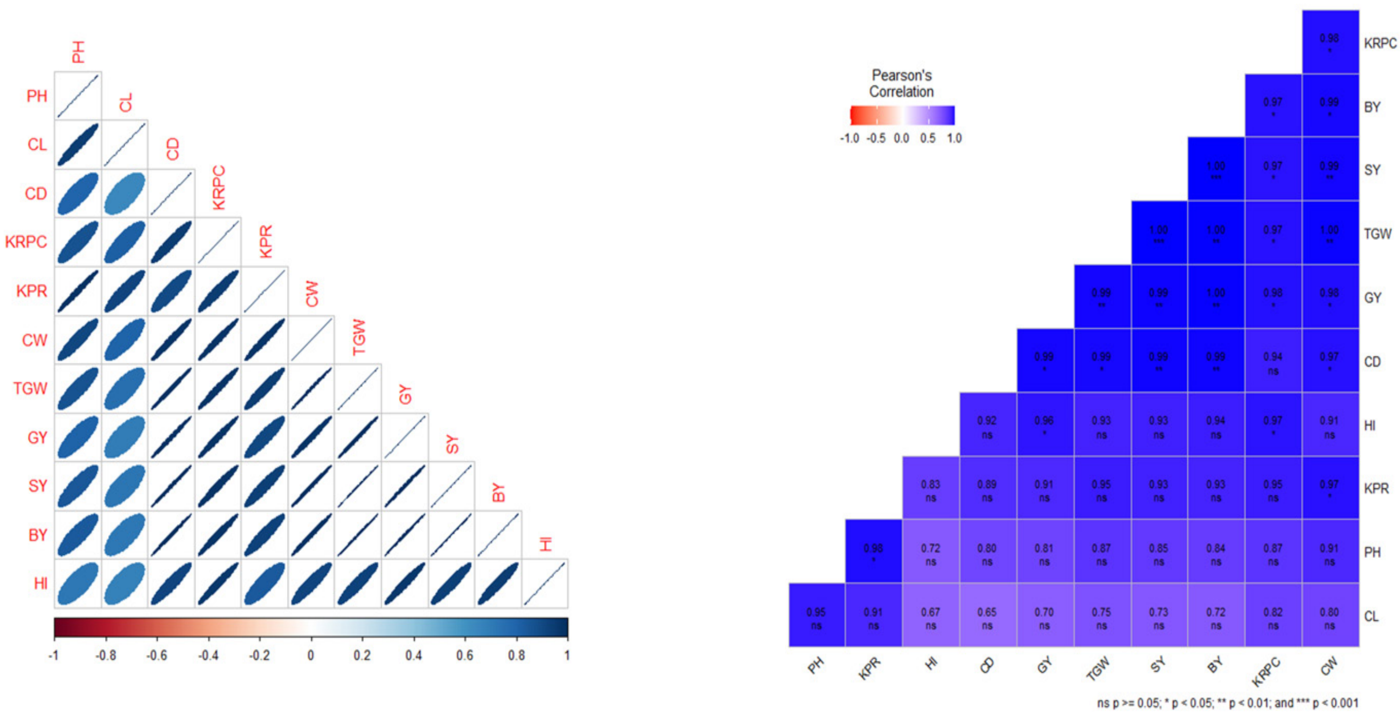

Figure 8: *Pearson correlation analysis of the GY and grain filling pattern of inbred and hybrid maize under Raincon. Acronyms and abbreviations in materials and methods provide more specifics.*

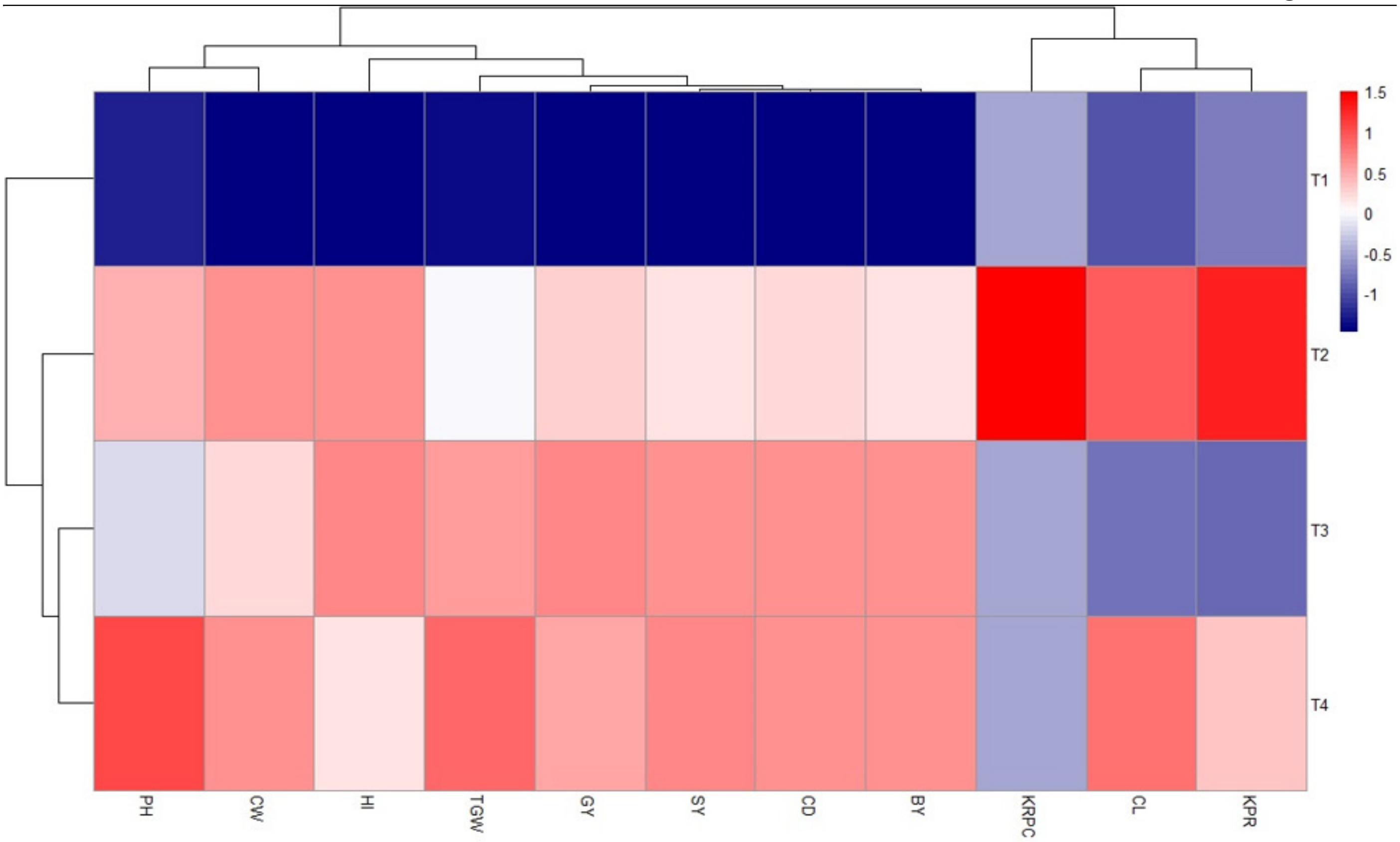

Figure 9: *Heat map analysis of the impact of the GY and grain filling pattern of inbred and hybrid maize under Irricon. Acronyms and abbreviations in materials and methods provide more specifics.*

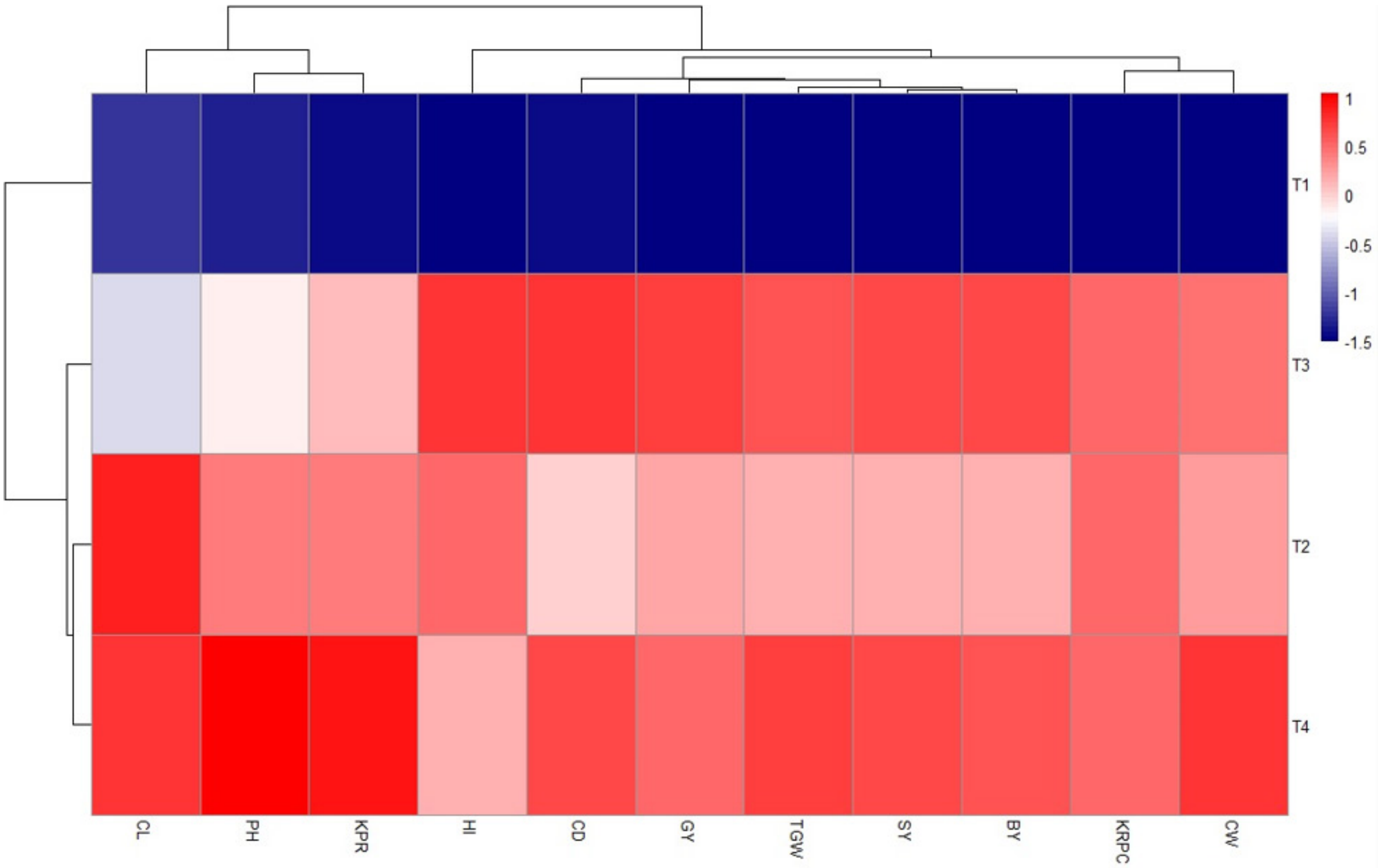

Figure 10: *Heat map analysis of the GY and grain filling pattern of inbred and hybrid maize under Raincon. Acronyms and abbreviations in materials and methods provide more specifics.*

positive correlation with CW. BY showed a positive correlation with the CW and KPRC.TGW also had a strong positive correlation with SY and moderately correlation with CW, BY and correlated with KPRC. GY demonstrated a moderately positive correlation with the BY, SY and TGW and corelated with the KPRC, CW. CD represented a moderately positive correlation with SY, BY and positive correlation with GY, TGW, CW. HI had positive correlation with the GY and KPRC. PH maintained a positive correlation with KPR.

A heat map was used to analyze the traits that best demonstrate the GY and grain filling pattern of inbred and hybrid maize under Irricon. The x-axis represents the variables, while the y-axis represents the different treatments (Figure 9). The T_1 had a lowest contribution while the highest contribution with T_4 which is statistically similar with T_3 and T_2. A heat map was used to analyze the traits that best demonstrate the GY and grain filling pattern of inbred and hybrid maize under Raincon. The x-axis represents the variables, while the y-axis represents the different treatments (Figure 10). The T_1 had a lowest contribution while the highest contribution with T_4 which is statistically similar with T_3 and T_2.

Discussion

Raincon and Irricon environments caused minor differences in the phenological stages of the maize types; hybrid P-3396 had the longest total growth time (126 days), while inbred Khoi Bhutta had the lowest (108 days). The time from anthesis to silking was largely consistent, with the exception of Khoi.

The superiority of hybrid P-3396, which showed the tallest growth, is indicated by the notable diversity in Bhutta in Raincon circumstances, which needed an additional day. These results show that hybrid cultivars typically take longer to reach maturity, which is indicative of their increased potential yield and irrigation response (Hasan *et al*., 2018).

PH across maize varieties. The shortest height was found in the inbred variety Khoi Bhutta, indicating that genetic variations affect plant vigor. The varieties' genetic variance may be the cause of these variations. Similar findings that PH varied according to varietal variety were discovered by Asaduzzaman *et al.* (2014). The PH was about 7% higher in Irricon than the Raincon. Water stress lowers crop height, which impacts production by lowering yield components including ear size and kernel weight, according to Payero *et al.* (2006). Additionally, Ghooshchi *et al.* (2008) found that when maize plants were subjected to water deficiency conditions, there was a significant decrease in pH when compared to the control. The difference in CL between the different types of maize demonstrates how well BARI hybrid maize-9 and P-3396 performed, as their cobs were longer and similar to Khoi Bhutta's. The notable disparity BHM-09 is almost 17% longer than Khoi Bhutta highlights the benefits of hybrid cultivars for increasing CL (Huda *et al*., 2016). Because the amount of KPR is one of the most crucial bases of yielding components and is directly related to the general function the more grains row^{-1}, the better the function grain there was a highly significant difference in the number of grains per row at ($P \leq 0.05$) with irrigation level as the main effect. When there is insufficient irrigation, insemination will be delayed, granule distribution will be problematic (Wassom *et al*., 2000), and ultimately, there will be fewer grains per row and fewer grains overall. With C-1921 having the largest diameter, 32% larger than the inbred Khoi Bhutta, the notable difference in CD between maize varieties demonstrates the superiority of hybrids. This implies that hybrid types typically yield thicker cobs, which raises the possibility of GY (Anjum, 2016). Among the several types of maize, hybrids C-1921 and P-3396 had the most kernel rows per cob (15 rows), which was almost 7% higher than the inbred Khoi Bhutta. This demonstrates the hybrid types' greater grain forming capacity, which raises yield (Hasan and Ullah, 2021). It is clear that irrigation has a major impact on TGW because grains grown under irrigation were 17.84% heavier than those grown under Raincon. The findings of this investigation align with those of other researchers. In order to determine the agronomic response of twelve maize hybrid cultivars under full and partial irrigation regimes, Aguilar *et al.* (2007) carried out an experiment in Southern Spain. They found that 1000 kernel weight were significantly reduced due to limited irrigation treatment. Water stress also decreased kernel weight, which significantly decreased GY, according to Pandey *et al.* (2000) and Payero *et al.* (2006).

The hybrid C-1921 produced the highest yield among the maize types, demonstrating its better productivity. This yield was roughly 57% higher than that of the

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inbred Khoi Bhutta. Furthermore, the yields of P-3396 and BHM-09, two further hybrids, show how hybrid types can improve overall grain production. These findings corroborate with the results obtained by Iptas and Acar, (2006). Grain production is improved by hybrid maize types, which also increase SY, which can improve soil fertility and livestock health (Kumar *et al*., 2023; Amanullah *et al*., 2019; Hellin *et al*., 2013). The favorable effect of irrigation on maize production is demonstrated by the GY under Irricon, which was 19% greater than under Raincon. Drought stress may have caused a difference in yield since it affected numerous plant physiological and metabolic functions (Ghooshchi *et al*., 2008). This conclusion is in line with the findings of Kipkorir *et al*. (2002), who studied the relationship between crop yield and water application under furrow irrigation on clay loam soil in a semi-arid region of Kenya.

Increased application level produced a higher yield, but increased deficit irrigation produced a poorer yield. In the same way, Oktem, (2008) examined the effects of deficit irrigation on drip- Irricon sweet corn in Turkey over two years (1998 and 1999) and discovered that full irrigation produced higher yield and all yield components, whereas maximal deficit irrigation (30% deficit) produced poorer output. According to Song *et al*. (1998), water stress slowed the development of pollen and filaments, which in turn reduced filament fertility, which in turn reduced grain weight and number. Nevertheless, some study found that optimal irrigation increased maximum output. Using a mix of alternate furrow irrigation and deficit irrigation tests conducted in China, Kang *et al*. (2000) administered varying volumes of irrigation water to one of the two adjacent furrows, resulting in a high GY (90.58 Qt ha^{-1}).

The results showed that irrigation conditions had a substantial impact on biomass yield (BY). Irricon-grown maize yielded a greater BY than Raincon-grown maize. This 14% rise during Irricon emphasizes how important proper irrigation is for promoting biomass accumulation. Under Irricon, taller plants typically exhibit superior vegetative development, which immediately raises biomass yield. In addition to supporting higher plant height, the increased water availability encourages grain filling, which eventually raises grain production and biomass (Mekonnen, 2017; Halder *et al*., 2024b), much like the GY. According to his report, the outside dry matter ranges from 11.067 to 17.933 t ha^{-1}. However, Mengiste and Tilahun (2009) found a greater maximum dry matter yield (25.89 t ha^{-1}) under non-deficit irrigation, while Gebreslassie (2008) reported a lower maximum dry matter output (9.44 t ha^{-1}). Cultivar variations, irrigation, and cultural management may be the cause of this disparity.

The greater performance of hybrids is demonstrated by the individual grain weight of the various varieties of maize; the inbred Khoi Bhutta has much lower weights than C-1921 and P-3396 (Balbaa *et al*., 2022). Maximum grain water content across maize types shows that hybrid P-3396 has a better ability to retain moisture, which is 49.12% more than the inbred Khoi Bhutta. This implies that hybrid varieties' rapid growth and effective resource allocation lead to improved grain development and moisture retention (Obeng-Bio *et al*., 2020). Hybrid maize variety P-3396 showed 23.78% higher grain filling rate than inbred maize variety khoi bhutta. For a series of inbred and hybrids with different grain-filling rates, Borras *et al*. (2009) demonstrated that the maximum kernel size was obtained at a stable maximum kernel size range from 300 to 330 g kg^{-1}. Current commercial hybrids cultivated in temperate climates vary widely in kernel weight. The time of grain filling and the rate of kernel expansion also exhibit this variation (Borras and Gambin, 2010).

Conclusions and Recommendations

Grain growth dynamics were studied in this investigation and it is found that grain growth pattern of the maize varieties varied due to the variation of the grain filling rate. Hybrid maize varieties outyielded the inbred maize variety under both Raincon and Irricon. Under Raincon maize yield reduced significantly that cultivation under Irricon. Individual grain weight variation was explained by maximum grain water content and grain filling rate. Importantly grain growth dynamics from anthesis to physiological maturity were studied for all the varieties and grain filling rate was the major cause of grain weight variation. Grain filling duration did not affect as among the varieties or between the treatments grain growth duration did not vary so much. Such kind of study may be useful for both Agronomist and plant breeders to manage their maize field or developed new variety for the water limited condition.

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Novelty Statement

Since maize is farmed in Bangladesh under water-limited conditions and water stress often adversely affects maize growth and metabolism, this study gives insight into the effects of rainfed and irrigated circumstances on grain filling pattern, grain morphology, yield and yield contributing parameters of maize. Results showed that maximum grain water content and grain filling rate explained grain weight variance regardless of variety or irrigation amount. Different maize varieties had different grain growth patterns due to different grain filling rates, but grain filling time did not alter the varieties or treatments.

Author's Contribution

Md. Azihullah: Conceptualization, methodology, data curation, writing - original draft
Ahmed Khairul Hasan: Conceptualization, writing - original draft, supervision, project administration
Md. Abdul Kader: Conceptualization, writing - review & editing, validation
Md. Liton Mia: Formal analysis, writing - review & editing
Md. Rakibul Hasan Sanet: Formal analysis
Md. Atikur Rahman: Data curation
Md. Shafiqul Islam: Writing - review & editing

Generative AI and AI-assisted technology statement
The author(s) declare that no Generative AI was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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