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RESEARCH PAPER

A comprehensive analysis of agronomic practices for cultivation of cotton (*Gossypium hirsutum* L.)

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Key Message: The importance of planting date and spacing for maximizing cotton growth and yield is highlighted in this research. Early sowing in April and wider plant spacing at 39 cm, consistently resulted in superior performance across various growth and yield parameters.

Abstract

Cotton, a versatile natural resource, holds a significant place in global socioeconomic dynamics. As the foremost source of natural textile fiber and a substantial contributor to oilseed production, cotton's impact on various sectors is great. Pakistan, a major player in cotton production and consumption, faces challenges in optimizing its yield due to multiple constraints. To enhance production, strategic agronomic interventions are imperative. The Central Cotton Research Institute (CCRI), Multan carried out a research study in 2023 to evaluate how sowing date and plant spacing affect different growth and yield characteristics in two cotton varieties, CIM-496 and CIM-499. The different treatments resulted in significant differences in the number of monopodial branches, sympodial branches, plant population, plant height, days until the first flower appeared, number of bolls per plant, boll weight, and seed cotton yield per plant. Sowing in the third week of April typically led to better outcomes in comparison to sowing later in May and June, particularly in terms of branch development, plant population, plant height, and yield characteristics. In the same way, increased plant spacing, especially at 39 cm, appeared to support improved growth and yield characteristics when compared to tighter spacing. CIM-499 displayed slightly superior performance compared to CIM-496 across different treatments. The significance of considering both the timing of sowing and the distance between plants in maximizing cotton growth and yield is illustrated by these results, providing valuable knowledge for implementing crop management techniques to improve productivity and quality.

Keywords: CIM-496, CIM-499, *Gossypium hirsutum*, Growth parameters, Plant spacing, Sowing date

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Introduction

Cotton, an essential natural material, plays a significant role in human life from birth to death. It is a valuable renewable resource primarily cultivated for its amazing fibers used in clothing, and it also has applications in food, feed, and fuel (Ali et al., 2012; Zia et al., 2015; Zia et al., 2018; Arif et al., 2022). Cotton is an important factor in global socioeconomic and political matters (Singh, 1997; Kairon et al., 2004). Being the fifth largest oilseed crop in the world, cotton is the main source of natural textile fabric (Shoukat et al., 2020; Shaukat et al., 2021; Zia et al., 2022). According to APTMA (2012), cotton provides 40% of the world's need for textiles, and it makes up 3.3% of all edible oil produced (FAS, 2014). Many countries rely on cotton as a key economic activity, generating income through its cultivation, processing, and trade, thereby supporting local livelihoods. Cotton is grown in various environmental settings, covering over 35 million hectares and yielding 25 million tons of fiber annually (FAO, 2011). This production involves 20 million farmers (Gala, 2005).

Pakistan stands as the world's fourth largest producer of cotton and holds the third position in terms of consumption. Additionally, it is a major exporter of yarn, ranking amongst the leaders in this industry (ICAC, 2012). But it still struggles to produce high-quality seed cotton per unit area because of biological (diseases, weeds, insects, etc.), physical (salinity, water scarcity, etc.), socioeconomic (high input costs, small landholdings, adulteration, etc.), and environmental (high temperature, unpredictable weather, drought, floods, etc.) constraints (Abbas et al., 2022). These constraints also include agronomic issues such as low plant density, mismanagement of nitrogen (Khan et al., 2023), cultivar selection, and inappropriate sowing time. In 2012, Pakistan's consumption of cotton increased to 14.5 million bales, and the nation annually imports 2.00 million bales of cotton to fulfill the increasing demand from domestic textile mills. In order to satisfy the demands of the textile sector as well as the worldwide market, the nation must immediately increase its production of cotton. High production levels are contingent upon the convergence of ideal soil, climate, and cultural practices. The yield of cotton produced per acre can be increased by using appropriate agronomic practices. The choice of cultivar, planting date, plant density, and nitrogen management significantly influence the crop's growth and ultimate yield. The growth, reproductive performance, yield, and quality of upland cotton were impacted by genotype, nutrient availability, and environmental conditions (Reddy et al., 2004; Wells & Stewart, 2010). Management has a significant impact on maintaining high fiber quality, even though the most environmental variables are hard to control in field conditions (Zhao et al., 2012). In order to maximize the yield potential, crop managers and producers must manage the crop, despite the presence of uncontrollable environmental circumstances (Wells & Stewart, 2010).

Choosing the right time to plant cotton is a significant agricultural consideration for farmers due to the potential decline in yield linked to incorrect planting timing. Cotton, with its indeterminate growth habit, is highly influenced by environmental conditions (Gormus & Yucel, 2002) throughout all stages of growth and development. The diverse temperature conditions associated with various sowing dates have a significant impact on the growth stages and physical characteristics of cotton plants (Shah, 2004). The number of days needed for square initiation, flowering onset, boll opening, and maturation can be affected by changes in temperature (Reddy et al., 1999). Additionally, altering the time of planting could lead to a longer, typical, or shorter growing season, thereby influencing the genetic expression (Shah, 2004). Determining the right timing for planting a specific genotype in different agro-climatic areas is crucial. Planting too early or too late could lead to potential issues with diseases and pests (Farooq et al., 2011). Ghazanfar et al. (2007) suggested that planting cotton between mid-April and mid-May is better than late sowing in order to minimize disease occurrence. Soomro et al. (2000) noted that planting cotton either before or after its ideal time resulted in a significant decrease in yield. Early planting of crops contributes to improved crop establishment and minimizes the crop's exposure to moisture stress (Iqbal, 2011). In a study conducted by Gormus and Yucel (2002), it was found that planting cotton earlier resulted in an 11.2% increase in lint yield compared to planting it later. Iqbal (2011) noted that planting cotton in the 3rd week of May led to a higher yield compared to planting it in the 2nd week of June. This was attributed to the longer growth period, greater canopy development, increased leaf area index (LAI), leaf area duration (LAD), and interception of photosynthetically active radiation (PAR), which resulted in increased total dry matter (TDM) production, more and heavier fruit-bearing branches, more mature bolls per plant. However, late planting causes the flowering to happen later, leading to boll development occurring in cooler weather, ultimately resulting in reduced yield (Akhtar et al., 2002). Late-planted cotton usually takes longer to fruit and mature, which reduces output and lowers the quality of the fiber (Bange et al., 2004; Bange et al., 2008). Soomro and colleagues (2000) discovered that a delay of just one week from the ideal timing led to a significant decrease in crop yield. In late planting (Anonymous, 2009), there was also a notable decrease in the number of bolls per plant and the weight of each boll. According to a research study conducted by Ali et al. (2011), planting the cotton crop after May 10th resulted in a significant drop in the yield of seed cotton. Hence, the most crucial management factor for a cotton variety in a specific area is regarded as the best time for sowing (Bozbek et al., 2006; Sekloka et al., 2008).

Selecting a cultivar is a crucial management decision for any farming system (Nichols et al., 2004) since cultivars bred for one region may not perform as well in another (Freeland et al., 2010). Some varieties easily adjust and thrive in different conditions, while others struggle to do the same. When choosing a plant variety, it is important to take into account various agricultural characteristics such as its potential yield, growth duration, and overall quality (Nichols et al., 2004). Kakar and colleagues (2012) reported notable variations in crop yield, ginning out turn, and staple length across various cultivars. Muhammad (2001) observed differences in environmental adaptability among different cotton genotypes based on yield, lint percentage, and fiber quality. Afzal et al. (2002) observed notable variations in crop yield, weight of cotton bolls, quantity of bolls per plant, and height of plants as a result of genetic differences. In varying ecological conditions, cotton genotypes exhibit different performances in terms of seed cotton yield and their ability to resist diseases such as cotton leaf curl virus (Iqbal & Khan, 2010). This variation is attributed to the diverse genetic composition of the genotypes, as highlighted by Iqbal et al. (2011). The quality of cotton fiber is primarily determined by genetics of the cultivar, but it is also affected by environmental conditions and management practices (Subhan et al., 2001). The main objective of this research study was to evaluate the effects of sowing date and plant spacing on the growth and yield characteristics of two cotton varieties, CIM-496 and CIM-499, in order to identify optimal agronomic practices for enhancing cotton production.

Materials and Methods

Experimental site

The experiments were carried out at the Central Cotton Research Institute (CCRI), Multan during the year 2023. The location of the experiment was at latitude of 30°, 12N, longitude of 71°, 28E, and an altitude of 123 meters.

Seed bed preparation

Irrigation of 10 cm depth was done before preparing the seed bed. After the soil reached the right moisture level, the fine seed bed was created by tilling the land 4 times using a tractor-mounted cultivator to a depth of 10-12 cm and then planking it three times. The land was leveled and formed into ridges and furrows using a tractor-mounted ridger. The furrows were irrigated, and cotton seeds without lint were manually planted in the moist soil in their designated spots on the same day. The furrows were re-irrigated 72 hours after planting to ensure successful seed emergence.

Sowing of crop

The sowing date treatments were followed at sowing the crop. Cotton was manually planted on ridges with a 75 cm row distance. Two seeds were dibbled per hill at a depth of 3 to 4 cm, maintaining 30 cm spacing in a row to achieve the required plant population. The acid delinted seed was subjected to treatment with a systemic insecticide Confidor (Imidacloprid 70WS) at a rate of 10 g per kg seed, providing protection from sucking insects at the early stage.

Cultural practices

At the four-leaf stage, the cotton was manually thinned to achieve the desired plant population based on plant spacing treatment. To effectively control early-season weeds, a pre-emergence herbicide, Pendimethalin @ 3.0 liters ha^{-1}, was applied in furrows 24 hours after seeding. Weeding was carried out through hoeing/inter-culturing for subsequent weed control. At the time of sowing, TSP (Triple Super Phosphate) was applied in the form of a uniform dose of 60 kg ha^{-1} of phosphorus. The recommended dose of N (120 kg ha^{-1}) was applied using urea. Chemical control methods were used to keep insect pests below the threshold level. Insecticides were utilized to manage sucking insects such as aphids, jassids, whiteflies, thrips, mites, and cotton mealy bugs, as well as bollworms including American bollworm, pink bollworm, and spotted bollworm. We applied the first irrigation when we sowed the seeds. After 72 hours, we irrigated the plots again to make sure that any un-soaked seeds would germinate during the first irrigation. Then, we continued to irrigate at varying intervals of 7 to 21 days until the crop matured, based on the plant's needs, temperature, and rainfall.

Agronomic parameters

Number of monopodial branches per plant

The number of monopodial (vegetative) branches was counted for ten randomly chosen plants from each plot, and the average number of monopodial branches per plant was then determined.

Number of sympodial branches per plant

The number of fruiting branches on ten chosen plants from each plot was tallied, and then the average number of fruiting branches per plant was computed.

Plant population

The number of plants in each plot was determined by counting all the plants 30 days after planting and then converted into plants per hectare.

Plant height (cm)

The height of ten plants chosen at random from each plot was measured from the base of the plant to the tip of the main stem during the last picking, and the average height was then calculated.

Number of days from planting to appearance of first flower

We recorded the number of days it took for the first flower to appear on ten randomly selected protected plants in each trial. We then calculated the average number of days it took for the first flower to appear.

Number of opened bolls per plant

The number of bolls per plant was determined by counting the opened bolls during the first and second picking of ten randomly chosen tagged plants, and then the average was calculated.

Boll weight (g)

The calculation for average boll weight (g) involved dividing the total plant seed cotton yield by the respective number of bolls per plant.

Seed cotton yield per plant (g)

The seed cotton from the ten identified plants in the designated area was harvested individually during each picking. The total weight of seed cotton from each picking was combined to determine the yield of seed cotton per plant, which is measured in grams.

Statistical analysis

Statistical analysis of data collected on various parameters was conducted using the Statistix 8.1 software to perform an analysis of variance. Means were then distinguished using Fisher's protected least significant difference (LSD) test with a 5% probability level (Steel et al. 1997).

Results

Number of monopodial branches per plant

The study examined how the planting date and distance between plants affected the number of monopodial branches per plant in two different types of cotton, CIM-496 and CIM-499. The study findings showed significant differences among the various treatments. Branch development in both types was affected by the timing of sowing, showing that sowing earlier in the third week of April led to a greater number of branches compared to sowing later in May and June (Table 1). In the same way, the distance between plants had an impact, as planting them closer together at 25 cm led to a decrease in the number of branches, whereas spacing them further apart at 39 cm encouraged more branching. It is worth mentioning that CIM-499 showed a slightly greater number of branches compared to CIM-496 in all the experimental conditions (Table 1). The results indicate that the timing of planting and the distance between plants have a clear effect on the growth of cotton branches, which could have important implications for agricultural strategies focused on maximizing crop output and canopy organization.

Table 1 Effect of planting date and distance between plants on the quantity of monopodial branches per cotton plant

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	1.7^a	1.9^a
SD_2 = 3rd Week of May	1.5^b	1.7^b
SD_3 = 3rd Week of June	1.3^c	1.4^c
LSD (0.05)	0.2	0.2
Plant spacing (PS)		
PS_1 = 25 cm	1.3^c	1.28^c
PS_2 = 32 cm	1.7^b	1.9^b
PS_3 = 39 cm	2.0^a	2.2^a
LSD (0.05)	0.09	0.11

A substantial difference is observed at p≤0.05 across means that share distinct letters.

Number of Sympodial branches per plant

There were notable variations in branch growth under different treatments in the study by the effects of plant spacing and sowing date on the number of sympodial branches per cotton plant. For both CIM-496 and CIM-499 varieties, the sowing date had a significant impact on the number of sympodial branches. Sowing in the third week of April led to a higher count of branches compared to sowing in May and June (Table 2). Furthermore, the distance between plants had a notable impact, as wider spacing typically led to higher branch numbers. In particular, when planted 39 cm apart, CIM-496 and CIM-499 exhibited the greatest number of sympodial branches. Moreover, CIM-499 consistently exhibited slightly higher branch counts compared to CIM-496 across various treatments (Table 2).

Table 2 Effect of plant spacing and sowing date on the quantity of sympodial branches per plant in cotton

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	22.6^a	21.5^a
SD_2 = 3rd Week of May	19.9^b	19.8^b
SD_3 = 3rd Week of June	14.5^c	15.4^c
LSD (0.05)	1.23	1.49
Plant spacing (PS)		
PS_1 = 25 cm	15.9^b	17.4^b
PS_2 = 32 cm	17.6^a	18.5^a
PS_3 = 39 cm	19.4^a	20.1^a
LSD (0.05)	0.85	0.92

Means sharing different letters differ significantly at p≤0.05.

Plant population per hectare

Results demonstrated significant variations in plant population across different treatments. Regarding sowing dates, earlier sowing in the third week of April led to higher plant populations compared to later sowing in May and June for both varieties (Table 3). Similarly, plant spacing significantly affected plant population, with closer spacing resulted in higher densities. Specifically, CIM-496 and CIM-499 exhibited the highest plant populations when planted at 25 cm spacing, followed by 32 cm and 39 cm spacings. Notably, CIM-496 generally displayed slightly higher plant populations compared to CIM-499 across various treatments (Table 3).

Table 3 Impact of plant spacing and sowing date on the quantity of sympodial branches per plant in cotton (*Gossypium hirsutum* L.)

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	44031	43692
SD_2 = 3rd Week of May	43565	42807
SD_3 = 3rd Week of June	42889	41996
LSD (0.05)	NS	NS
Plant spacing (PS)		
PS_1 = 25 cm	55836[a]	56198[a]
PS_2 = 32 cm	44189[b]	45841[b]
PS_3 = 39 cm	38809[c]	39538[c]
LSD (0.05)	292	286

A substantial difference is observed at $p \leq 0.05$ across means that share distinct letters.

Plant height (cm)

There were significant differences in plant stature amongst treatments in the study of how plant spacing and sowing date affected plant height in cotton. For both CIM-496 and CIM-499 varieties, sowing date significantly influenced plant height, with plants sown in the third week of April exhibiting the tallest stature compared to those sown in May and June (Table 4). Additionally, plant spacing had a remarkable effect on plant height, with closer spacing resulting in taller plants. Specifically, CIM-496 and CIM-499 displayed the tallest plants when planted at 25 cm spacing, followed by 32 cm and 39 cm spacings. The variety CIM-499 generally exhibited slightly taller plants compared to CIM-496 across various treatments (Table 4).

Table 4 Effect of sowing date and plant spacing on plant height (cm) in cotton (*Gossypium hirsutum* L.)

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	135.2[a]	139.2[a]
SD_2 = 3rd Week of May	125.8[b]	129.4[b]
SD_3 = 3rd Week of June	95.9[c]	110.6[c]
LSD (0.05)	3.65	4.91
Plant spacing (PS)		
PS_1 = 25 cm	127.9[a]	135.2[a]
PS_2 = 32 cm	125.1[b]	132.5[b]
PS_3 = 39 cm	122.5[c]	129.2[c]
LSD (0.05)	1.46	1.88

A substantial difference is observed at $p \leq 0.05$ across means that share distinct letters.

Number of days from planting to appearance of first flower

The investigation into the effect of sowing date and plant spacing on the number of days from planting to the appearance of the first flower in cotton revealed interesting findings. For CIM-496, the number of days to first flower appearance varied significantly depending on the sowing date, with the earliest sowing in the third week of June resulted in the shortest time to flowering, followed by May and April sowings (Table 5). However, for CIM-499, there was less variation in the number of days to first flower appearance across different sowing dates. Regarding plant spacing, there were no significant differences observed in the number of days to first flower appearance among the different spacing treatments for both varieties (Table 5). Overall, these results suggest that while sowing date can influence the timing of flowering, plant spacing may have less impact on this aspect of cotton growth and development.

Table 5 Effect of plant spacing and sowing date on the number of days from planting to the first blossom appearance

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	55.2[c]	56.5
SD_2 = 3rd Week of May	56.2[b]	55.8
SD_3 = 3rd Week of June	57.1[a]	55.5
LSD (0.05)	0.53	NS
Plant spacing (PS)		
PS_1 = 25 cm	58.9	53.7
PS_2 = 32 cm	59.2	53.9
PS_3 = 39 cm	59.5	54.2
LSD (0.05)	NS	NS

A substantial difference is observed at $p \leq 0.05$ across means that share distinct letters.

Number of bolls per plant

Results in Table 6 indicated significant variations in boll production across different treatments. For both varieties, sowing date significantly influenced boll formation, with plants sown in the third week of April producing the highest number of bolls per plant compared to those sown in May and June. Similarly, plant spacing had a notable impact on boll production, with wider spacing generally associated with higher boll counts per plant. Specifically, CIM-496 and CIM-499 exhibited the highest number of bolls when planted at 39 cm spacing, followed by 32 cm and 25 cm spacings. Notably, across all treatments, CIM-496 consistently showed a little larger number of bolls per plant than CIM-499.

Table 6 Effect of planting date and plant spacing on cotton boll production per plant

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	35.9[a]	31.1[a]
SD_2 = 3rd Week of May	30.0[b]	29.0[b]
SD_3 = 3rd Week of June	16.2[c]	18.0[c]
LSD (0.05)	0.91	0.58
Plant spacing (PS)		
PS_1 = 25 cm	21.1[c]	20.3[c]
PS_2 = 32 cm	27.9[b]	26.1[b]
PS_3 = 39 cm	33.0[a]	31.7[a]
LSD (0.05)	0.73	0.68

A substantial difference is observed at $p \leq 0.05$ across means that share distinct letters.

Boll weight (g)

The results shown in Table 7 indicate that the spacing between plants and the timing of sowing had a substantial effect on boll weight in each of the treatments. In the case of both CIM-496 and CIM-499 varieties, boll weight showed significant variation based on the sowing date, with plants sown in the third week of April yielding the heaviest bolls compared to those sown in May and June. Furthermore, the distance between plants also played a significant role, as wider spacing generally resulted in heavier bolls per plant. Particularly, when planted at 39 cm spacing, CIM-496 and CIM-499 showed the heaviest bolls, followed by 32 cm and 25 cm spacings. Interestingly, across all treatments, CIM-496 generally showed slightly heavier bolls than CIM-499.

Seed cotton yield per plant (g)

There were significant differences in yield across the various treatments when the impact of planting date and plant spacing on seed cotton production per plant in cotton was examined (Table 8). For the CIM-496 and CIM-499 types, plant spacing, and the date of sowing had a major impact on the amount of seed cotton produced per plant. In terms of planting date, plants planted during the third week of April yielded more than those planted in May and June. Similarly, wider plant spacing was associated with higher yields per plant. Specifically, CIM-496 and CIM-499 varieties produced the highest yields per plant when planted at 39 cm spacing, followed by 32 cm and 25 cm spacings. Notably, CIM-496 generally yielded slightly higher than CIM-499 across various treatments. These results, which may have an impact on crop production and management strategies, emphasize the significance of taking into account both plant spacing and sowing date when maximizing seed cotton yield per plant in cotton farming.

Table 7 Effect of sowing date and plant spacing on boll weight (g) in cotton

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	3.83[a]	2.68[a]
SD_2 = 3rd Week of May	3.77[b]	2.62[b]
SD_3 = 3rd Week of June	3.65[c]	2.53[c]
LSD (0.05)	0.06	0.07
Plant spacing (PS)		
PS_1 = 25 cm	3.71[b]	2.47[b]
PS_2 = 32 cm	3.76[a]	2.52[a]
PS_3 = 39 cm	3.78[a]	2.53[a]
LSD (0.05)	0.03	0.03

Means sharing different letters differ significantly at $p \leq 0.05$.

Table 8 Impact of plant spacing and sowing date on the amount of seed cotton produced per plant (g) in cotton

Treatments	CIM-496	CIM-499
Sowing dates (SD)		
SD_1 = 3rd Week of April	82.1[a]	68.4[a]
SD_2 = 3rd Week of May	64.0[b]	61.3[b]
SD_3 = 3rd Week of June	24.6[c]	27.5[c]
LSD (0.05)	2.49	1.57
Plant spacing (PS)		
PS_1 = 25 cm	43.8[c]	41.0[c]
PS_2 = 32 cm	63.5[b]	57.6[b]
PS_3 = 39 cm	78.5[a]	70.6[a]
LSD (0.05)	2.08	1.86

Means sharing different letters differ significantly at $p \leq 0.05$.

Discussion

The number of monopodial branches seemed to depend on the growth environment and genetics, as evidenced by the considerable effects of plant spacing, cultivar, and sowing date. A greater number of monopodial branches were produced by early seeding. Butter et al. (2004) noted a similar pattern, although El Shahawy (1999) discovered no relationship between planting dates and monopodial branches. Similar to earlier studies (Wankhade et al., 2002; Shah, 2004; Obasi & Msaakpa, 2005; Ali et al., 2009) which also reported an increase in monopodias with low plant density, close plant spacing (25 cm) inhibits the growth of monopodial branches. This might be the outcome of cotton plants with close plant spacing engaging in intraspecific competition. Significant variations in monopodias between cultivars support earlier findings by Hussain et al. (2007), which suggested that cultivars range considerably in the number of monopodial branches they produce per plant as a result of innate genetic variety.

A healthy yield is indicated by more sympodial branches per plant. The production of a higher number of sympodial branches per plant during the early planting period (third week of April) is attributed to early fruiting and extended growth period, given that cotton has an indeterminate growth habit and produces more fruiting branches over time (Shah, 2004; Dong et el., 2005; Dong et al., 2006; Dong et al., 2007). The results are consistent with the findings of Butter et al. (2004); Dong et al. (2006), who reported that early sowing increased the frequency of sympodia. Due to the decreased rate at which nodes appeared on the main stem, presumably as a result of severe competition between plants, close plant spacing decreased the number of sympodias per plant. Even though Ahmad et al. (2009) found that closely spaced plants consumed more sympodia per plant, earlier investigations by Nichols et al. (2004); Obasi & Msaakpa (2005) also observed a similar pattern. Due to differences in genetic composition, the number of sympodial branches per plant varied significantly among genotypes, in line with previous research (Arshad et al., 2007; Ali et al., 2009).

In cotton, the morphological framework governing plant type and canopy growth is significantly influenced by plant height. According to Wankhade et al. (2002), crop plants' genetic make-up and environmental factors both have an impact on plant height. The main stem nodes and the lengthening of the internodal gap determine the final plant height (Hake et al., 1989). All of the cultivars in this experiment produced taller plants when sown in the third week of April, likely due to a longer growth period (Shah, 2004), the creation of more main stem nodes and internodal distance (Nuti et al., 2006; O'Berry et al., 2008), among other reasons. These findings are comparable to those of Pettigrew (2002), Hassan et al. (2005); Gormus & Yucel (2002). But according to Cathey and Meredith (1988), late-planted cotton grows taller and faster than early- or regular-planted cotton. Wider plant spacing may result in less intense competition between plants for nutrients and light, as seen by the shorter plants observed there compared to closer plant spacing. Others (Obasi & Msaakpa 2005; Ahmad et al., 2009; Ali et al., 2009) came to similar conclusions.

The number of days till the first flower appeared was determined by the date of sowing. There is ample evidence about the effects of temperature on different phenological stages, such as the number of days till squaring, blooming, boll opening, and boll maturation period (Hussain et al., 2000; Shaheen et al., 2001; Jost & Cothren, 2001). Temperature proved to have an impact on the number of days until the first flower developed after planting. In CIM-496, early sowing (the third week of April) took comparatively fewer days to begin blooming, whereas late sowing (the third week of June) took longer due to the weather, with May and June having higher temperatures. Heat sums have been used to predict the time to first blossom, which is a function of temperature (Mauney, 1986; Viator et al., 2005). Square growth and initiation depend on cultivar (Hodges et al., 1993) and temperature (Jost & Cothren, 2001). Similar to this, cultivars and ambient temperature can affect the first flower's appearance throughout the cotton crop growth phase (Anjum et al., 2001; Shaheen et al., 2001). Reddy et al. (1997) stated that an increase in temperature tends to shorten plant life and speed up plant development. The first cultivar to begin flowering quickly was CIM-496. Plant spacing did not significantly affect flower initiation, which was in line with the findings of Silva et al. (1999) where there was no relationship between plant spacing and squaring, blooming, or boll opening.

According to Iqbal et al. (2003), boll set was the primary factor in the rise of seed cotton yield. The largest number of bolls per plant in this study was achieved by early planting in the third week of April. This can be the result of a longer growth period that produces more flower buds and matures the final boll by accumulating sufficient heat units. These findings support those of Gormus and Yucel (2002), Ahuja (2006); Ali et al. (2009), who argued that planting later in the season accelerated boll growth in cooler weather and decreased time to form squares and flowers because of warmer days. In contrast, early planting permits the last bolls to mature on schedule while displacing the need for full use of soil moisture and nutrients to yield more squares. As stated by Ogola et al. (2006); Oad et al. (2002), narrow plant spacing may increase competition for nutrients and moisture, as well as encourage pests to accumulate in the canopy, which lowers the quantity of bolls per plant. In contrast, wide plant spacing produced more bolls per plant. Higher fruit retention was linked by Siebert et al. (2006) to lower plant populations (2.0-5.1 plants m^{-2}). Additionally, Rajakumar and Gurumurthy (2008) found that bolls m^{-2} decreased with greater spacing. The genetic structure of the cultivars caused differences in the number of bolls per plant and bolls m^{-2}. Numerous studies confirmed that there were notable differences amongst cotton cultivars in terms of yielding bolls (Arshad et al., 2007; Bednarz et al., 2007; Hussain et al., 2007; Meena et al., 2007).

In a prior study, Butter et al. (2004) reported that early-sown cotton had a greater seed index and boll weight. These findings are corroborated by other researchers (Bozbek et al., 2006; Dong et al., 2006; Bange et al., 2008), who found that early sowing increased boll number, seed index, and boll weight by moving the flowering period earlier, enabling the crop to grow in more hospitable conditions and ward off insects that feed during the late season (Bozbek et al., 2006). Larger boll sizes in early planted cotton were also linked by Hallikeri (2008) to increased photosynthate accumulation and more time for boll development and maturity. Higher boll weight was linked to earlier sowing, which is consistent with the results of the current study. Similar to how plant spacing changed the location and size of the fruit, close spacing decreased the weight of the boll (Hake et al., 1991). Reduced seed index, lint index, and boll weight may result from dense plant stands' severe competition for nutrients, water, and light (Ogola et al., 2006). Additionally, Clawson et al. (2006) found an inverse relationship between population density and boll weight. Because cultivars differ in their genetic composition, there were notable differences in their boll weight.

The sowing date and plant spacing have a major impact on the production of seed cotton per plant and per hectare. Because there is less time to begin and mature an acceptable number of bolls, seed cotton production decreases with planting delay (Bange et al., 2008). On the other hand, by moving the flowering phase earlier, allowing crops to flourish under more favorable weather conditions, and allowing them to escape late season insects, early planting increased cotton yield (Killi & Bolek, 2006; Ali et al., 2009). Due to early spring rains, crops had sown a few days earlier benefit greatly from soil hydration, nutrients, and radiation that is intercepted. Additionally, a small extension of the cotton crop's flowering season allows late-season blossoms to ripen into open bolls (Pettigrew & Johnson, 2005). Furthermore, early-planted cotton has a greater rate of boll retention (Hallikeri, 2008) because it can more effectively replace damaged floral structures by producing new ones and turning them into components that constitute the yield, as opposed to late-planted cotton. According to O'Berry et al. (2008), fluctuations in early season heat unit accumulation may be responsible for yield discrepancies between early and late planted cotton. Higher seed cotton yields per plant or per hectare were obtained with wider plant spacing. On the other hand, closely spaced plants may increase competition for moisture and nutrients, as well as encourage insect accumulation in the canopy, which would reduce the production of seed cotton (Ogola et al., 2006). Sawan et al. (2008) also provided information regarding how increasing plant density or lowering spacing can reduce the amount of seed cotton produced per plant. The relationship between sowing date and plant spacing was substantial. Higher seed cotton production was reported with wide plant spacing when seed was sown early (3rd week of April).

Conclusion

The results of this study revealed significant variations across different treatments. Early sowing in the third week of April consistently resulted in superior performance compared to later sowing in May and June, particularly in terms of branch development, plant population, plant height, and yield attributes. Similarly, wider plant spacing, notably at 39 cm, tended to promote better growth and yield parameters compared to closer spacing. The variety CIM-499 exhibited slightly better performance than CIM-496 across various treatments. These results highlight the importance of considering both sowing date and plant spacing as key factors in optimizing cotton growth and yield.

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