Zoo Botanica
ISSN: 3007-2050 (E), 3007-2042 (P)

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Research Article

FH-492: An early-maturing, climate-resilient cotton (*Gossypium hirsutum* L.) variety with tolerance to cotton leaf curl disease

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ABSTRACT

Cotton productivity is threatened by climate change driven heat extremes, unpredictable rainfall, Cotton Leaf Curl Disease (CLCuD) and insect pests. The limited availability of climate resilient cotton cultivars is a primary concern among farmers in Pakistan. To address this bottlenecks, a new climate smart, high yielding, early maturing Bt. cotton variety “FH-492” tolerant to Cotton Leaf Curl Disease (CLCuD) developed at the Cotton Research Station, AARI, Faisalabad through hybridization of FH-113 (Bt, bollworm resistant) and FH-1200 (Non-Bt., heat tolerant). The F_2 to F_6 generations were advanced through pedigree selection (2011–2016) and subsequently evaluated in Preliminary Yield Trials (PYT), Advanced Yield Trials (AYT), Provincial Coordinated Cotton Trials (PCCT), and multi-location National Coordinated Varietal Trials (NCVT) from 2017 to 2021. FH-492 proved superior performance and produced 19.2% and 15.1% higher seed cotton yield than the check variety CIM-602 during 2019–20 and 2020–21, respectively, in the National Coordinated Varietal Trial (NCVT). Fiber quality assessed by standardized High Volume Instrument (HVI) demonstrated industry compatible and thermally stable fiber profiles with mean values of a staple length (29.80 mm), ginning out-turn (42%), micronaire (4.5 $\mu g inch^{-1}$), fiber strength (31 $g tex^{-1}$) and a uniformity index (88%). Punjab Seed Council (PSC) finally approved the variety for general cultivation in 2021. Morphologically, FH-492 Plants are medium compact (160–180 cm), cluster boll habit, 50–70 bolls per plant, maturing in 150–160 days with a seed cotton yield potential of 5500 kg/acre. Thus, FH-492 offers a sustainable solution for cotton production under changing climatic conditions and meets the needs of farmers and the cotton industry.

Keywords: *Gossypium hirsutum*; variety development; FH-492 climate resilient; early-maturing; CLCuD.

OPEN ACCESS

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Article History
Received: December 02, 2025
Accepted: December 22, 2025
Published: December 31, 2025

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is a cornerstone cash crop for millions of smallholder and commercial farmers particularly in Pakistan, India, China, Brazil and the United States. It providing raw material for the textile industry and substantially contribute to rural livelihoods and national economies (Voora *et al*., 2023). It accounts 31.92 million hectares cultivated area across 80 countries with an estimated annual turnover of USD $5.68 billion (Vitale *et al*., 2024). It contributes 0.6% to GDP and 3.1% to total agricultural value-addition in Pakistan and is a major source of foreign-exchange earnings through its long value chain from cultivation to textile exports (Government of Pakistan, 2025). The cotton productivity has been rapidly destabilized by climate change, with heat extremes and erratic rainfall emerging as dominant abiotic constraints, particularly in South Asia (Saini *et al*., 2023). The high temperatures during flowering and fiber development trigger severe square and boll shedding, reduced fiber elongation and overall yield instability (Bashir *et al*., 2022). In response, heat tolerance has become a major focus as demonstrating significant variation in traits including cell membrane stability, antioxidant responses and root morphology under high-temperature conditions (Luqman *et al*., 2025).

Among biotic constraints, Cotton Leaf Curl Disease (CLCuD) causes severe damage to cotton crops as leaf deformation, growth reduction, and yield loss due to infection by rapidly evolving begomoviruses transmitted by whiteflies. Controlling this disease remains a challenge because of viral diversity and resistance breakdown (Zaidi *et al*., 2019, Nadeem *et al*., 2024). Resistance to Cotton Leaf Curl Disease (CLCuD) is a critical trait for cotton cultivation especially in Pakistan and India where the disease has historically imposed severe yield and quality losses. Germplasm screening and recent breeding effort have produced improved cotton lines such as Cyto 124 showing enhanced tolerance against CLCuV (Ashraf *et al*., 2023).

Fiber yield and quality traits such as staple length, micronaire, fiber strength, and uniformity directly influence spinning efficiency, market preference, and profitability for both farmers and global textile industry (de Araújo *et al*., 2022). Furthermore, early-maturity regulation governed by flowering-time genes such as GhAP1-D3 has proven essential for maximizing production efficiency in heat-prone and short-season production windows without compromising fiber or yield performance (Wang *et al*., 2023).

Cotton crop has to counter many challenges including insect pest pressure, Cotton Leaf Curl Disease (CLCuD) and changing climatic conditions collectively constrain overall crop productivity (Subedi *et al*., 2023). Although Bt. cotton adoption since the mid-1990s has drastically improved bollworm control and reduced pesticide dependency which has economic benefits through cost reduction and increased farm-level profitability (Tokel *et al*., 2021). The pyramiding diverse abiotic-stress traits with insect-resistance has remained limited in approved cultivars of cotton and is still an emerging research goal rather than a widespread commercial reality (Malenica *et al*., 2021).

Breeding efforts in Pakistan increasingly emphasize planned hybridization and targeted selection to develop climate-resilient cotton cultivars (Ahmed *et al*., 2024, Ijaz *et al*., 2024). However, despite progress in single-trait improvement, a major breeding gap persists for cotton cultivars that simultaneously integrates transgenic pest protection (Bt), durable viral resistance (CLCuD), abiotic stress tolerance (heat) and phenological efficiency (early maturity) without compromising fiber quality or yield stability. To bridge this gap, the Cotton Research Station, AARI, Faisalabad has initiated strategic breeding to develop a new cotton variety “FH-492”. This new cotton variety will mark a targeted step toward delivering a climate-smart and industry-compatible cultivar suited for Pakistan’s evolving cotton production environments.

MATERIALS AND METHODS

Location of the experiment

The hybridization for cotton variety “FH-492” was started during 2009 at Cotton Research Station, Faisalabad, which is located in northeastern Punjab at 31°25′00″ N and 73°05′00″ E and 186 meters above sea level. The average annual rainfall is about 13.4 mm, while mean temperatures range from 21°C to 28.6°C during winter and 30°C to 45°C in summer. The mean annual humidity is around 35.17 $g.m^{-3}$ (https://www.weather atlas.com/en/pakistan/faisalabad-climate).

Plant material

The cross between local varieties FH-113 (female) and FH-1200 (male) was performed at Cotton Research Station (CRS). The F1 to F6 progenies of this cross were advanced using the pedigree selection method and a superior line was bulked in F7 and designated as FH-492. The key characteristics of Parents are presented in the Figure 1.

Breeding history

The breeding of cotton variety FH-492 was initiated during 2009–10 at the Cotton Research Station, Faisalabad, through conventional hybridization between local varieties FH-113 and FH-1200. The resultant F_1 was grown in 2010–11 for F_2 generation advancement, and superior plants were selected using the pedigree method. Successive generations F_3–F_6 were advanced from single-plant progenies during 2012–16 to achieve homozygosity and uniformity for desired traits. A stable line was selected in F_7 based on high seed cotton yield, early maturity, heat and CLCuD tolerance, desirable fiber quality and presence of the Cry1Ac gene. From 2017–2021, FH-492 was evaluated in Preliminary, Advanced, PCCT, NCVT, 1.25-acre spot examination, DUS, Biosafety, and Agronomy trials using FH-142 and CIM-602 as checks (Figure 2). Data on morphological, yield and fiber quality traits were recorded from five randomly tagged plants per replication and subjected to analysis of variance (Steel *et al*., 1997) with mean comparisons using Tukey's test (1949) to assess genetic variation among traits.

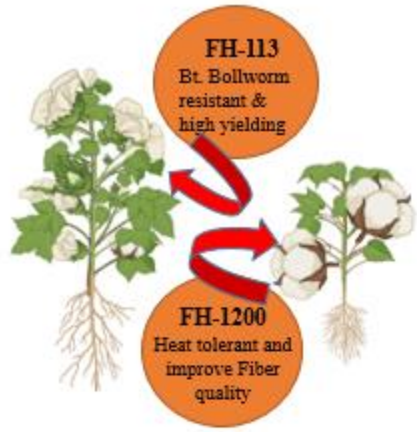

Figure 1. Characteristics of parents used to developed candidate variety FH-492.

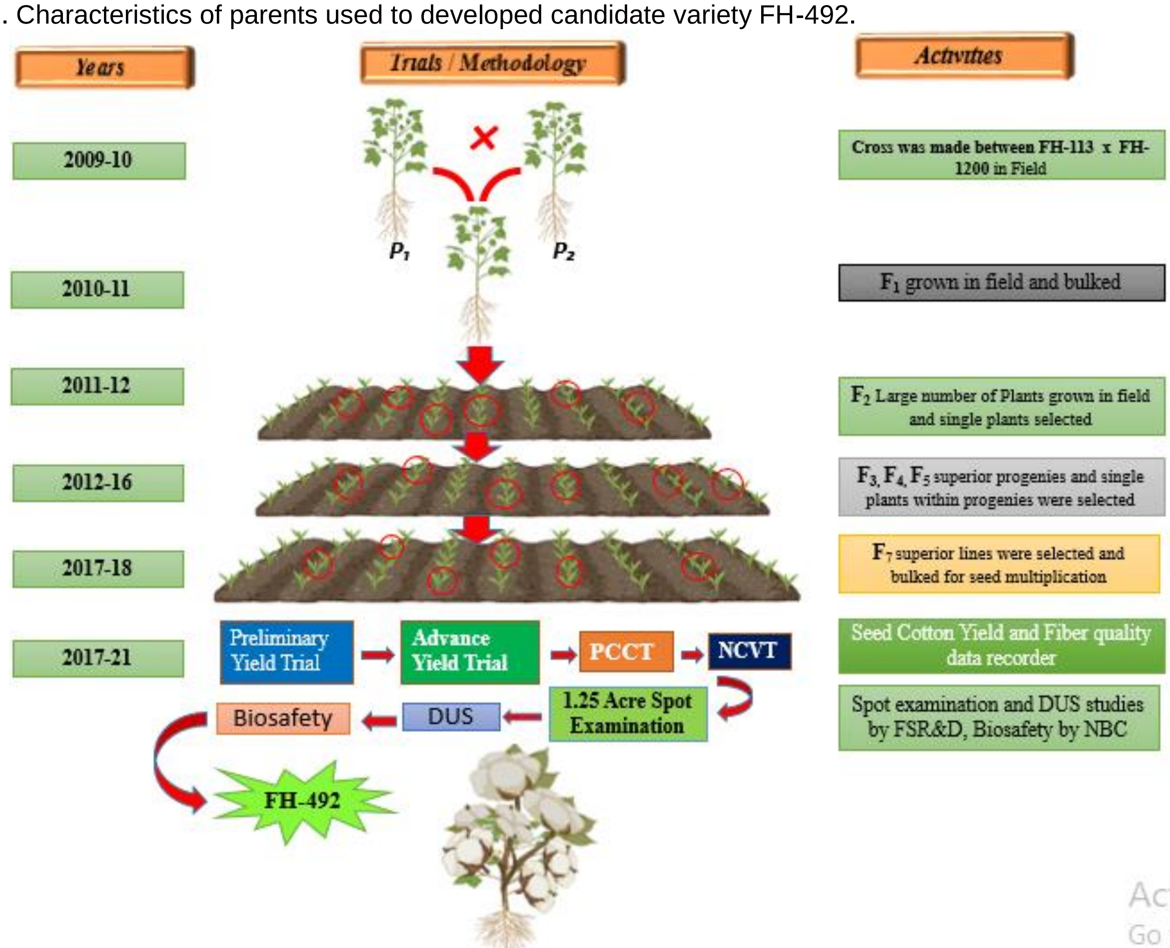

Figure 2. Schematic diagram of the developmental pathway for FH-492.

RESULTS AND DISCUSSION

Preliminary & advanced yield trials

The candidate cotton variety FH-492 (Bt.) was compared with check variety FH-142 in preliminary and advance yield trials at Cotton Research Station, Faisalabad during 2017-18 to 2018-19, respectively. The candidate line performed best than check in both station trials. In the preliminary yield trial, it produced 10.3 % higher seed cotton yield (2439 kg/ha) as compared to check (2212 kg/ha). It gives 5.8 % higher seed cotton yield (2546 kg/ha) as compared to check (2406 kg/ha) in the advance yield trial.

Provincial coordinated cotton trials (PCCT)

During 2020–21, Provincial Coordinated Cotton Trials (PCCT) of FH-492 were conducted at six locations across different districts of Punjab in comparison with check FH-142. Average seed cotton yield of candidate variety FH-492 was 11.4% more (2204 kg/ha) than check FH-142 (1978 kg/ha) and it ranked 6th among 21 strains.

National coordinated varietal trials (NCVT)

The Pakistan Central Cotton Committee (PCCC) Multan conducted the National Coordinated Varietal Trials (NCVT) during 2019-20 and 2020-21 at different locations to check its adaptability and yield. The FH-492 produced 19.2% higher seed cotton yield (1631 kg/ha) than check CIM-602 (1536 kg/ha) during 2019-20 and 15.1% higher (1592 kg/ha) in comparison to check (1381 kg/ha) during 2020-21(Figure 3). Its recorded seed cotton yield outperformed the local check CIM-602.

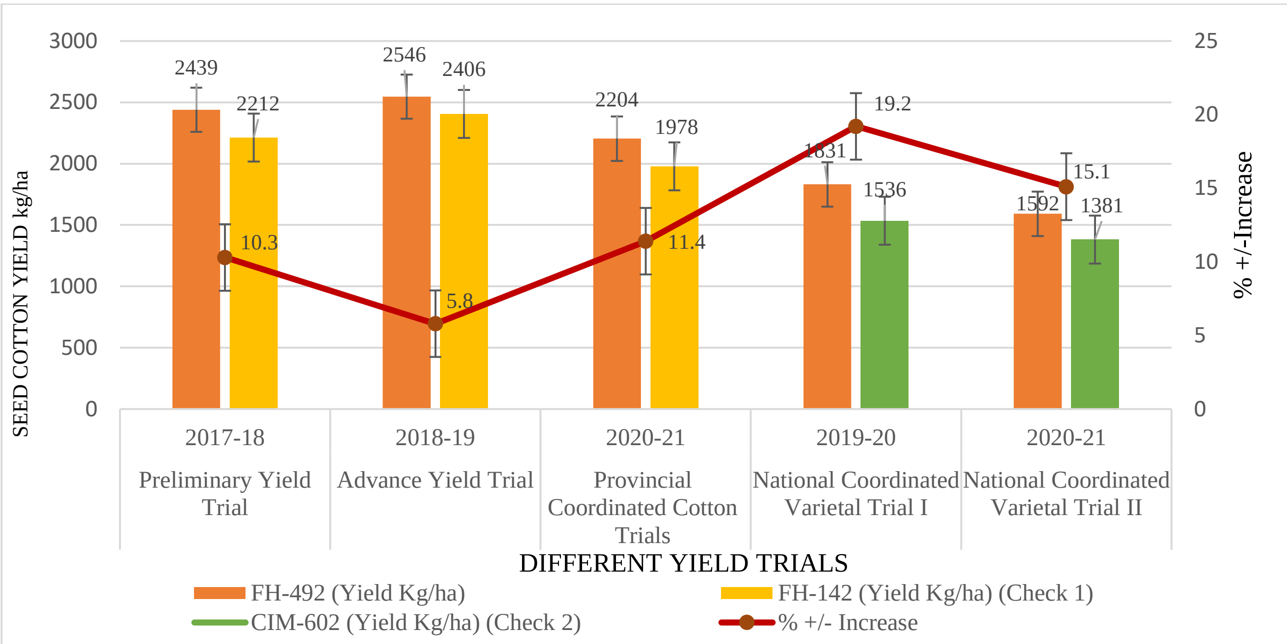

Figure 3. Seed cotton yield (kg ha^{-1}) of the candidate variety FH-492 compared with the check varieties FH-142 and CIM-602 across different yield trials conducted from 2017 to 2021. Bars show the mean values of three replications, while error bars denote the standard error of the mean (± SE). The red line illustrates the percentage yield advantage of the candidate variety over the respective check variety in each trial.

FH-492 tolerance to CLCuD

CLCuD data of FH-492 was recorded in Advance yield trials at CRS, Faisalabad during 2018-19 along with other regular cultivars using a 0–4 disease reaction scale. FH-492 exhibited a significantly lower disease incidence of 4.9% compared to the check variety FH-142 (15.3%). The candidate variety shown comparatively superior tolerance over other tested cotton genotypes in the trial (Figure 4). This trend aligns with the results described by Nadeem *et al*. (2024), Who identified CIM-608 as highly tolerant to CLCuD based on significantly reduced disease incidence relative to commercial checks. These findings support the validity of our result.

Biosafety trials

The candidate cotton variety FH-492 was evaluated under biosafety trials for Bt gene detection & quantification, trait purity and expression consistency. Initial screening was performed using a lateral flow strip assay, where two leaf discs per sample were tested for Cry1Ac, Cry2Ab, and glyphosate-tolerance proteins. FH-492 showed a positive response for the Cry1Ac protein only. Quantitative estimation of Cry1Ac endotoxin at 60 days after sowing revealed a mean concentration of 2.99 µg g^{-1} of fresh leaf tissue. Molecular confirmation through event-specific PCR verified the presence of the MON-531 transformation event in FH-492. To ensure expression reliability, trait-presence (+/–) PCR, transgene purity and Cry1Ac expression quantification were independently performed at ABRI and NIBGE. The results confirmed high genetic stability and compliance with commercial biosafety standards (Figure 5).

Spot examination & fiber quality profiling of FH-492

A field spot examination trial of the candidate cotton variety FH-492 was conducted at Punjab Seed Corporation, Khanewal, on 23-10-2020, where the variety was sown on a 1.25-acre experimental plot during 2020–21. Fiber quality assessment was performed through standardized High Volume Instrument (HVI) analysis across four accredited

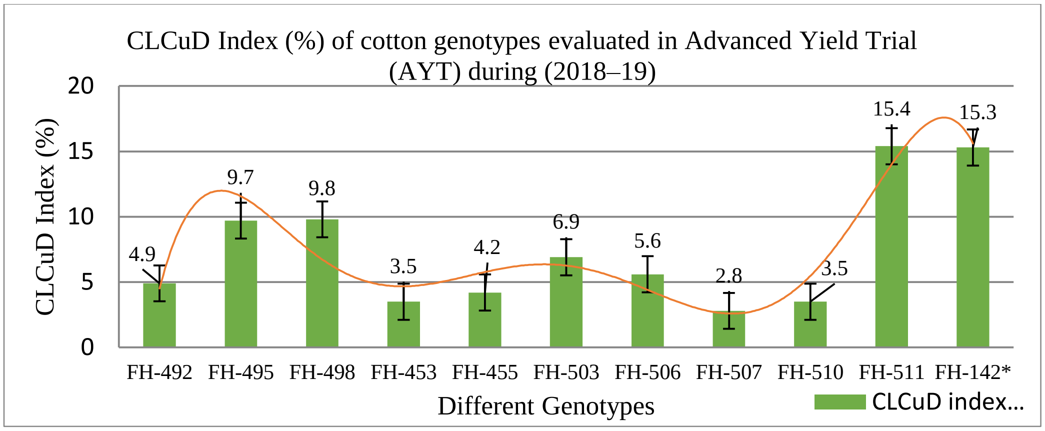

Figure 4. CLCuD Index (%) of different cotton genotypes evaluated in the Advanced Yield Trial (AYT) during 2018–19. Green bars represent the mean CLCuD incidence for each genotype with error bars showing standard error, while the orange polynomial trend line illustrates overall variation in disease response across genotypes. Disease reaction scoring is based on symptom expression on leaf veins: 0 = no visible symptoms; 1 = vein thickening with minute & scattered enations; 2 = major portions of veins involved; 3 = whole veins involved but leaf lamina unaffected; 4 = veins fully involved with severe leaf curling and distortion.

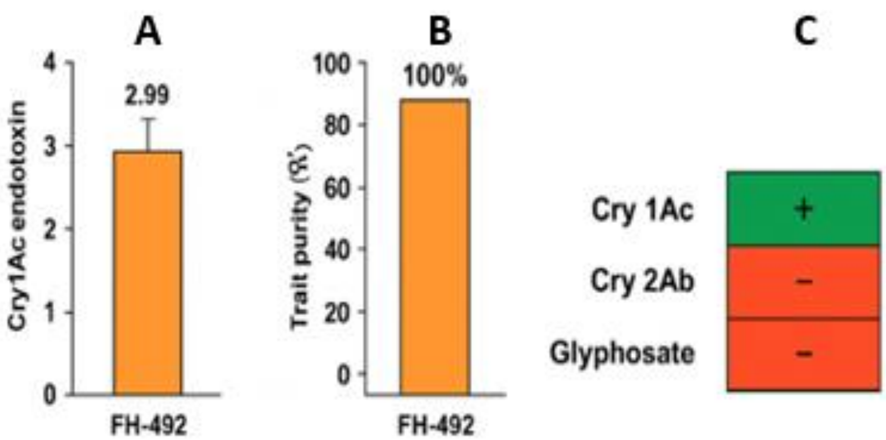

Figure 5. Molecular characterization of candidate variety FH-492. A. Quantification of Cry1Ac Bt endotoxin in leaf tissues at 60 DAS (2.99 µg/g). B. Trait purity analysis showing 100% purity for the Cry1Ac (Mon-531) event in FH-492. C. Presence/absence profile of key transgenic traits showing detection of Cry1Ac protein and absence of Cry2Ab and glyphosate tolerance.

laboratories, including NIBGE Faisalabad, CRI Multan, CCRI Multan, and APTMA Lahore to ensure data reliability and inter-laboratory validation. FH-492 exhibited superior fiber quality parameters recording a staple length (29.80 mm), ginning out-turn (42%), micronaire (4.5 µginch^{-1}), fiber strength (31 gtex^{-1}) and a uniformity index (88%) as given in (Figure 6). This highlights the commercial fiber potential and quality stability of FH-492 under varietal evaluation trials. Beegum *et al*. (2025) assessed fiber quality traits of 40 upland cotton cultivars under standardized experimental conditions, reporting ranges for fiber length, strength, micronaire, and length uniformity index that are comparable to the values observed in FH-492.

Agronomic studies

Agronomic trials were conducted at cotton Research Station, AARI, Faisalabad, during 2020-21 & 2021-22 to fix specific agronomic requirements of the candidate variety FH-492. For sowing date trial, it was sown at six different sowing dates from 1st April to 15 June at 15-days interval. Results of the sowing-date trial revealed that FH-492 achieved the highest seed cotton yield (4795 kg ha^{-1}) when planted on 1 April, while the lowest yield (1255 kg ha^{-1}) was recorded from the 15 June sowing during the first year of experimentation (2020–21) (Figure 7). A similar response was observed in the second year (2021–22), where maximum yield (4680 kg ha^{-1}) was obtained from the 1 April planting, whereas minimum yield (1198 kg ha^{-1}) resulted from sowing on 15 June. These findings indicate that FH-492 performs optimally when sown between 1 April and 15 May. Wahid *et al*., 2024 reported that early April sowing ensures

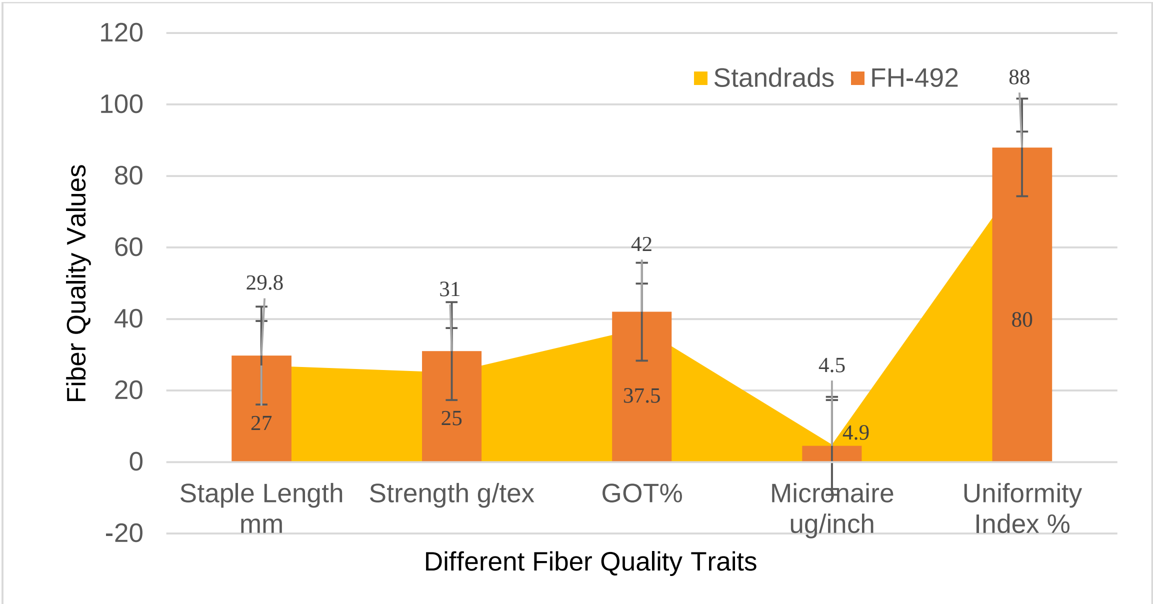

Figure 6. Fiber quality traits of cotton candidate variety FH-492 relative to varietal registration standards in Pakistan. Red bars represent FH-492 fiber quality traits with corresponding standard thresholds (orange reference levels): Standards are Staple Length >27 mm, Fiber Strength >25 g tex⁻¹, Ginning Out Turn (GOT%) >37.5%, Micronaire <4.8 µg inch⁻¹, and Uniformity Index >80%. Error bars indicate observed variability.

maximum seed cotton yield, improved ginning out-turn and stable fiber quality under Punjab agro-climatic conditions. In comparison with check variety (FH-142) the FH-492 was sown at four different plant to plant distances (15, 30, 45 and 60cm) during 2020-21 and 2021-22. FH-492 performance was best with respect to check variety. It was observed that FH-492 performed very well at 45 cm P x P distance and gave seed cotton yield of 5977 kg/ha during 2020-21 and 4782 kg/ha during 2021-22, respectively (Figure 8).

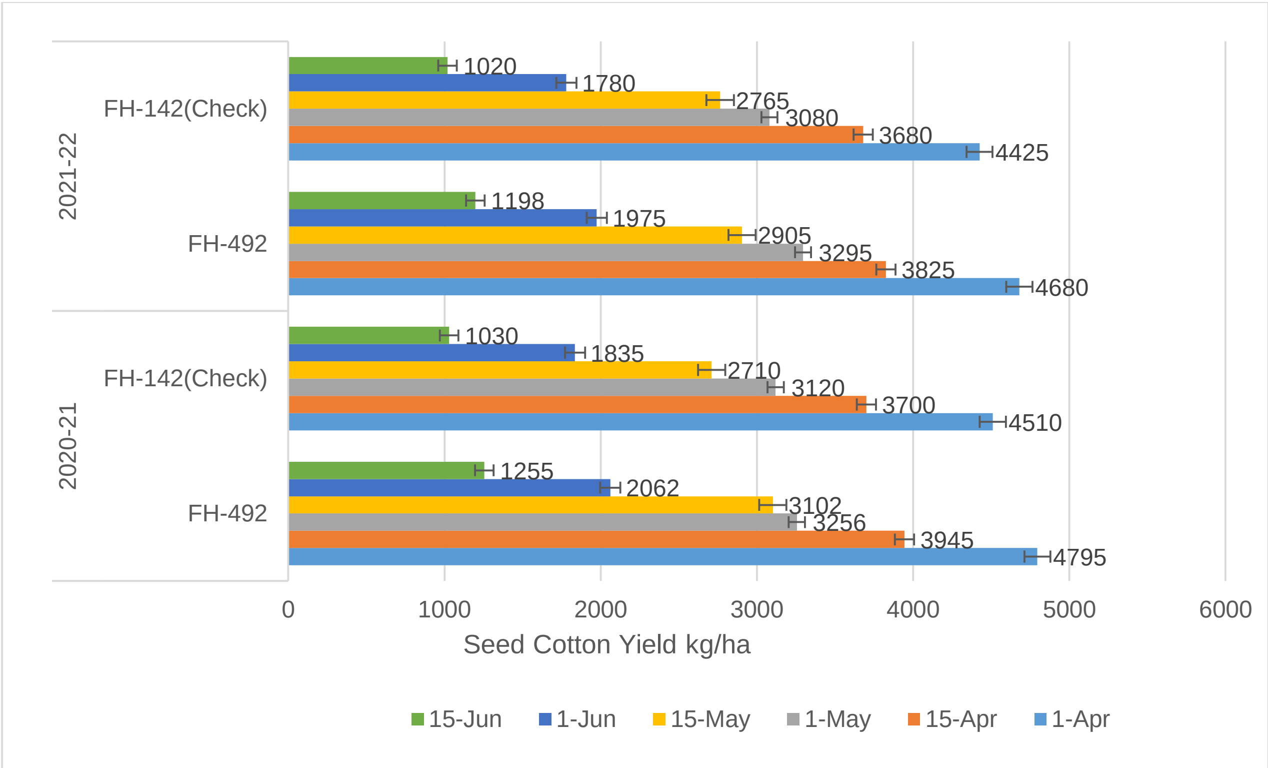

Figure 7. Seed cotton yield (kg ha⁻¹) of the candidate variety FH-492 in comparison with the check variety FH-142 across different sowing dates during 2021–22 and 2022–23. Bars represent mean values of three replications, and error bars denote the standard error of the mean (± SE)

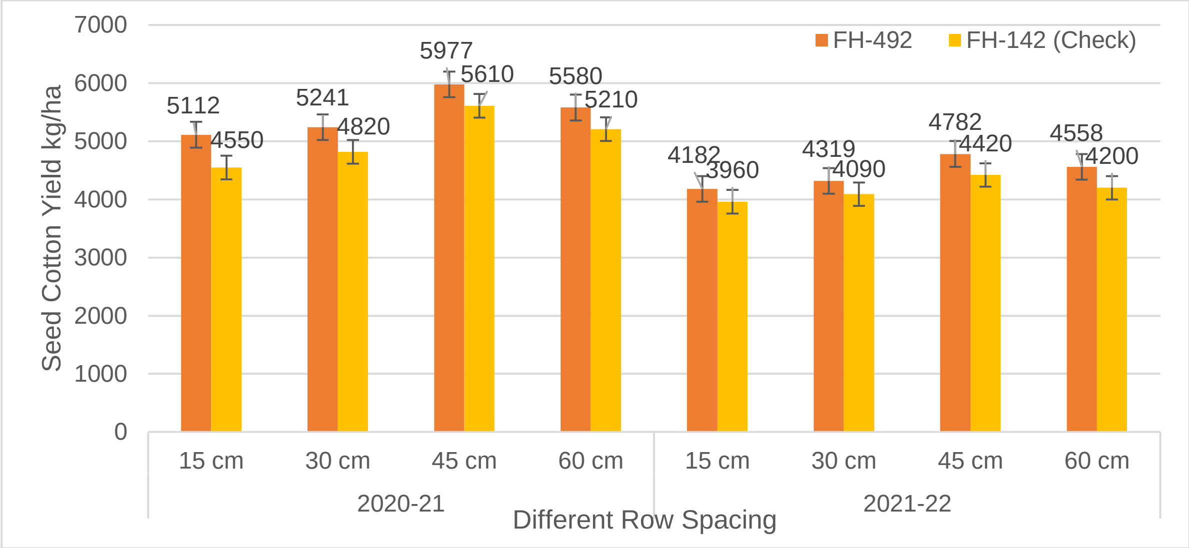

Figure 8. Effect of different row spacing on seed cotton yield of candidate variety (FH-492) and FH-142 (Check 1) during 2020–21 and 2021–22. Bars represent mean values of three replications, and error bars denote the standard error of the mean (± SE).

Morphological characters

Morphological characterization of FH-492 was conducted under National Coordinated Varietal Trials (NCVT) to validate its agronomic distinctness and yield-related plant attribute. FH-492 expressed a mean plant height of 160 cm, days to first square 33, days to first flower 52, sympodial branches per plant 32, and bolls per plant 28, showing a comparatively stronger fruiting framework than check variety, which recorded a plant height of 150 cm, days to first square 37, days to first flower 56, sympodial branches 28, and bolls per plant 22. Figure 9 supports the early phenology and enhanced boll-bearing capacity of FH-492 that is key indicators of its high-yielding growth habit.

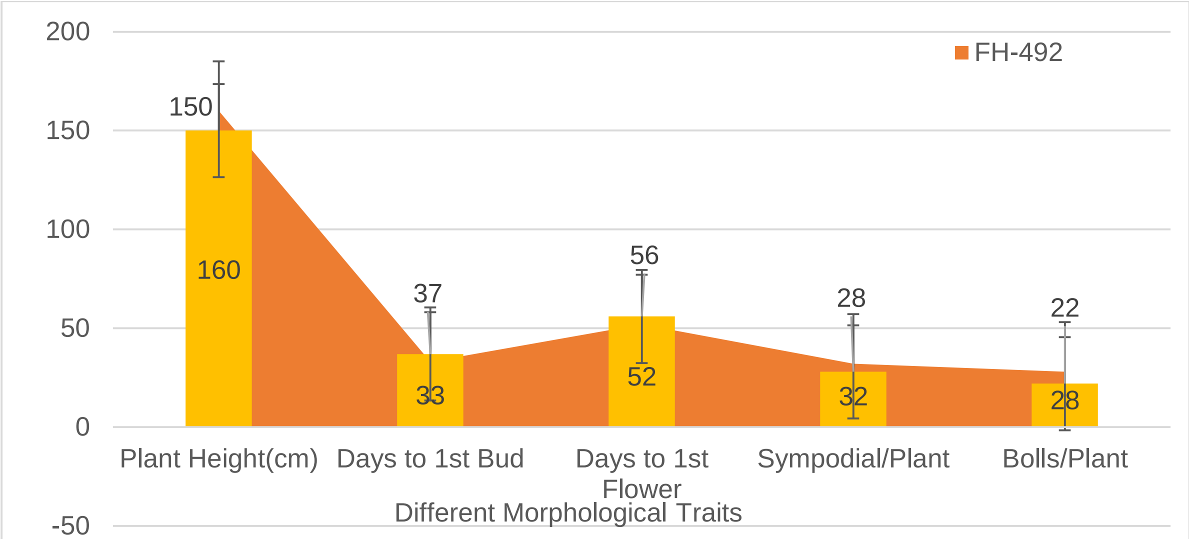

Figure 9. Comparison of key morphological traits of FH-492 and the check variety for traits include plant height, days to first bud, days to first flower, number of sympodia branches per plant and number of bolls per plant.

Entomological evaluation of FH-492

The candidate variety FH-492 was evaluated for pest incidence at CRS, Faisalabad during 2018–19 alongside FH-142 (check). FH-492 exhibited lower populations of major sucking pests with thrips (8.24/leaf), whitefly (6.87/leaf) and jassid (2.18/leaf) as compared to the check variety FH-142, which recorded thrips (10.52/leaf), whitefly (9.63/leaf), and jassid (2.33/leaf). Pink bollworm infestation was also small in FH-492 (22.34%) relative to FH-142 (28.43%), while both varieties showed no incidence of spotted or American bollworm. The results (Figure 10) validates that FH-492 is moderate to high tolerance against major sucking pests and pink bollworm.

DNA fingerprinting

In accordance with the Plant Breeders' Rights Act (2016), DNA fingerprinting of the candidate variety FH-492 was carried out at the Department of Agricultural Biotechnology Research Institute, AARI, Faisalabad. A set of fifty

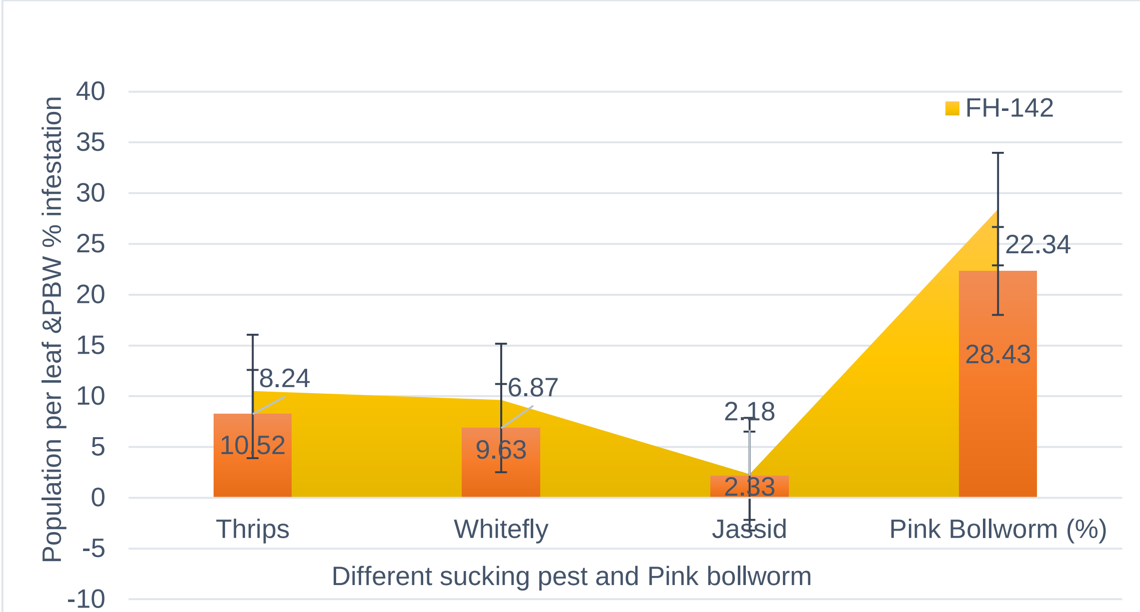

Figure 10: Comparison of pest incidence in cotton candidate variety FH-492 and FH-142 (Check) at CRS, Faisalabad (2018–19). Bars represent FH-492 populations, while the area graph represents FH-142 populations for thrips, whitefly, jassid, and pink bollworm (%). The data indicate lower pest populations in FH-492 than economic threshold.

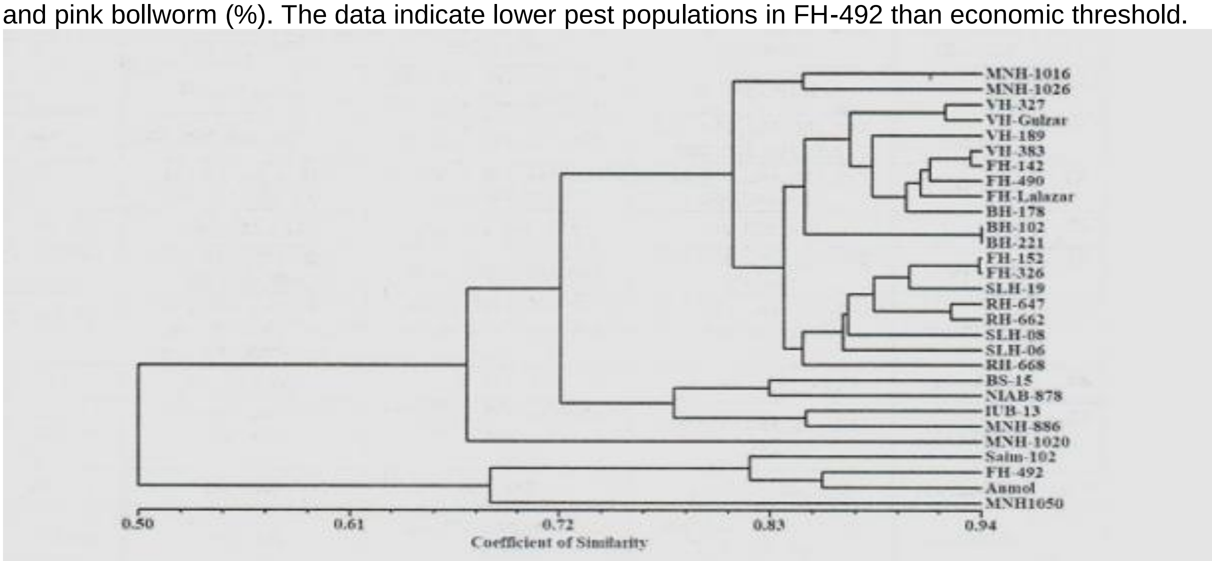

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Figure 11. DNA fingerprinting revealed marked genetic differentiation of FH-492 from the reference cultivars MNH-886, NIAB-78, and FH-142.

polymorphic Simple Sequence Repeat (SSR) markers was selected from a collection of pre-validated and highly informative cotton SSRs, based on their high polymorphism information content (PIC). Prior to large-scale fingerprinting, each marker was assessed for reproducibility, clarity of banding, and amplification efficiency through PCR optimization and gel electrophoresis. Molecular characterization was performed in parallel with three check varieties (MNH-886, NIAB-878, and FH-142) following the standard operating procedures prescribed by the Punjab Ministry of Agriculture and institutional guidelines. Genetic relationships were analyzed using the UPGMA clustering method to generate a Cultivar Identification Diagram (CID). Similarity coefficients ranged from 0.50 to 0.94, reflecting substantial genetic variation among the genotypes. The CID (Figure 11) revealed marked genetic divergence of FH-492, showing approximately 50% dissimilarity with MNH-886, 50% with NIAB-878, and 51% with FH-142. These findings confirm the genetic distinctness of FH-492 and provide strong evidence for its distinctness, uniformity, and stability (DUS), fulfilling a critical requirement for varietal registration and potential protection under the Plant Breeders' Rights framework.

CONCLUSION

FH-492 is a high yielding, early maturing, Bt. Cotton variety developed at the Cotton Research Station, Faisalabad and approved by Punjab Seed Council in 2021. It recorded a 19.2% increase in seed cotton yield over FH-142 in multi-location National Coordinated Varietal Trials (NCVT). FH-492 expresses Cry1Ac protein-based bollworm, heat and CLCV resistance suitable for both biotic and abiotic stress environments. Fiber quality evaluated through High Volume Instrument (HVI) standards showed 42% ginning out-turn (GOT), 29.0 mm staple length, 4.6 µg $inch^{-1}$ micronaire, and 31 g tex^{-1} fiber strength classifying it as medium-to-long staple cotton. The ability of FH-492 to maintain boll retention and lint strength under high-temperature validates it as a climate-smart cultivar. These attributes confirm FH-492 as a promising variety for the future advancement of Pakistan's cotton sector.

AUTHOR'S CONTRIBUTION

Ghulam Sarwar: Conceptualization and supervision of the research; Jehanzeb Farooq: Experimental design and overall project coordination; Asma Parveen: Writing – original draft preparation; Abia Younas: Writing – original draf; Abid Mehmood: Review and editing; Amjad Farooq: Data statistical analysis; Hafiz Ghazanfar Abbas: Field management and technical support; Shahid Munir Chohan: Proofreading and critical revision of the manuscript; Muhammad Rizwan: Assisted in data collection and field experimentation.

FUNDING

Government of the Punjab.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed in this study are presented within this article in the form of figures.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the relevant forum.

CONSENT FOR PUBLICATION

All the authors are agreed on the publication.

CONFLICT OF INTERESTS

Authors have no conflict of Interest regarding this publication.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Ayub Agricultural Research Institute (AARI), Faisalabad, for providing institutional support, research facilities, and technical assistance throughout the variety development process.

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