**Evaluation of stay-green genotypes at post-flowering stage Sorghum**

**[*Sorghum* *bicolor* (L.) Moench]**

**Abstract**

Reduced leaf senescence, or stay-green, has been shown to enhance tolerance to post-flowering moisture stress in grain sorghum. This study evaluated stay-green donor and recipient lines, including F3 recombinant lines, in both well-watered and post-flowering drought stress environments. The results demonstrated that most of the introgression lines exhibited higher leaf chlorophyll content at maturity and a greater percentage of green leaf area during the grain-filling stage compared to the recurrent parents, including R16, indicating the successful expression of the STG3B QTL for stay-green under drought stress. These findings suggested that the F3 recombinants might contain the STG3B QTL is significant potential for improving post-flowering drought tolerance in sorghum.

**Keywords:** Sorghum,Post-flowering, Stay-green, Drought tolerance

**1. Introduction**

Trailing behind the global giants wheat, maize, rice, and barley- sorghum [*Sorghum bicolor* (L.) Moench] stands tall as the resilient fifth pillar in the world’s cereal kingdom (Muitire et al., 2021). In the sun-scorched stretches of the semiarid tropics, sorghum grain serves as a lifeline, the humble staple that sustains the world’s poorest and most food-insecure communities (Gomashe et al., 2025). The world harvested around 58.3 million metric tons of sorghum an overwhelming 90% of which lay in developing nations, where the crop thrives across the semi-arid expanses of Africa and Asia (Charyulu et al., 2024). Across peninsular India, sorghum covers 5.5 million hectares after the monsoon retreats, drawing life from lingering soil moisture (Chadalavada et al., 2021). This distinctive growing season yields high-quality grain and stover, yet farmers face a mounting challenge intensifying moisture stress as the rainfed and the deepened dry spell (Karthik & Hanamaratti, 2025). The most devastating blow from drought strikes during the crop’s final act is post-flowering, when terminal drought sets in, threatening yield just as the grain begins to fill (Otwani et al., 2025). Genotypes vulnerable to terminal drought often show early signs of decline leaves and plants wither prematurely, stalks weaken and collapse, lodging becomes common, charcoal rot takes hold, and grain number and size diminish (Suman & Chandra, 2025). In sorghum, the most well-known defense against terminal drought is the 'stay-green' trait, a remarkable ability to resist early senescence, maintain green leaf area, stand firm against lodging, and continue grain filling (Pugh et al. 2025). When water grows scarce during the grain-filling stage, sorghum genotypes with the stay-green trait hold keeping their leaves green and photosynthetically active far longer than their drought-sensitive counterparts (Tulu et al., 2025). Delayed leaf senescence in sorghum has been closely tied to higher grain yields, especially in environments where water runs short during grain filling and can’t meet the crop’s full thirst for transpiration (Kamal et al., 2025). Collaborative efforts by various research groups have shed light on the genetic roots of the stay-green trait, leading to the identification and mapping of QTLs linked to post-flowering drought tolerance in sorghum (Endalamaw et al., 2025). To strengthen sorghum’s resilience against terminal drought, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) had perfomed a large-scale marker-assisted backcrossing program, focused on embedding the stay-green trait into elite lines (Gomashe et al., 2025). As a key part of this initiative, the current study was carried out to assess the performance of the introgression line K359W, focusing on its stay-green expression and other vital agronomic traits under post-flowering drought stress.

**2. Materials and methods**

This study focused on the evaluation of the F3 recombinants, K359W stay-green donor parent, alongside its recurrent parent, R16, and a range of other sorghum lines. The test group also included various stay-green donors (B35, K260, E36-1, and 296B) as well as senescent lines (M35-1, Parbhani Moti, CRS1, and Phule Vasudha). K359W, developed at ICRISAT, Patancheru, is an introgressed line of STG3B, while R16 was a high-yielding, but highly senescent, variety grown in the post-rainy (rabi) season. The donor and recurrent parents were crossed, and the resulting F1 plants were selfed to generate a segregating F2 population. Using KASP genotypic data, 200 plants homozygous for the donor alleles were selected and selfed to produce the F3 progenies.The F3 recombinant lines plus parental lines along with checks were sown during the post-rainy 2022–2023 season, at the ICRISAT research station in Patancheru, India. The experimental setup followed the methodologies of Mahalakshmi & Bidinger (2002). An alpha lattice design was used, comprising 16 blocks per replication, with each block containing 14 entries. Each experimental unit was a single-row plot, 4 meters long, with 45 cm between rows and 15 cm between plants. Before sowing, a basal fertilizer application of 20 kg ha⁻¹ nitrogen (N) and 20 kg ha⁻¹ phosphorus (P₂O₅) was made in the form of diammonium phosphate. The seeds were sown using a machine, and irrigation was provided via overhead sprinklers to ensure uniform germination. The field was located on shallow (40–60 cm) vertical inceptisol soil, ideal for root penetration but with limited plant-available water. Thinning was performed 7 days after emergence (DAE). During the growing period, temperatures ranged from 30 to 40°C during the day and 28 to 37°C at night, providing optimal conditions for assessing the performance of the sorghum genotypes under both well-watered and drought-stressed environments. For supplementary irrigation, furrow irrigation was applied during flowering to ensure enough water for grain filling, preventing severe drought stress. One set of plants was subjected to stress shortly after flowering, while the other set continued to receive regular irrigation until the grain reached maturity. To control pests, weekly sprays of cypermethrin were used for the first four weeks after emergence to manage shoot fly, and a whorl application of carbofuran was applied four weeks after emergence to control stem borer. At flowering, three plants per plot were tagged for observations. Chlorophyll content (SPAD value) was measured using a Minolta Chlorophyll Meter (SPAD-502), following the method of Rama reddy et al. (2014). SPAD readings were taken from the middle of the second and fourth leaves from the top of three plants per plot, and the average was calculated for each plot. Genotypic variation for several stay-green related traits as well as agronomic traits were analyzed using one-way ANOVA followed by the Tukey–Kramer post-hoc test (CoStat v6.204, Cohort Software).

**3. Results and discussion**

**3.1. SPAD at flowering**

The SPAD at flowering values across the genotyped show some variation. The highest SPAD at flowering value was recorded for B35 at 48.85, while the lowest was observed for CRS1 at 38.55. Other significant values included 47.52 for K359W, 45.02 for E36-1, and 44.41 for R16 (Table 1). The SPAD values at booting under water stress (WS) conditions showed the highest recorded for B35 at 49.05, followed closely by K359W at 47.97. Other notable values included 44.92 for R16, 44.65 for 296B, and 44.5 for E36-1. The lowest SPAD value was observed for CRS1 at 39.17, indicating a lower chlorophyll content compared to other genotypes (Table 3). The mean values for SPAD at booting under well-watered (WW) and water stress (WS) were measured. Under well-watered conditions, R16 had a mean SPAD value of 44.41, F3 recombinants had a mean of 44.59, and K359W had a mean of 47.53. Under water stress, R16's SPAD value increased slightly to 44.92, F3 recombinants showed a small increase to 44.67, and K359W experienced a marginal increase to 47.98 (Table 5). This indicated that while all genotypes showed a slight increase in SPAD values under water stress, the changes were relatively small, suggesting that water stress had a minimal effect on chlorophyll content at booting for these genotypes. In line with Rajarajan et al. (2021), our findings also indicated that drought-stressed plants exhibit a significant reduction in chlorophyll content compared to control plants.

**3.2. SPAD at maturity**

The SPAD values across the genotypes exhibited a range of measurements. The highest SPAD\_AM value was recorded for B35 at 41.8, while the lowest was observed for CRS1 at 29.72 (Table 1). The SPAD values at maturity under water stress (WS) the highest SPAD value was recorded for 296B at 40.45, followed closely by K359W at 39.61 and B35 at 39.45. In contrast, genotypes like CRS1 and M35-1 showed the lowest SPAD values at 25.65 and 29.87, respectively, indicating significantly lower chlorophyll content (Table 3). The mean values for SPAD at maturity under well-watered (WW) and water stress (WS) conditions were estimated. Under well-watered conditions, R16 had a mean SPAD value of 38.31, F3 recombinants had a mean of 39.13, and K359W had a mean of 41.36 (Table 5). Under water stress, R16 saw a significant decrease in SPAD value to 31.09, F3 recombinants dropped to 33.59, and K359W showed a slight decline to 40.08 (Table 5). This suggested that water stress resulted in a substantial reduction in chlorophyll content, particularly for R16, while K359W maintained relatively better chlorophyll levels under stress. The highest SPAD was recorded for K359W followed by progeny. At WS, F3 recombinants performed high SPAD than parents indicating, progeny have better chlorophyll content until physiological maturity. Similar results were reported by Abebe et al. (2021), where introgressed STG3B QTL-responsive genes significantly enhanced total chlorophyll content in leaves, contributing to improve structural and functional integrity under water stress conditions.

**3.3. Green leaf area at booting (GLAB, cm²)**

The maximum green leaf area was recorded for 296B at 417.69, while the minimum was observed for R16 at 295.6 (Table 1). The green leaf area at booting under water stress (WS) conditions showed variation in leaf development across the genotypes. The highest green leaf area was recorded for 296B at 420.26 cm², followed by CRS1 at 352.64 cm² and B35 at 349.19 cm² (Table 3). Other notable values included 340.88 cm² for Phule Vasudha, 340.14 cm² for K359W, and 346.78 cm² for M35-1. The smallest green leaf area was observed for R16 at 293.35 cm², followed by E36-1 at 314.88 cm² and K260 at 318.66 cm². The mean values for green leaf area at booting under well-watered (WW) and water stress (WS) conditions were obtained. For R16, the green leaf area was 290 cm² under well-watered conditions and slightly increased to 295.35 cm² under water stress. F3 recombinants showed a similar pattern, with a slight increase from 297.74 cm² under well-watered conditions to 296.71 cm² under water stress. For K359W, the green leaf area remained almost the same, with 341.7 cm² under well-watered and 340.64 cm² under water stress (Table 5). These results suggested that water stress did not significantly affect the green leaf area at booting for any of the genotypes. The findings of the present study are in agreement with those reported by Harris et al. (2007), reported that stay-green lines (Stg1, Stg2, and Stg1+4) maintained higher GLA than the recurrent parent TAB under various drought conditions.

**3.4. Green leaf area at maturity (GLAM, cm²)**

Under well-watered (irrigated) conditions, the maximum green leaf area was recorded for 296B at 363.87, while the minimum was observed for R16 at 254.92 (Table 1). The green leaf area at maturity under water stress (WS) conditions showed considerable variation across the genotypes. The highest green leaf area was recorded for 296B at 353.2 cm², followed by B35 at 326.74 cm² (Table 3). The smallest green leaf areas were observed for Parbhani Moti at 185.48 cm² and R16 at 186.9 cm². The mean values for green leaf area at maturity under well-watered (WW) and water stress (WS) conditions showed a noticeable reduction across all genotypes when subjected to water stress (Table 4). For R16, the green leaf area decreased from 254.93 cm² under well-watered conditions to 186.93 cm² under water stress. F3 recombinants exhibited a similar decrease, from 203.79 cm² under well-watered conditions to 190.62 cm² under water stress. K359W had a relatively higher green leaf area, with 302.54 cm² under well-watered conditions and 284.39 cm² under water stress (Table 5). These results suggested that water stress led to a reduction in the green leaf area with R16 showing the greatest decrease. Abebe et al. (2021) reported higher projection of green leaf area at maturity (PGLAM) in recombinants and converted progeny, indicating improved drought tolerance.

**3.5. Rate of leaf senescence (RLS)**

The lowest rate of senescence was observed for B35 at 0.44, while the highest was recorded for Phule Vasudha at 1.15. (Table 1). The rate of leaf senescence under water stress (WS) indicated that the lowest rate of senescence was for B35 and E36-1, both at 1.22, indicating slower senescence. The highest rate of leaf senescence was recorded for Parbhani Moti at 2.87, followed by CRS1 at 2.64 and M35-1 at 2.37. Other genotypes like Phule Vasudha and R16 had intermediate values of 2.45 and 2.35, respectively (Table 3). The rate of leaf senescence increased under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the rate of leaf senescence rose from 0.75 under WW to 2.36 under WS, indicating a significant increase. Similarly, F3 recombinants showed an increase from 2.04 under WW to 2.31 under WS. K359W exhibited a milder change, with the rate of senescence increasing from 0.44 under WW to 1.43 under WS (Table 5). This pattern suggested that water stress accelerated leaf senescence with R16 showing the most notable increase in senescence rate. Kirnmayee et al. (2020) observed that the donor parent RSG04008-6 exhibited a lower rate of senescence than the recurrent J2614-11, indicating its stable stay-green nature.

**3.6. Stay green score at 7 days after flowering (STG score@7 DAF)**

The Stg score at 7 days after flowering (7DAF) data showed significant variation. The lowest Stg score, indicating the most-green and least senescent, was recorded for B35 at 2.36. On the other hand, genotypes like Parbhani Moti and Phule Vasudha had the highest scores, 4.37 and 3.97, respectively, indicating more senescence (Table 1). The Stg score at 7 days after flowering (DAF) under water stress (WS) conditions showed Stg variation in the degree of senescence across the genotypes. The lowest STG score, was observed for 296B at 3.17, followed closely by B35 at 3.25 and K260 at 3.42. Other genotypes with lower senescence scores included K359W at 3.45 and M35-1 at 3.69 (Table 3). The highest Stg scores, indicating more senescence, were recorded for Parbhani Moti at 4.62 and Phule Vasudha at 4.24. The Stg score at 7 DAF showed an increase under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the score increased from 3.24 under WW to 3.91 under WS, indicating a notable rise in the senescence rate. The F3 recombinants also displayed an increase, from 2.09 under WW to 2.94 under WS, and K359W showed an increase from 2.95 under WW to 3.46 under WS (Table 5). Based on these increases, R16 exhibited the highest Stg score under both conditions, indicating that it has the most pronounced leaf senescence compared to F3 recombinants and K359W, which showed relatively lower scores. Subudhi et al. (2000) further demonstrated the effectiveness of visual ratings by comparing RILs with different QTL combinations, showing that RILs possessing Stg2 and Stg3 had better stay-green scores than those with other QTL combinations, and revealing possible epistatic interactions.

**3.7. Stay green score at 14 days after flowering (Stg score@14 DAF)**

Based on the data for Stg score at 14 days after flowering (14DAF), lower values indicated more greenness and less senescence. The lowest Stg score was recorded for B35 at 2.61, indicating the greenest and least senescent. Other genotypes with relatively low scores include 296B at 3.07 and M35-1 at 3.15. In contrast, Parbhani Moti showed the highest Stg score at 4.85, suggesting more senescence. Other genotypes with higher scores included Phule Vasudha at 4.27 and R16 at 4.23 (Table 1). These values reflected the variation in leaf senescence and greenness across the genotypes at 14DAF. The Stg score at 14 days after flowering (DAF) under water stress (WS) conditions showed variation in senescence across the genotypes. The lowest Stg score, indicating less senescence, for E36-1 at 3.55, followed by B35 at 3.37 and K359W at 3.64. Other genotypes with relatively low senescence included M35-1 at 3.75. The highest STG scores, indicating more senescence, were recorded for Parbhani Moti at 4.9, followed by Phule Vasudha at 4.6 and R16 at 4.56. Other genotypes like 296B, K260, and CRS1 showed intermediate senescence with scores ranging from 4.25 to 4.37 (Table 3). These values highlighted the variation in leaf senescence at 14 DAF under water stress conditions, with some genotypes showing more resistance to senescence than others. The Stg score at 14 DAF for all genotypes also indicated an increase under water stress (WS) compared to well-watered (WW) conditions. R16 showed a higher Stay Green score than both F3 recombinants and K359W. Under water stress (WS), R16's Stg score increased from 4.34 (WW) to 4.56 (WS), indicating a higher level of senescence compared to the other two. On the other hand, the F3 recombinants exhibited a smaller increase in their Stg score, going from 2.56 (WW) to 3.48 (WS), suggesting moderate senescence under water stress. K359W, with a score increase from 3.45 (WW) to 3.69 (WS), also showed an increase in senescence, but it was less pronounced than the increase seen in R16 (Table 5). Therefore, R16 had the highest Stg score, indicating more pronounced senescence and less green retention under water stress. Reddy et al. (2007) reported variation in Stg scores among parental lines, with 296B showing a Stg score of 2.5, M35-1 scoring 3.0, and R16 having a higher score of 3.5, indicating a relatively higher degree of senescence.

**3.8. Stay green score at 21 days after flowering (Stg score@21 DAF)**

The Stg score at 21 days after flowering (21DAF) data showed a continued range of senescence across the genotypes. The lowest Stg score, indicating the most green and least senescent, was recorded for B35 at 3.02. Other genotypes with relatively low scores included K359W at 3.60 and M35-1 at 4.37. On the other hand, genotypes like Parbhani Moti and R16 had the highest scores, 5.17 and 5.13, respectively, reflecting more senescence. Other notable values included 4.60 for Phule Vasudha and 4.47 for CRS1 (Table 1). These values highlight the variation in leaf senescence and greenness at 21DAF among the genotypes. The STG score at 21 days after flowering (DAF) under water stress (WS) conditions reflects further variation in the rate of senescence across the genotypes. The lowest STG score, indicating less senescence, was observed for B35 at 3.52, followed by M35-1 at 4.25 and K359W at 4.15. Other genotypes with relatively low senescence include E36-1 at 4.42. The highest STG scores, indicating more senescence, were recorded for R16 at 6.25, followed by Parbhani Moti at 5.52 and K260 at 5.27. Other genotypes such as 296B, CRS1, and Phule Vasudha had intermediate senescence scores ranging from 4.65 to 5.12 (Table 3). These values highlighted the variation in leaf senescence at 21 DAF under water stress conditions, with some genotypes demonstrating better resistance to senescence than others. The Stg score at 21 DAF shows an increase under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the score increased from 5.54 under WW to 6.21 under WS, indicating a significant rise in the senescence rate. The F3 recombinants also displayed an increase, from 3.08 under WW to 4.15 under WS, and K359W showed an increase from 3.6 under WW to 4.25 under WS (Table 5). Based on these increases, R16 exhibited the highest Stg score under both conditions, indicating that it has the most pronounced leaf senescence compared to F3 recombinants and K359W, which showed relatively lower scores. Thus, R16 is the most senescent genotype under water stress conditions at 21 DAF. These result echoed the findings of Abebe et al. (2021) who found that donor parent B35 had a low LS score of 2.25, and genotypes exhibiting the stay-green trait showed consistently lower RLS.

**3.9. Stay green score at 28 days after flowering (Stg score@28 DAF)**

The Stg score at 28 days after flowering (28DAF) data showed further variation in leaf senescence across the genotypes. The lowest Stg score, indicating the most green and least senescent for B35 at 3.42. Other genotypes with relatively low scores include K359W at 4.00 and E36-1 at 4.35. On the other hand, genotypes like R16 and Parbhani Moti had the highest scores, 5.45 and 5.27, respectively, indicating more senescence. Other notable values include 4.65 for M35-1 and Phule Vasudha, and 4.57 for K260 (Table 1). These values illustrated the variation in leaf senescence and greenness at 28DAF among the genotypes. The Stg score at 28 days after flowering (DAF) under water stress (WS) conditions showed continued variation in the degree of senescence among the genotypes. The lowest Stg score, indicating less senescence for B35 at 3.96, followed by E36-1 at 4.47 and K359W at 4.75. Other genotypes with relatively low senescence included 296B at 4.72 (Table 3). The highest Stg scores, indicating more senescence, were recorded for R16 at 6.57, followed by Parbhani Moti at 5.82 and K260 at 5.65. Other genotypes like M35-1, CRS1, and Phule Vasudha had intermediate senescence scores ranging from 5.12 to 5.35. These values highlight the differences in leaf senescence at 28 DAF under water stress, with some genotypes demonstrating greater resistance to senescence than others. The Stg score at 28 DAF showed an increase under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the score increased from 5.85 under WW to 6.57 under WS, indicating a notable rise in the senescence rate. The F3 recombinants also displayed an increase, from 3.36 under WW to 4.7 under WS, and K359W showed an increase from 4 under WW to 4.6 under WS (Table 5). Based on these increases, R16 exhibited the highest Stg Score under both conditions, suggesting that it has the most pronounced leaf senescence compared to F3 recombinants and K359W, which showed relatively lower scores. Thus, R16 is the most senescent genotype under water stress conditions at 28 DAF. This trend was similarly observed in the study by Kebede et al. (2001), where the Stg rating for SC56 (2.1) was significantly higher than Tx7000 (3.7). The mean Stg rating for the RILs was 2.5, ranging from 1.1 to 4.8.

**3.10. Stay green score at 35 days after flowering (Stg score@35 DAF)**

The Stg score at 35 days after flowering (35DAF) data showed continued variation in leaf senescence across the genotypes. The lowest Stg score, indicating the most green and least senescent, was recorded for B35 at 3.67. Other genotypes with relatively low scores included K359W at 4.10 and 296B at 4.72. In contrast, genotypes like Parbhani Moti and R16 had the highest scores, 6.17 and 6.11, respectively, reflecting more senescence. Other notable values include 5.32 for CRS1, 5.21 for M35-1, and 5.12 for E36-1 (Table 1). These values highlight the variation in leaf senescence and greenness at 35DAF among the genotypes. The STG score at 35 days after flowering (DAF) under water stress (WS) conditions shows continued variation in leaf senescence across the genotypes. The lowest STG score, indicating less senescence, was observed for B35 at 4.15, followed by 296B at 5.05 and K260 at 5.32. Other genotypes with relatively lower senescence include K359W at 5.45 and E36-1 at 5.42. The highest STG scores, indicating more senescence, were recorded for R16 at 6.71, followed by Parbhani Moti at 6.32. Other genotypes, such as M35-1, CRS1, and Phule Vasudha, showed intermediate senescence scores ranging from 5.74 to 5.82 (Table 3). These values highlight the variation in senescence at 35 DAF under water stress, with some genotypes demonstrating more resistance to senescence than others. The Stg score at 35 DAF shows an increase under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the score increased from 6.21 under WW to 6.91 under WS, indicating a significant rise in the senescence rate. The F3 recombinants also displayed an increase, from 3.68 under WW to 5.24 under WS, while K359W showed an increase from 4.1 under WW to 5.63 under WS (Table 5). Based on these results, R16 exhibited the highest Stg score under both conditions, suggesting that it is the most senescent genotype compared to F3 recombinants and K359W, which showed relatively lower scores. Therefore, R16 has the highest level of senescence under water stress at 35 DAF.

**3.11. Stay green score at 42 days after flowering (Stg score@42 DAF)**

The Stg score at 42 days after flowering (42DAF) data showed continued variation in leaf senescence among the genotypes. The lowest Stg score, indicating the greenest and least senescent, was recorded for B35 at 4.06. Other genotypes with relatively low scores included K359W at 4.40 and 296B at 4.95. In contrast, genotypes like Parbhani Moti and R16 had the highest scores, 6.35 and 6.25, respectively, indicating more senescence. Other notable values included 5.45 for CRS1, 5.37 for M35-1, and 5.25 for E36-1 (Table 1). These values illustrated the variation in leaf senescence and greenness at 42DAF among the different genotypes. The Stg score at 42 days after flowering (DAF) under water stress (WS) conditions showed continued differences in the rate of leaf senescence across the genotypes. The lowest Stg score, indicating less senescence, was observed for B35 at 4.65, followed by 296B at 5.22 and E36-1 at 5.65. Other genotypes with relatively lower senescence included K359W at 5.72 and K260 at 5.75. The highest STG scores, indicating more senescence, were recorded for R16 at 6.76, followed by Parbhani Moti at 6.57. Other genotypes, such as M35-1, CRS1, and Phule Vasudha, showed intermediate senescence scores ranging from 6.25 to 6.36 (Table 3). These values illustrated the variation in leaf senescence at 42 DAF under water stress, with some genotypes exhibiting more resistance to senescence than others. The Stg score at 42 DAF shows an increase under water stress (WS) for all genotypes compared to well-watered (WW) conditions. For R16, the score increased from 6.45 under WW to 7.19 under WS, indicating a noticeable rise in senescence. The F3 recombinants also showed an increase, from 3.97 under WW to 5.74 under WS, while K359W showed an increase from 4.4 under WW to 5.85 under WS (Table 5). Based on these results, R16 exhibited the highest Stg score under both conditions, suggesting that R16 was the most senescent genotype compared to F3 recombinants and K359W, which showed lower levels of senescence. Thus, R16 had the highest level of senescence under water stress at 42 DAF. Similar patterns were also reported by Tao et al. (2000), where QL41 had a lower Stg rating than QL39. In the RIL, stay-green scores ranged from 5.4 to 8.4 at DA-96 and 2.6 to 7.2 at HE-96.

**3.12. Stay green score at 49 days after flowering (Stg score@49 DAF)**

The Stg score at 49 days after flowering (49DAF) data continues to showed variation in leaf senescence across the genotypes. The lowest Stg score, indicating the most green and least senescent, was recorded for B35 at 4.75. Other genotypes with relatively low scores included K359W at 4.95 and 296B at 5.1. In contrast, genotypes like R16 and Parbhani Moti had the highest scores, 6.5 and 6.47, respectively, indicating more senescence. Other notable values include 5.75 for M35-1, 5.57 for E36-1, and 5.55 for CRS1 (Table 1). These values reflect the variation in leaf senescence and greenness at 49DAF among the genotypes. The Stg score at 49 days after flowering (DAF) under water stress (WS) conditions showed continued variation in the degree of leaf senescence among the genotypes. The lowest Stg score, indicating less senescence, was observed for B35 at 5.25, followed by 296B at 5.37 and K260 at 5.70. Other genotypes with relatively lower senescence include E36-1 at 5.8 and K359W at 6.15. The highest STG scores, indicating more senescence, were recorded for Parbhani Moti at 6.92, followed by R16 at 6.83. Other genotypes such as M35-1, CRS1, and Phule Vasudha had intermediate senescence scores ranging from 6.25 to 6.43 (Table 3). These values highlighted the variation in leaf senescence at 49 DAF under water stress, with some genotypes demonstrating better resistance to senescence than others. The Stg score at 49 DAF shows an increase under water stress (WS) for all genotypes compared to well-watered (WW) conditions. For R16, the score increased from 6.59 under WW to 7.41 under WS, indicating a notable rise in senescence. The F3 recombinants also exhibited an increase, from 4.22 under WW to 6.09 under WS, while K359W showed an increase from 4.95 under WW to 6.16 under WS (Table 5). Based on these results, R16 shows the highest Stay Green Score under both conditions, suggesting that R16 is the most senescent genotype compared to F3 recombinants and K359W, which had lower levels of senescence. Therefore, R16 has the highest level of senescence under water stress at 49 DAF. These observations support the conclusions drawn by Kiranmayee et al. (2020), where F2:4 recombinants showed better stay-green performance than their parents.

**3.13. Plant height (PH, cm)**

The plant height (PH) data for the different genotypes shows notable variation. The maximum plant height was observed in PV at 194.60 cm, while the minimum was recorded in B35 at 81.00 cm. Other significant heights include 162.70 cm for PM, 152.60 cm for M35-1, and 145.80 cm for CRS1(Table 2). These values highlight the diversity in plant heights among the genotypes. The plant height (PH) data under water stress conditions shows considerable variation across the genotypes. The tallest plant under water stress was observed for Phule Vasudha at 198.50 cm, followed by Parbhani Moti at 159.77 cm and M35-1 at 156.37 cm. Other genotypes with relatively high plant heights include CRS1 at 142.15 cm, K260 at 121.67 cm, and E36-1 at 121.60 cm. In contrast, the shortest plant height under water stress was recorded for B35 at 82.97 cm, followed by 296B at 86.62 cm and R16 at 111.83 cm. These values highlight the variation in plant height under water stress conditions among the different genotypes (Table 4). The mean plant height (PH) values for R16, F3 recombinants, and K359W under well-watered (WW) and water stress (WS) conditions showed varying degrees of response to water stress. Under well-watered conditions, the mean plant height for R16 was 114.34 cm, for F3 recombinants it was 121.3 cm, and for K359W it was 116.63 cm. Under water stress, the mean plant height decreased slightly for R16 to 111.84 cm, showing a moderate reduction. The F3 recombinants experienced a more significant drop, with the mean plant height decreasing to 109.92 cm. K359W had a smaller reduction, with the mean plant height dropping to 111.39 cm under water stress (Table 6). Overall, while all genotypes exhibited some reduction in plant height under water stress, the F3 recombinants showed the most pronounced decrease, whereas R16 and K359W exhibited relatively better resilience under stress conditions. Our results reaffirmed previous findings by Galyuon et al. (2019) found no significant differences between WW and WL plants, but both RSG 03123 and R16 were significantly taller, suggesting the SG QTL from B35 did not affect height.

**3.14 Effective tillers (ET)**

The data for tillers across the different genotypes showed a range of values. The maximum number of tillers was recorded in PV with 5.75, while the minimum was seen in B35 with 4.00. Other notable values included 6.5 for E36-1, 5.5 for PM, and 5.25 for M35-1 (Table 2). These values illustrated the variation in tiller production among the genotypes. The data for tillers under water stress (WS) conditions showed variation across the genotypes. The highest number of tillers was recorded for E36-1 at 4.75, followed by CRS1 at 4, and both Parbhani Moti and Phule Vasudha with 4.25 tillers. Other notable values included 3.85 for 296B, 3.8 for K260, and 3.75 for both B35 and M35-1. The lowest number of tillers under water stress was observed for K359W at 3.12, while R16 had 3.84 tillers (Table 4). These values highlight the differences in tiller production under water stress among the genotypes. The mean values for ET (tillers) under well-watered (WW) and water stress (WS) conditions showed varied responses for R16, F3 recombinants, and K359W. Under well-watered conditions, R16 had a mean of 4.25 tillers, F3 recombinants had a mean of 1.49 tillers, and K359W had a mean of 4.13 tillers. Under water stress, R16's tiller number decreased to 3.58, F3 recombinants showed a larger drop to 1.24, and K359W had a slight reduction to 3.13 tillers (Table 6). This indicated that all genotypes experienced a reduction in tiller production under water stress, with F3 recombinants showing the most significant decrease, while R16 and K359W maintained relatively better tiller numbers under stress. These differences are thought to reduce crop water usage prior to anthesis, resulting in greater water availability at the post-flowering stage. These result corroborated the findings of Borrell et al. (2022)

**3.15. Days to anthesis (DA)**

The anthesis data across the genotypes revealed a range of flowering times. The earliest anthesis occurred in E36-1 and R16, both at 62.25 days, while the latest was recorded for PV at 71.5 days. Other notable values included 71.25 days for CRS1, 66.00 days for 296B, and 65.75 days for B35 (Table 2). These values illustrated the variation in flowering time across the different genotypes. The data for days to anthesis under water stress (WS) conditions showed variation in the time to flowering across the genotypes. The earliest anthesis occurred in E36-1, with a value of 62 days, followed by K359W at 64.5 days and R16 at 64.75 days. Other genotypes, such as K260 at 65.21 days and Parbhani Moti at 66.46 days, had relatively early anthesis. The latest anthesis was observed for Phule Vasudha at 70.42 days, followed by CRS1 at 68.53 days and M35-1 at 67.71 days (Table 4). These values highlight the variation in the time to anthesis under water stress conditions among the different genotypes. The mean values for Days to Anthesis under well-watered (WW) and water stress (WS) conditions show that water stress had a slight impact on the timing of anthesis for R16, F3 recombinants, and K359W. Under well-watered conditions, R16 took 62.63 days to reach anthesis, F3 recombinants took 69.21 days, and K359W took 63.5 days. Under water stress, R16 experienced a slight delay, with anthesis occurring at 64.79 days, while F3 recombinants remained unchanged at 69.21 days, and K359W also showed a small delay, with anthesis occurring at 65 days (Table 6). These results suggest that water stress led to a minor delay in anthesis, particularly for R16 and K359W, though the effect was relatively modest across the genotypes. It was believed that the difference in DTF was attributed to the genetic background. In agreement with our results, Abebe et al. (2021) reported a mean of 82 days to flowering, with genetic background influencing DTF under uniform irrigation. Upadhyaya et al. (2021) observed no significant difference in flowering between irrigated and drought-stressed conditions, though stress reduced grain yield.

**3.16. Days to 50% flowering (DFF)**

The data for days to 50% flowering showed a wide range of flowering times across the genotypes. The earliest flowering occurred in E36-1 and R16, both at 70.25 days, while the latest was observed in PV at 81.00 days. Other significant values included 80.25 days for CRS1, 74.25 days for B35, and 73.75 days for PM (Table 2). These values highlighted the variation in the time to reach 50% flowering across the different genotypes. The data for days to 50% flowering under water stress (WS) conditions showed variation in the flowering time across the genotypes. The earliest 50% flowering occurred in E36-1 at 70.75 days, followed by K359W at 71.8 days and M35-1 at 71.42 days. Other genotypes with relatively early flowering included K260 at 72.75 days and R16 at 73.37 days. The latest flowering was observed for Phule Vasudha at 82.14 days, followed by B35 at 79.25 days and CRS1 at 78.35 days (Table 4). These values illustrated the differences in flowering time under water stress conditions across the genotypes. The mean values for days to 50% flowering under well-watered (WW) and water stress (WS) conditions indicated that water stress resulted in a slight delay in flowering for R16, F3 recombinants, and K359W. Under well-watered conditions, R16 reached 50% flowering in 70.29 days, F3 recombinants in 83.23 days, and K359W in 70.88 days. Under water stress, R16 took 73.44 days, a slight delay from the well-watered condition, while F3 recombinants and K359W also experienced slight delays, with F3 recombinants reaching 50% flowering at 83.21 days and K359W at 71.75 days (Table 6). These results suggested that water stress caused a minor delay in flowering, with F3 recombinants showing the most consistent both conditions. These observations supported the conclusions drawn by Shivalli (2000), who found that genotype M35-1 took the longest duration from 50% flowering to maturity and recorded higher grain yield.

**3.17. Time taken to grain maturity (TGM)**

The grain maturity data showed a range of maturity times across the genotypes. The earliest grain maturity was recorded for E36-1 at 112.47 days, while the latest was observed for Phule Vasudha at 122.3 days. Other notable maturity times include 122.12 days for K359W, 119.87 days for CRS1, and 119.7 days for Parbhani Moti (Table 2). These values highlighted the variation in grain maturity across the different genotypes. The days to grain maturity under water stress (WS) conditions showed slight variation among the genotypes. The earliest maturity was observed in E36-1, with a value of 115.62 days, followed by K260 at 116.87 days and 296B at 117.57 days. Other genotypes such as R16 (117.86 days), M35-1 (118.82 days), and CRS1 (119.27 days) also matured relatively early. The latest grain maturity was observed in Phule Vasudha, with 123.15 days, followed by Parbhani Moti at 120.02 days and B35 at 119.2 days (Table 4). These values indicated that, under water stress, certain genotypes reach maturity faster than others, with E36-1 and K260 showing earlier maturity compared to the rest. The days to grain maturity trait showed a decrease under water stress (WS) for most genotypes compared to well-watered (WW) conditions. For R16, the days to maturity decreased from 116.41 days under WW to 113.87 days under WS, indicating that water stress slightly accelerated the maturity. Similarly, F3 recombinants also showed a small decrease from 119.14 days under WW to 119.11 days under WS, while K359W had a slight decrease from 122.13 days under WW to 121.41 days under WS (Table 6). These results suggested that water stress slightly reduced the time to grain maturity for all genotypes, with R16 showing the most notable reduction in maturity days under water stress. Our results aligned with Abebe et al. (2021), where the longest days to maturity (DTM) were recorded for the developed progeny, ranging from 114 to 126.7 days, with B35 at 116.9 days. About 23% of the converted progeny showed significant delays in DTM, likely due to high vegetative growth, characteristic of the "stay-green" behavior. Borrell et al. (2000) observed a similar delay in physiological maturity in A35 (stay-green) hybrids.

**3.18. Harvested panicle per plant (HPPP)**

The harvested panicle per plant data showed variation in panicle production across the genotypes. The highest number of panicles per plant was recorded for Phule Vasudha at 6.5, followed closely by E36-1 at 6.25 and Parbhani Moti at 5.75. Other notable values included 5.5 for M35-1, 5.25 for K260 and CRS1, and 4.75 for 296B (Table 2). The lowest number of panicles was observed for R16 at 3.75. These values demonstrated the differences in panicle production per plant among the genotypes. The number of harvested panicles per plant under water stress (WS) conditions varied among the genotypes. The lowest number of panicles was observed for R16 with 3.37, followed by M35-1 at 3.54 and Parbhani Moti at 3.69. The highest number of panicles per plant was recorded for E36-1 at 5.35, followed by K260 at 5.14 and 296B at 4.52. Other genotypes, such as B35 and CRS1, had intermediate values of 4, and Phule Vasudha recorded 4.25 (Table 4). These results suggested that certain genotypes, like E36-1 and K260, perform better in terms of panicle production under water stress conditions, while others, like R16, showed a lower number of harvested panicles per plant. The harvested panicle per plant trait showed a decrease under water stress (WS) for all genotypes compared to well-watered (WW) conditions. For R16, the number of harvested panicles per plant decreased from 3.58 under WW to 3.38 under WS, indicating a slight reduction due to water stress. Similarly, F3 recombinants exhibited a decline from 4.07 under WW to 2.99 under WS, showing a more significant decrease under water stress. K359W also showed a decrease from 4.38 under WW to 3.5 under WS (Table 6). These results suggested that water stress negatively impacts the number of harvested panicles per plant, with F3 recombinants experiencing the most substantial reduction.

**3.19.** **Threshold grain dry weight (TGDW, g)**

The grain dry weight data showed a range of values across the genotypes. The highest grain dry weight was recorded for Parbhani Moti at 238.87, followed by E36-1 at 207.87 and Phule Vasudha at 206.75. Other notable values included 202.6 for M35-1, 201.22 for K359W, and 188.57 for K260. The lowest grain dry weight was observed for R16 at 166.52, followed by 296B at 168.5 (Table 2). These values highlighted the variation in grain dry weight across the different genotypes. The grain dry weight under water stress (WS) conditions showed significant variation across the genotypes. The highest grain dry weight was observed for Parbhani Moti at 204 g, followed closely by Phule Vasudha at 196 g. Other genotypes with relatively high grain dry weight included K359W at 189.32 g and E36-1 at 185 g. The lowest grain dry weight was recorded for R16 at 136.37 g, followed by 296B at 160.5 g and CRS1 at 149.92 g. Genotypes such as K260 (175 g), M35-1 (163.9 g), and B35 (166.82 g) showed moderate grain dry weight values (Table 4). These results highlight that certain genotypes, like Parbhani Moti and Phule Vasudha, are more productive under water stress in terms of grain dry weight, while others, like R16 and 296B, perform less efficiently. The grain dry weight trait shows a decrease under water stress (WS) for all genotypes when compared to well-watered (WW) conditions. For R16, the grain dry weight decreased from 166.53 under WW to 136.38 under WS, indicating a notable reduction due to water stress. Similarly, F3 recombinants exhibited a decrease from 185.03 under WW to 125.52 under WS, showing a significant decline. K359W also experienced a reduction, from 201.23 under WW to 192.47 under WS (Table 6). These results suggest that water stress negatively impacts the grain dry weight across all genotypes, with F3 recombinants showing the largest decrease. This observation was consistent with the findings of Adotey et al. (2021), who reported that total grain yield of all genotypes was reduced under water-deficit stress, though the reduction was not significant for P898012, SC1103, and SC35, with RTx430 showing the least reduction.

**3.20. Grain yield per plant (GYPP, g)**

The grain yield per plant data shows a range of yields across the genotypes. The highest grain yield per plant was recorded for Parbhani Moti at 69.62, closely followed by E36-1 at 69.29 and Phule Vasudha at 68.91. Other notable yields included 67.07 for K359W, 62.85 for K260, and 62.83 for CRS1. The lowest yield per plant was observed for 296B at 54.82, followed by R16 at 55.5 and M35-1 at 56.87 (Table 2). These values highlight the variation in grain yield per plant among the different genotypes. The grain yield per plant under water stress (WS) conditions showed notable differences across the genotypes. The highest grain yield was observed in E36-1 at 61.69 g, followed by K260 at 58.34 g. Other genotypes with relatively high grain yields include K359W at 53.11 g and B35 at 52.27 g. The lowest grain yields were recorded for M35-1 at 41.32 g and Parbhani Moti at 43.26 g. Other genotypes, such as R16 (45.45 g), CRS1 (46.64 g), and Phule Vasudha (45.33 g), exhibited moderate grain yield values (Table 4). These results indicate that certain genotypes, like E36-1 and K260, perform better in terms of grain yield under water stress, while others, such as M35-1, show lower productivity. The grain yield per plant trait shows a decrease under water stress (WS) for all genotypes compared to well-watered (WW) conditions. In well-watered (WW) conditions, K359W had the maximum grain yield per plant at 67.08, while in water stress (WS) conditions, R16 had the maximum yield of 53.11. For F3 recombinants, the highest yield under WW was 61.68, and under WS, it was 45.46 (Table 6). These results suggested that K359W performs the best in WW conditions, while R16 performed the best under WS conditions. Our results aligned with Abebe et al. (2021) reported higher yields in stay-green lines under drought, with Stg3 boosting yield up to 186.1%.

**3.21. Dry stover weight (DSW, g)**

The dry stover weight data showed variation in biomass production across the genotypes. The highest dry stover weight was recorded for Phule Vasudha at 925.85, followed closely by CRS1 at 921.47 and M35-1 at 856.35. Other notable values included 852.76 for Parbhani Moti, 823.83 for K359W, and 749.17 for R16. The lowest dry stover weight was observed for 296B at 629.97, followed by K260 at 671.8 and B35 at 652.05 (Table 2). These values reflected the differences in dry stover weight among the genotypes. The dry stover weight under water stress (WS) conditions varied among the genotypes. The highest dry stover weight was observed for K359W at 636.1 g, followed by 296B at 587.07 g and K260 at 576.60 g. Other genotypes with notable dry stover weights included B35 at 553.12 g and Phule Vasudha at 552.5 g. The lowest dry stover weight was recorded for CRS1 at 449 g, followed by R16 at 482.1 g and M35-1 at 525.1 g. E36-1 also showed a moderate value of 536.9 g (Table.4). These results suggested that some genotypes, like K359W and 296B, accumulated more dry stover under water stress, while others, such as CRS1 and R16, exhibit lower dry stover weight. For the dry stover yield trait, the genotypes showed distinct performance under both well-watered (WW) and water stress (WS) conditions. In WW conditions, K359W exhibited the highest dry stover yield at 823.84, followed by R16 at 749.18 and F3 recombinants at 682.84 (Table 4). However, under WS conditions, K359W still maintained the highest dry stover yield of 634.64, although the yield decreased in comparison to WW conditions. Following K359W under WS, R16 had a yield of 486.04, and F3 recombinants yielded 460.71 (Table 6). These findings indicated that K359W consistently produced the highest dry stover yield in both WW and WS conditions, though all genotypes experience a reduction in yield when subjected to water stress (Table 4). These results corroborated the work of Navyashree et al. (2024), who reported significantly higher stover yield under irrigation (5413 kg/ha) compared to rainfed conditions (3761 kg/ha), with M-35-1 showing the highest yield and SVD1272R the greatest reduction under stress. Blümmel et al. (2015) found that introgression lines with B35 QTLs achieved >2× stover yield and 1.6× stover content compared to recurrent parents.

**3.22.** **Hundred seed weight (HSW, g)**

The hundred seed weight data showed variation across the genotypes. The highest hundred seed weight was recorded for Parbhani Moti at 4.2, followed by M35-1 at 4.02. Other notable values included 3.77 for K260, 3.57 for both B35 and CRS1, and 3.55 for E36-1. The lowest hundred seed weight was observed for Phule Vasudha at 3.27, followed by R16 at 3.4 and 296B at 3.47 (Table 2). These values highlighted the differences in seed size among the genotypes. The hundred seed weight under water stress (WS) conditions varies across the genotypes. The highest hundred seed weight was observed for E36-1 at 3.32 g, followed closely by 296B at 3.29 g and K260 at 3.22 g. K359W also showed a relatively high value of 3.26 g. On the other hand, R16 and CRS1 recorded the lowest hundred seed weight at 2.23 g and 2.25 g, respectively. Other genotypes, such as B35 (3.15 g), M35-1 (2.89 g), Parbhani Moti (2.64 g), and Phule Vasudha (2.82 g), displayed intermediate values (Table 4). These results indicate that some genotypes, like E36-1 and 296B, maintain a higher hundred seed weight under water stress, while others, like R16 and CRS1, showed a significantly lower weight. For the hundred seed weight trait, the genotypes displayed a noticeable difference between well-watered (WW) and water stress (WS) conditions. Under WW conditions, K359W had the highest hundred seed weight at 3.91, followed by F3 recombinants at 3.57, and R16 at 3.4. In contrast, under WS conditions, F3 recombinants showed a slight increase in hundred seed weight to 2.81, while K359W decreased to 3.46, and R16 dropped significantly to 2.28 (Table 6). These results indicated that K359W maintains the highest seed weight under WW, while F3 recombinants performed better under WS, although all genotypes showed a reduction in hundred seed weight under water stress. These observations supported the conclusions drawn by Abebe et al. (2021), who reported TSW ranging from 20.8 to 41.7 g, with 36.1% of converted progeny showing superior weights (33.8–41.7 g).

**Table 1: ANOVA for stay-green related traits under WW condition in F3 generation**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Genotypes** | **SPAD\_AF** | **SPAD\_AM** | **GLAB** | **GLAM** | **RLS** | **STG@7**  **DAF** | **STG@14**  **DAF** | **STG@21**  **DAF** | **STG@28**  **DAF** | **STG@35**  **DAF** | **STG@42**  **DAF** | **STG@49**  **DAF** |
| K359W | 47.52 b | 41.36 ab | 341.69 d | 302.54 cd | 0.46 bc | 2.95 e | 3.45 e | 3.6 g | 4 e | 4.1 e | 4.4 d | 4.95 g |
| B35 | 48.85 a | 41.8 a | 356.7 ab | 334.82f | 0.44 | 2.36 h | 2.61 g | 3.02 h | 3.42 f | 3.67 e | 4.06 d | 4.75 h |
| K260 | 44.22 cde | 38.1 c | 322.17 f | 306.62 c | 0.55 | 2.72 f | 3.7 d | 4.07 | 4.57 c | 4.77 c | 5.2 bc | 5.42 e |
| E36-1 | 45.02 c | 40.375 b | 315.62 g | 298.78 cd | 0.65 d | 2.62 fg | 3.42 e | 4.2 ef | 4.35 d | 5.12 | 5.25 b | 5.57 d |
| 296B | 43.22 ef | 37.87 cd | 417.69 a | 363.87 a | 0.54 a | 2.55 g | 3.07 c | 4.09 de | 4.45 cd | 4.72 c | 4.95 c | 5.1 f |
| R16 | 44.41 cd | 38.12 c | 295.60 h | 254.92 e | 0.76 c | 3.23 d | 4.23 b | 5.13 a | 5.45 a | 6.11 a | 6.25 a | 6.50 a |
| M35-1 | 43.32 def | 32.55 cd | 347.31 c | 296.23 cd | 1.1 ab | 2.85 h | 3.15 f | 4.37 f | 4.65 c | 5.21 c | 5.37 bc | 5.75 c |
| Parbhani Moti | 44.12 cde | 30.95 cd | 328.47 e | 298.46 cd | 0.77 c | 4.37 a | 4.85 a | 5.17 b | 5.27 b | 6.17 a | 6.35 a | 6.47 b |
| CRS1 | 38.55 g | 29.72 d | 361.33 b | 321.11 b | 0.87 abc | 3.67 c | 4.05 c | 4.47 cd | 5.1 b | 5.32 b | 5.45 b | 5.55 de |
| Phule Vasudha | 42.62 f | 32.5 c | 344.55 cd | 292.09 d | 1.15 a | 3.97 b | 4.27b | 4.6 c | 4.65 c | 5.27 b | 5.47 b | 6.10 de |
| **GMS** | 35.4 | 14.46 | 8635.15 | 6851.59 | 0.343 | 2.24 | 2.45 | 3.45 | 3.12 | 3.99 | 3.47 | 3.47 |
| **EMS** | 0.29 | 0.312 | 5.2 | 27.3 | 0.016 | 0.003 | 0.005 | 0.009 | 0.007 | 0.007 | 0.03 | 0.003 |
| **P value** | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* |
| **CV** | 1.21 | 1.43 | 0.69 | 1.79 | 16.09 | 1.88 | 1.89 | 2.22 | 1.81 | 1.69 | 3.6 | 1.05 |
| **LSD 0.05** | 0.77 | 0.8 | 3.26 | 7.48 | 0.18 | 0.082 | 0.1 | 0.137 | 0.12 | 0.122 | 0.285 | 0.08 |

(SPAD AF -SPAD at flowering; SPAD AM-SPAD at maturity; GLAB- Green leaf area at booting; GLAM- Green leaf area at maturity; RLS-Rate of leaf senescence; STG@7 T0 49 DAF-Stay green score at weekly interval days after flowering)

**Table 2: ANOVA for agronomic and yield related traits under WW condition in F3 generation**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Genotypes** | **PH** | **ET** | **DA** | **DFF** | **TGM** | **HPP** | **TGDW** | **GYPP** | **DSW** | **HSW** |
| K359W | 116.62 f | 4.12 c | 63.5 bcd | 70.87 fg | 122.12 a | 4.37 cd | 201.22 c | 67.07 c | 823.83 c | 3.51 ab |
| B35 | 81 i | 4 c | 65.75 b | 74.25 cd | 114.5 de | 4.25 cd | 174.9 e | 57.12 | 652.05 g | 3.57 ef |
| K260 | 123.37 e | 4.5 bc | 64 bcd | 73.25 def | 113.55 e | 5.25 bc | 188.57 d | 62.85 d | 671.8 f | 3.77 bc |
| E36-1 | 124.05 e | 6.5 a | 62.25 d | 70.25 efg | 112.47 | 6.25 ab | 207.87 b | 69.29 b | 727.52 e | 3.55 cd |
| 296B | 85 h | 4.5 bc | 66 b | 73.31 bc | 114.52 bc | 4.75 cd | 168.5 ef | 54.82 g | 629.97 h | 3.47 f |
| R16 | 114.33 g | 4.25 c | 62.25 d | 70.25 g | 116.41 cd | 3.75 d | 166.52 f | 55.50 e | 749.17 d | 3.4 d |
| M35-1 | 152.6 c | 5.25 a | 65.25 bc | 72.25 efg | 116.4 cd | 5.5 ab | 202.6 bc | 56.87 e | 856.35 b | 4.02 ab |
| Parbhani Moti | 162.7 b | 5.5 ab | 64.25 bcd | 73.75 cde | 119.7 ab | 5.75 a | 238.87 a | 69.62 a | 852.76 b | 4.2 a |
| CRS1 | 145.8 d | 4.75 bc | 71.25 a | 80.25 ab | 119.87 ab | 5.25 bc | 188.5 d | 62.83 d | 921.47 a | 3.57 cd |
| Phule Vasudha | 194.6 a | 5.75 ab | 71.5 a | 81 a | 122.3 a | 6.5 ab | 206.75 bc | 68.91 bc | 925.85 a | 3.27 de |
| **GMS** | 5023.4 | 3.84 | 47.69 | 71.54 | 52.79 | 6.011 | 2271.36 | 832.83 | 112971.5 | 0.84 |
| **EMS** | 1.56 | 0.332 | 1.01 | 1.91 | 1.33 | 0.312 | 8.19 | 0.852 | 14.63 | 0.02 |
| **P value** | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* |
| **CV** | 0.98 | 11.82 | 1.54 | 1.87 | 0.97 | 10.86 | 1.48 | 1.54 | 0.5 | 4.31 |
| **LSD 0.05** | 1.79 | 0.82 | 1.44 | 1.98 | 1.65 | 0.8 | 4.09 | 1.32 | 5.47 | 0.22 |

(PH-Plant height; ET-Effective tillers; DA-Days to anthesis; DFF-Days to fifty per cent flowering; TGM-Time taken to grain maturity; HPP-Harvested panicles per plant; TGDW-Threshold grain dry weight; GYPP-Grain yield per plant; DSW-Dry stover weight; HSW-Hundred seed weight)

**Table 3: ANOVA for stay-green related traits under WS condition in F3 generation**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Genotypes** | **SPAD\_AF** | **SPAD\_AM** | **GLAB** | **GLAM** | **RLS** | **STG@7**  **DAF** | **STG@14**  **DAF** | **STG@21**  **DAF** | **STG@28**  **DAF** | **STG@35**  **DAF** | **STG@42**  **DAF** | **STG@49**  **DAF** |
| K359W | 47.97 a | 39.61 a | 340.14 bc | 285.23 b | 1.32 bc | 3.45 f | 3.64 f | 4.15 f | 4.75 ef | 5.45 e | 5.72 de | 6.15 e |
| B35 | 49.05 a | 39.45 a | 349.19 e | 326.74 c | 1.22 bc | 3.25 e | 3.37 de | 3.52 g | 3.96 h | 4.15 h | 4.65 g | 5.25 g |
| 296B | 44.65 b | 40.45 b | 420.26 a | 353.2 a | 1.35 ab | 3.17 b | 4.37 c | 4.65 d | 4.72 f | 5.05 g | 5.22 f | 5.37 g |
| K260 | 43.90 | 37.57 | 318.66 | 286.43 | 1.45 | 3.42 | 4.27 | 5.27 | 5.65 | 5.32 | 5.75 | 5.70 |
| E36-1 | 44.5 b | 38.05 f | 314.88 cd | 287.5 b | 1.22 bc | 3.65 d | 3.55 d | 4.42 e | 4.47 g | 5.42 ef | 5.65 e | 5.8 f |
| R16 | 44.92 b | 30.83 cd | 293.35 d | 186.9 c | 2.35 a | 3.98 d | 4.56 b | 6.25 a | 6.57 a | 6.71 a | 6.76 a | 6.83 a |
| M35-1 | 43.8 bc | 29.87 bcd | 346.78 b | 194.57 b | 2.37 bc | 3.69 f | 3.75 e | 4.25 ef | 5.12 e | 5.74 f | 6.25 c | 6.25 de |
| CRS1 | 39.17 d | 25.65 ef | 352.64 bc | 256.49 b | 2.64 abc | 3.92 c | 4.25 c | 4.65 d | 5.35 c | 5.75 d | 6.36 d | 6.35 de |
| Parbhani Moti | 43.67 bc | 36.37 b | 325.70 bc | 185.48 b | 2.87 c | 4.62 a | 4.9 a | 5.52 b | 5.82 b | 6.32 c | 6.57 b | 6.92 b |
| Phule Vasudha | 42.47 c | 28.95 de | 340.88 bc | 230.62 b | 2.45 bc | 4.24 a | 4.6 b | 5.12 c | 5.15 d | 5.82 d | 6.28 c | 6.43 d |
| **GMS** | 34.87 | 22.02 | 8470.22 | 10846.2 | 1.244 | 2.67 | 2.64 | 3.16 | 3.76 | 4.31 | 4.7 | 3.91 |
| **EMS** | 0.545 | 0.44 | 150.06 | 252.35 | 0.195 | 0.006 | 0.005 | 0.008 | 0.005 | 0.005 | 0.005 | 0.006 |
| **P value** | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* |
| **CV** | 1.65 | 1.9 | 3.74 | 6.16 | 29.18 | 2.18 | 1.88 | 1.95 | 1.48 | 1.34 | 1.25 | 1.27 |
| **LSD 0.05** | 1.05 | 0.95 | 17.53 | 22.73 | 0.63 | 0.11 | 0.106 | 0.13 | 0.109 | 0.108 | 0.1 | 0.11 |

(SPAD AF -SPAD at flowering; SPAD AM-SPAD at maturity; GLAB- Green leaf area at booting; GLAM- Green leaf area at maturity; RLS-Rate of leaf senescence; STG@7 T0 49 DAF-Stay green score at weekly interval days after flowering)

**Table 4: ANOVA for agronomic and yield related traits under WS condition in F3 generation**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Genotypes** | **PH** | **ET** | **DA** | **DFF** | **TGM** | **HPP** | **TGDW** | **GYPP** | **DSW** | **HSW** |
| K359W | 112.51 f | 3.12 b | 64.5 a | 71.8 a | 121.41 ab | 3.87 b | 189.32 e | 53.11 e | 636.1 g | 3.26 a |
| B35 | 82.97 g | 3.75 b | 67.5 ab | 79.25 abc | 119.2 cd | 4 b | 166.82 e | 52.27 e | 553.12 i | 3.15 d |
| 296B | 86.62 h | 3.85 b | 67.25 bcd | 74.36 bc | 117.57 de | 4.52 b | 160.5 g | 48.85 g | 587.07 h | 3.29 d |
| K260 | 121.67 | 3.8 | 65.21 | 72.75 | 116.87 | 5.14 | 175.00 | 58.34 | 576.60 | 3.22 |
| E36-1 | 121.6 e | 4.75 a | 62 e | 70.75 de | 115.62 e | 5.35 a | 185.0 c | 61.69 c | 536.9 f | 3.32 ab |
| R16 | 111.83 f | 3.84 b | 64.75 d | 73.37 d | 117.86 de | 3.37 b | 136.37 f | 45.45 f | 482.1 h | 2.23 c |
| M35-1 | 156.37 b | 3.75 a | 67.71 a | 71.42 ab | 118.82 cd | 3.54 a | 163.9 c | 41.32 c | 525.1 d | 2.89 a |
| CRS1 | 142.15 d | 4 b | 68.53 bc | 78.35 bc | 119.27 cd | 4.25 a | 149.92 ab | 46.64 ab | 449 c | 2.25 bc |
| Parbhani Moti | 159.77 c | 4.25 b | 66.46 cd | 76.56 c | 120.02 bc | 3.69 a | 204 a | 43.26 a | 558.12 b | 2.64 abc |
| Phule Vasudha | 198.5 a | 4.25 b | 70.42 a | 82.14 a | 123.15 a | 4.25 b | 196 b | 45.33 b | 552.5 a | 2.82 a |
| **GMS** | 6000.43 | 6.733 | 67.07 | 93.27 | 76.79 | 10.54 | 4268.2 | 474.27 | 112474 | 1.27 |
| **EMS** | 5.012 | 0.378 | 1.57 | 2.18 | 2.99 | 0.28 | 5.98 | 0.66 | 12.83 | 0.011 |
| **P value** | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* | .0000 \*\*\* |
| **CV** | 1.75 | 15.45 | 1.85 | 1.91 | 1.48 | 10.81 | 1.46 | 1.46 | 0.68 | 3.32 |
| **LSD 0.05** | 3.2 | 0.88 | 1.74 | 2.11 | 2.47 | 0.76 | 3.5 | 1.16 | 5.12 | 0.15 |

(PH-Plant height; ET-Effective tillers; DA-Days to anthesis; DFF-Days to fifty per cent flowering; TGM-Time taken to grain maturity; HPP-Harvested panicles per plant; TGDW-Threshold grain dry weight; GYPP-Grain yield per plant; DSW-Dry stover weight; HSW-Hundred seed weight)

**Table 5: Mean values of parents for stay-green related traits under WW and WS condition**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Trait** | **R16** | | **F3** | | **K359W** | | **B35** | | **K260** | | **E36-1** | | **296B** | | **M351** | | **Parbhani Moti** | | **CRS 1** | | **Phule Vasudha** | |
| **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** |
| **SPAD AF** | 44.41 | 44.92 | 44.59 | 44.67 | 47.53 | 47.98 | 48.85 | 49.04 | 44.22 | 43.88 | 45.03 | 44.50 | 43.23 | 44.65 | 43.33 | 43.78 | 44.13 | 40.10 | 38.54 | 44.43 | 42.63 | 42.46 |
| **SPAD AM** | 38.31 | 31.09 | 39.13 | 33.59 | 41.36 | 40.08 | 41.80 | 40.40 | 38.10 | 37.03 | 40.38 | 38.60 | 38.55 | 40.93 | 37.55 | 29.58 | 31.20 | 25.91 | 36.73 | 28.60 | 33.09 | 29.40 |
| **GLAB** | 290.00 | 295.35 | 297.74 | 296.71 | 341.70 | 340.64 | 356.95 | 350.02 | 322.17 | 322.66 | 315.62 | 314.88 | 417.69 | 422.26 | 347.31 | 346.78 | 328.47 | 355.53 | 361.34 | 326.90 | 344.56 | 338.89 |
| **GLAM** | 254.93 | 186.93 | 203.79 | 190.62 | 302.54 | 284.39 | 340.81 | 335.48 | 306.60 | 284.47 | 298.74 | 285.27 | 363.87 | 353.43 | 293.48 | 196.18 | 298.45 | 257.10 | 321.10 | 184.73 | 292.06 | 232.40 |
| **RLS** | 0.75 | 2.36 | 2.04 | 2.31 | 0.44 | 1.43 | 0.48 | 1.25 | 0.55 | 1.45 | 0.67 | 1.25 | 0.50 | 1.50 | 1.14 | 2.40 | 0.65 | 2.65 | 0.87 | 2.85 | 1.14 | 2.45 |
| **STG@**  **7DAF** | 3.24 | 3.91 | 2.09 | 2.94 | 2.95 | 3.46 | 2.38 | 3.23 | 2.71 | 3.50 | 2.63 | 3.45 | 2.55 | 3.08 | 2.95 | 3.65 | 4.38 | 4.00 | 3.68 | 4.65 | 3.98 | 4.45 |
| **STG@**  **14DAF** | 4.34 | 4.56 | 2.56 | 3.48 | 3.45 | 3.69 | 2.63 | 3.38 | 3.70 | 4.29 | 3.43 | 3.55 | 3.83 | 4.38 | 3.15 | 3.83 | 4.85 | 4.20 | 4.05 | 4.98 | 4.28 | 4.60 |
| **STG@**  **21DAF** | 5.54 | 6.21 | 3.08 | 4.15 | 3.60 | 4.25 | 3.10 | 3.63 | 4.18 | 5.28 | 4.20 | 4.43 | 4.33 | 4.64 | 4.08 | 4.27 | 5.18 | 5.30 | 4.48 | 5.63 | 4.59 | 5.13 |
| **STG@**  **28DAF** | 5.85 | 6.57 | 3.36 | 4.70 | 4.00 | 4.60 | 3.48 | 3.98 | 4.58 | 5.64 | 4.35 | 4.48 | 4.45 | 4.73 | 4.65 | 5.13 | 5.28 | 5.55 | 5.10 | 5.68 | 4.64 | 5.28 |
| **STG@**  **35DAF** | 6.21 | 6.91 | 3.68 | 5.24 | 4.10 | 5.63 | 3.70 | 4.08 | 4.78 | 5.85 | 5.23 | 5.43 | 4.73 | 5.05 | 4.93 | 5.78 | 6.18 | 5.83 | 5.33 | 6.43 | 5.28 | 5.73 |
| **STG@**  **42DAF** | 6.45 | 7.19 | 3.97 | 5.74 | 4.40 | 5.85 | 4.13 | 4.55 | 5.20 | 6.00 | 5.45 | 5.55 | 4.95 | 5.23 | 5.38 | 6.26 | 6.35 | 6.25 | 5.45 | 6.53 | 5.45 | 6.26 |
| **STG@**  **49DAF** | 6.59 | 7.41 | 4.22 | 6.09 | 4.95 | 6.16 | 4.75 | 5.33 | 5.43 | 6.15 | 5.58 | 5.80 | 5.10 | 5.28 | 5.75 | 6.65 | 6.48 | 6.40 | 5.55 | 6.90 | 5.55 | 6.38 |

(SPAD AF -SPAD at flowering; SPAD AM-SPAD at maturity; GLAB- Green leaf area at booting; GLAM- Green leaf area at maturity; RLS-Rate of leaf senescence; STG@7 T0 49 DAF-Stay green score at weekly interval days after flowering)

**Table 6: Mean values of parents for agronomic and yield related traits under WW and WS condition**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Trait** | **R16** | | **F3** | | **K359W** | | **B35** | | **K260** | | **E36-1** | | **296B** | | **M351** | | **Parbhani Moti** | | **CRS 1** | | **Phule Vasudha** | |
| **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** | **WW** | **WS** |
| **PH** | 114.34 | 111.84 | 121.30 | 109.92 | 116.63 | 111.39 | 81.00 | 84.00 | 123.38 | 122.13 | 124.05 | 123.18 | 85.00 | 86.63 | 152.65 | 155.65 | 162.75 | 143.08 | 145.80 | 161.30 | 194.68 | 201.93 |
| **ET** | 4.25 | 3.58 | 1.49 | 1.24 | 4.13 | 3.13 | 4.00 | 3.75 | 4.25 | 3.50 | 6.50 | 5.25 | 4.50 | 3.25 | 5.75 | 3.25 | 5.50 | 4.25 | 4.50 | 4.00 | 5.75 | 4.25 |
| **DA** | 62.63 | 64.79 | 69.21 | 69.21 | 63.50 | 65.00 | 65.67 | 68.00 | 64.00 | 65.58 | 62.42 | 61.92 | 66.00 | 67.17 | 65.33 | 69.00 | 64.17 | 66.58 | 71.25 | 67.50 | 71.50 | 71.25 |
| **DFF** | 70.29 | 73.44 | 83.23 | 83.21 | 70.88 | 71.75 | 74.00 | 77.25 | 73.25 | 70.58 | 70.25 | 70.75 | 73.50 | 75.25 | 72.25 | 77.08 | 73.75 | 76.58 | 80.25 | 74.50 | 80.75 | 82.05 |
| **TGM** | 116.41 | 113.87 | 119.14 | 119.11 | 122.13 | 121.41 | 114.58 | 118.75 | 113.56 | 111.88 | 113.48 | 110.63 | 118.53 | 114.58 | 116.40 | 116.80 | 119.70 | 119.04 | 119.88 | 119.08 | 122.30 | 123.15 |
| **HPPP** | 3.58 | 3.38 | 4.07 | 2.99 | 4.38 | 3.50 | 4.25 | 4.00 | 5.25 | 6.75 | 6.25 | 5.25 | 4.75 | 3.50 | 5.25 | 4.25 | 5.25 | 4.50 | 5.25 | 3.75 | 6.50 | 4.25 |
| **TGDW** | 166.53 | 136.38 | 185.03 | 125.52 | 201.23 | 192.47 | 174.90 | 166.60 | 188.58 | 175.05 | 207.88 | 185.08 | 168.50 | 160.58 | 202.60 | 165.08 | 238.88 | 152.75 | 188.50 | 199.93 | 206.75 | 196.00 |
| **GYPP** | 55.51 | 45.46 | 61.68 | 41.84 | 67.08 | 53.11 | 57.13 | 52.28 | 62.86 | 58.35 | 69.29 | 61.69 | 54.94 | 48.82 | 56.88 | 41.29 | 73.91 | 46.48 | 62.83 | 44.08 | 68.92 | 45.25 |
| **DSW** | 749.18 | 486.04 | 682.84 | 460.71 | 823.84 | 634.64 | 651.30 | 552.78 | 671.80 | 576.63 | 727.53 | 536.95 | 636.69 | 587.69 | 856.35 | 533.23 | 852.77 | 450.53 | 921.48 | 649.00 | 925.85 | 554.23 |
| **HSW** | 3.40 | 2.28 | 3.57 | 2.81 | 3.91 | 3.46 | 3.58 | 3.13 | 3.65 | 3.23 | 3.55 | 3.43 | 3.45 | 3.23 | 4.03 | 3.10 | 4.20 | 2.80 | 3.58 | 2.60 | 3.28 | 2.73 |

(PH-Plant height; ET-Effective tillers; DA-Days to anthesis; DFF-Days to fifty per cent flowering; TGM-Time taken to grain maturity; HPP-Harvested panicles per plant; TGDW-Threshold grain dry weight; GYPP-Grain yield per plant; DSW-Dry stover weight; HSW-Hundred seed weight)

**Conclusion**

This study phenotypic stay-green donor and recipient lines including a set of 200 F2-derived F3 recombinants for stay-green-related traits under water stress conditions during the rabi season. Significant variation in chlorophyll retention, leaf area, senescence rate, and agronomic traits were observed across genotypes, with K359W and F3 recombinants showing superior stay-green potential and better performance under stress. F3 recombinants exhibited delayed senescence and high agronomic performance, particularly in terms of grain yield, biomass, and 100-seed weight, making them promising candidates for breeding drought-tolerant sorghum varieties.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

Abebe, T., Belay, G., Tadesse, T., & Keneni, G. (2021). Stay-green genes contributed for drought adaptation and performance under post-flowering moisture stress on sorghum (Sorghum bicolor L. Moench). *Journal of Plant Breeding and Crop Science*, *13*(4), 190-202.

Adotey, R. E., Patrignani, A., Bergkamp, B., Kluitenberg, G., Prasad, P. V., & Jagadish, S. K. (2021). Water‐deficit stress alters intra‐panicle grain number in sorghum. *Crop Science*, *61*(4), 2680-2695.

Blümmel, M., Deshpande, S., Kholova, J., & Vadez, V. (2015). Introgression of staygreen QLT's for concomitant improvement of food and fodder traits in Sorghum bicolor. *Field Crops Research*, *180*, 228-237.

Borrell, A. K., & Hammer, G. L. (2000). Nitrogen dynamics and the physiological basis of stay‐green in sorghum. *Crop science*, *40*(5), 1295-1307.

Borrell, A. K., Wong, A. C., George-Jaeggli, B., van Oosterom, E. J., Mace, E. S., Godwin, I. D., ... & Jordan, D. R. (2022). Genetic modification of PIN genes induces causal mechanisms of stay-green drought adaptation phenotype. *Journal of Experimental Botany*, *73*(19), 6711-6726.

Chadalavada, K., Gummadi, S., Kundeti, K. R., Kadiyala, D. M., Deevi, K. C., Dakhore, K. K., ... & Thiruppathi, S. K. (2021). Simulating potential impacts of future climate change on post-rainy season sorghum yields in India. *Sustainability*, *14*(1), 334.

Charyulu, D. K., Afari-Sefa, V., & Gumma, M. K. (2024). Trends in Global Sorghum Production: Perspectives and Limitations. In *Omics and Biotechnological Approaches for Product Profile-Driven Sorghum Improvement* (pp. 1-19). Singapore: Springer Nature Singapore.

Endalamaw, C., Nida, H., Tsegaye, D., van Biljon, A., Herselman, L., & Labuschagne, M. (2025). Genetics of sorghum: grain quality, molecular aspects, and drought responses. *Planta*, *261*(3), 1-25.

Galyuon, I. K., Gay, A., Hash, C. T., Bidinger, F. R., & Howarth, C. (2019). A comparative assessment of the performance of a stay-green sorghum (Sorghum bicolor (L) Moench) introgression line developed by marker-assisted selection and its parental lines. *African Journal of Biotechnology*, *18*(26), 548-563.

Gomashe, S. S., Tayade, N., & Ganapathy, K. N. (2025). Sorghum. In *Plant Genebank Utilization for Trait Discovery in Millets: Volume IV* (pp. 43-76). Singapore: Springer Nature Singapore.

Kamal, N. M., Gorafi, Y. S. A., Abdelrahman, M., Tahir, I. S. A., & Tsujimoto, H. (2025). Enhancing and protecting the innate system in stay-green sorghum is the secret behind high drought tolerance capacity. *Plant Stress*, 100840.

Karthik, R., & Hanamaratti, N. G. (2025). Multivariate analysis and multitrait genotype-ideotype distance index (MGIDI) for selection of promising genotypes under drought stress in post rainy sorghum (Sorghum bicolor L. Moench). *Electronic Journal of Plant Breeding*, *16*(1), 57-69.

Kebede, H., Subudhi, P. K., Rosenow, D. T., & Nguyen, H. T. (2001). Quantitative trait loci influencing drought tolerance in grain sorghum (Sorghum bicolor L. Moench). *Theoretical and Applied Genetics*, *103*, 266-276.

Kiranmayee, K. U., Hash, C. T., Sivasubramani, S., Ramu, P., Amindala, B. P., Rathore, A., ... & Deshpande, S. P. (2020). Fine-mapping of sorghum stay-green QTL on chromosome10 revealed genes associated with delayed senescence. *Genes*, *11*(9), 1026.

Mahalakshmi, V., & Bidinger, F. R. (2002). Evaluation of stay‐green sorghum germplasm lines at ICRISAT. *Crop Science*, *42*(3), 965-974.

Muitire, C., Kamutando, C., & Moyo, M. (2021). Building stress resilience of cereals under future climatic scenarios:‘the case of maize, wheat, rice and sorghum’. In *Cereal Grains-Volume 1*. IntechOpen.

Otwani, D., McLean, G., Hammer, G., Cruickshank, A., Hunt, C., Tao, Y., ... & Jordan, D. (2025). Extended grain filling has potential to improve yield in grain sorghum. *Journal of Experimental Botany*, eraf117.

Pugh, N. A., Young, A., Emendack, Y., Sanchez, J., Xin, Z., & Hayes, C. (2025). High‐throughput phenotyping of stay‐green in a sorghum breeding program using unmanned aerial vehicles and machine learning. *The Plant Phenome Journal*, *8*(1), e70014.

Rajarajan, K., Ganesamurthy, K., Raveendran, M., Jeyakumar, P., Yuvaraja, A., Sampath, P., ... & Senthilraja, C. (2021). Differential responses of sorghum genotypes to drought stress revealed by physio-chemical and transcriptional analysis. *Molecular biology reports*, *48*, 2453-2462.

Rama Reddy, N. R., Ragimasalawada, M., Sabbavarapu, M. M., Nadoor, S., & Patil, J. V. (2014). Detection and validation of stay-green QTL in post-rainy sorghum involving widely adapted cultivar, M35-1 and a popular stay-green genotype B35. *BMC genomics*, *15*, 1-16.

Reddy, B. V., Ramaiah, B., Ashok Kumar, A., & Reddy, P. S. (2007). Evaluation of sorghum genotypes for the stay-green trait and grain yield. *Journal of SAT Agricultural Research*, *3*(1), 1-4.

Shivalli, S. N. (2000). *CHARACTERISATION OF MORPHO-PHYSIOLOGICAL TRAITS FOR HIGHER PRODUCTIVITY IN RABI SORGHUM* (Doctoral dissertation, University of Agricultural Sciences, Dharwad).

Subudhi, P. K., Rosenow, D. T., & Nguyen, H. T. (2000). Quantitative trait loci for the stay green trait in sorghum (Sorghum bicolor L. Moench): consistency across genetic backgrounds and environments. *Theoretical and Applied Genetics*, *101*, 733-741.

Suman, S., & Chandra, S. (2025). Introduction to millet and challenges of millet production due to extreme environmental conditions in India: a review. *Cereal Research Communications*, *53*(1), 101-125.

Tao, Y. Z., Henzell, R. G., Jordan, D. R., Butler, D. G., Kelly, A. M., & McIntyre, C. L. (2000). Identification of genomic regions associated with stay green in sorghum by testing RILs in multiple environments. *Theoretical and Applied Genetics*, *100*, 1225-1232.

Tulu, A., Diribsa, M., Gadisa, B., & Temesgen, W. (2025). Stover yield, morphological fractions and nutrient composition of five stay-green sorghum (Sorghum biochar L.) varieties at the physiological maturity stage. *Heliyon*, *11*(1).

Upadhyaya, H. D., Vetriventhan, M., & Azevedo, V. C. (2021). Variation for photoperiod and temperature sensitivity in the global mini core collection of sorghum. *Frontiers in Plant Science*, *12*, 571243.