**From Millet’s ‘Pearl’ To Desert’s ‘Gold’:**

**GHB 538 Improved (*Maru Sona*) Emerges Through Genomics-Assisted Breeding**

**ABSTRACT**

**Downy mildew (DM) is the most devasting disease of pearl millet caused by *Sclerospora graminicola* (Sacc.) Schroet, remains a major biotic constraint to pearl millet production in India. Looking to this constraint, Junagadh Agricultural University, Jamnagar (Gujarat), in collaboration with ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Hyderabad, decided to improve notified popular pearl millet hybrid GHB-538 through marker-assisted backcross breeding due to which this hybrid make a comeback in as improved version. Christened *Maru Sona* or *Desert Gold* in the local language, the new version is equipped with the genes to fend off devastating downy mildew disease and was released for cultivation in Gujarat state and A1 zone dry regions of Rajasthan, Gujarat, Haryana during *Kharif* season. The pearl millet hybrid GHB 538 Improved was developed by introgression of downy mildew resistance QTLs from P7-3-P13 and 863B-P2-P7 lines in the pollen parent J-2340 of earlier released GHB-538 with marker-assisted backcross method using foreground selection and notified at state and national level for *Kharif* season cultivation. The screening against downy mildew of GHB 538 Improved was carried out under the downy mildew sick plot, and yield trials testing work against original GHB-538 was carried out at state and national levels across different locations. In comparison to the original hybrid, *Maru Sona* shows markedly high resistance to downy mildew disease along with an increase in grain yield (3.5 and 1.8%) and dry fodder yield (10.8 and 1.9%); it also hallmarks early flowering (44 and 45 days) at state and AICRP testing, respectively. It also shows resistance reaction to other pearl millet diseases and possesses good quality parameters.**

**Key Words:** downy mildew, pearl millet, early, EDV, marker, backcross

**1. INTRODUCTION**

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an important cereal crop in arid and semi-arid tropical regions of Gujarat and Rajasthan. It is a significant dietary energy source and nutritional security for poor farmers and consumers.

Downy mildew (DM) or green ear disease is the most devasting disease of pearl millet caused by *Sclerospora graminicola* (Sacc.) Schroet, remains a major biotic constraint to pearl millet production in India [1,2,3,4]. It is the most widespread and destructive disease of pearl millet in India and Western Africa [3]. DM epidemics were not reported till the introduction of F1 hybrids. This disease, first reported in India [5], is present in more than 20 countries [6] and is a significant factor limiting the full exploitation of the high-yield potential of hybrids in India [7]. In India, DM epidemics caused substantial yield losses during the 1970s and 1980s. Grain yield losses of 10% to 80% have been reported. The yield-reducing potential of DM is very high, and this was adequately demonstrated in HB 3, a popular hybrid, when pearl millet grain production in India was reduced from 8 million tons in 1970-71 to 5.3 million tons in 1971-72. This reduction was primarily due to the DM epidemic, in which yield in some fields was reduced by 60 to 70%. The estimated annual grain yield loss due to DM is approximately 20-40% [4,8,9]. However, this could be much higher under favorable conditions of disease development [4,10,11], where a susceptible cultivar is repeatedly grown in the same field. Grain yield losses due to DM can reach alarmingly higher levels when a genetically uniform pearl millet cultivar is repeatedly and extensively grown.

The cultural and chemical control measures have been worked out, but the use of resistant cultivars is the most cost-effective and sustainable management method for DM. Conventional and molecular breeding methods have been successfully used in the DM resistance breeding program [8,12]. The MAB method was used in the molecular breeding program to transfer DM-resistant QTLs into the hybrid parental lines [13]. Several DM-resistant lines, such as IP 18292, 7042R and 700651, have been used in developing hybrid parental lines. A number of DM-resistant QTLs effective against diverse Indian pathotypes of *S. graminicola* have been mapped on the pearl millet linkage groups, and some of them have been transferred to the commercial B-lines (843B, 81B) and R-lines (H 77/833-2, ICMP 451). The development and commercial deployment of DM-resistant version of HHB 67 is the first successful story of MAB in field crops in the public domain in India [14].

Our earlier released early segment hybrid GHB-538 becomes susceptible to DM disease, a very popular and good hybrid. It is recommended for pearl millet growing the A1 zone of India, and moreover, it is also recommended for *Kharif*, summer and semi-*rabi* cultivation in Gujarat. This hybrid is suitable for its consumer-preferred yellow-grain color. Looking to these requirements, Junagadh Agricultural University, Jamnagar (Gujarat), in collaboration with ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Hyderabad efforts have been taken for the improvement of the GHB-538 through marker-assisted backcross breeding due to which an improved version that shows resistant to DM. Hence, research will be helpful for the young scientist. Introgression of additional downy mildew resistance QTLs has not just enhanced downy mildew resistance. Still, it will also impart stability to downy mildew resistance and significantly improve the life span of GHB-538.

**2. MATERIALS AND METHODS**

GHB 538 Improved (*Maru sona*) is an essentially derived variety (EDV) version of the immensely popular pearl millet early segment hybrid GHB-538 released in 2002 and notified in 2003 for A1 zone dry regions (receiving less than 400 mm rainfall annually) of Rajasthan, Gujarat and Haryana. It is also recommended for *Kharif*, summer and semi-*rabi* cultivation in Gujarat. The restorer line J-2340 Improved is a MAS-improved version of J-2340 developed through molecular breeding by making use of the downy mildew (DM) resistant donor parents, each carrying different DMR QTL. The donor parent P7-3-P13 contributed LG3 DMR QTL, while the donor parent and 863B-P2-P7 contributed LG1 and LG4 QTLs. These two donor parents were crossed to the original male recurrent parent J-2340, resulting in two different crosses and populations. Each of the two populations was carried forward using marker-assisted backcrossing (MABC) and foreground selection. The improved introgression lines in BC3F5 were crossed, resulting in a QTL heterozygote. This line was selfed for three generations to generate a DMR double QTL introgression line carrying three QTLs (one from P7-3-P13 and two from 863B-P2-P7). The final DM resistant version of J-2340 Improved was derived from ((ICMR 11019-P27 × ICMR 11009-P17)-P101)-P1819). The resistance alleles pyramided improved hybrid developed by crossing the original seed parent (ICMA 95444) with the improved pollinator parent J-2340.

Screening against DM of the GHB 538 Improved hybrid was carried out under the DM sick plot at different locations of Gujarat, and yield trials testing against original GHB-538 was carried out at Jamnagar and other substations from 2018 to 2020 during the *Kharif* season. It is also tested as a testing code MH 2661 in AICRP on pearl millet crop improvement A1 zone trials for yield testing and plant pathology trials for screening against DM from 2021 to 2022 during the *Kharif* season.

**3. RESULTS AND DISCUSSION**

In state trials, GHB 538 Improved, tested along with original GHB-538 as a check and shows significant improvement in downy mildew resistance under field conditions, along with a 3.5% increase in grain yield and a 10.8% increase in dry fodder yield over the original GHB-538. The average grain yield of GHB 538 Improved was 2589 kg ha-1 over 2502 kg ha-1 of GHB-538, while the average dry fodder yield of GHB 538 Improved was 6320 kg ha-1 over 5703 kg ha-1 of GHB-538 (Table 1 and 2).

**Table 1: Grain yield performance of pearl millet hybrid GHB 538 Improved in comparison with a check**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **No of Testing location** | **Grain yield (kg ha-1)** | | **% increase over check** | **S.Em ±** | **CV (%)** |
| **GHB 538 Improved** | **GHB-538 (c)** |
| **State Trials (*Kharif* 2018-2020)** | | | | | | |
| 2018 | 3 | 2886 | 2844 | 1.5 | 86 | 8.4 |
| 2019 | 4 | 2816 | 2673 | 5.3 | 81 | 11.9 |
| 2020 | 3 | 1989 | 1931 | 3.0 | 59 | 10.9 |
| **Mean** | **10** | **2589** | **2502** | **3.5** |  |  |
| **AICRP on Pearl Millet A1 Zone Trials (*Kharif* 2021 & 2022)** | | | | | | |
| 2021 | 8 | 2047 | 1973 | 3.8 | 352 | 18.2 |
| 2022 | 11 | 1861 | 1856 | 0.3 | 186 | 12.1 |
| **Mean** | **19** | **1939** | **1905** | **1.8** | -- | -- |

In AICRP trials, it also recorded a 1939 kg ha-1 grain yield, which was 1.8% higher than check hybrid GHB-538’s 1905 kg ha-1, and an average 4351 kg ha-1 dry fodder yield, which was 1.93% higher than check GHB-538’s 4268 kg ha-1 (Table 1 and 2).

**Table 2: Dry fodder yield performance of pearl millet hybrid GHB 538 Improved in comparison with a check**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **No of Testing location** | **Dry fodder yield (kg ha-1)** | | **% increase over check** | **S.Em ±** | **CV (%)** |
| **GHB 538 Improved** | **GHB-538 (c)** |
| **State Trials (*Kharif* 2018-2020)** | | | | | |  |
| 2018 | 3 | 7284 | 6715 | 8.5 | 294 | 13.1 |
| 2019 | 4 | 6220 | 5845 | 6.4 | 299 | 11.0 |
| 2020 | 3 | 5488 | 4500 | 22.0 | 321 | 15.5 |
| **Mean** | **10** | **6320** | **5703** | **10.8** |  |  |
| **AICRP on Pearl Millet A1 Zone Trials (*Kharif* 2021 & 2022)** | | | | | |  |
| 2021 | 8 | 5488 | 5154 | 6.5 | 876 | 16.9 |
| 2022 | 11 | 3523 | 3624 | -- | 379 | 12.1 |
| **Mean** | **19** | **4351** | **4268** | **1.9** | -- | -- |

It highly resistant to downy mildew (1.8 and 1.5%) as compared to original version GHB-538 (10.7 and 3.6%), when tested against it at the state and AICRP trials, respectively (Table 3). Further, it is also resistant to blast, rust, smut, and ergot diseases. In the case of pearl millet, major insect-pest *i.e.,* stem borer, shoot fly and *helicoverpa* infestation is less than the check, and it falls under the resistant category (Table 4).

**Table 3: The reaction of disease incidence on pearl millet hybrid GHB 538 Improved in comparison with a check under natural field conditions with a check**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Disease** | **State Trials**  **(*Kharif* 2018-2020)** | | | | **AICRP on Pearl Millet Trials**  **(*Kharif* 2021 & 2022)** | | |
| **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** | **7042 S**  **(DM Susceptible)** | **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** |
| Downy mildew (%) at 60 DAS | 9 | 1.8  (0.0-12.50) | 10.7  (0.0-39.5) | 100.0  (92.9-100.0) | 6 | 1.5  (0.0-4.6) | 3.6  (1.3-6.0) |
| Blast  (Score 0-9) | 9 | 1.1  (0.0-3.0) | 2.5  (1.0-4.0) | **-** | 6 | 1.4  (0.5-2.5) | 2.2  (0.5-4.0) |
| Rust (%) at 60 DAS | 9 | 1.8  (0.0-11.0) | 5.6  (0.0-22.0) | **-** | 4 | 0.3  (0.0-1.0) | 0.3  (0.0-1.0) |
| Smut (%) at 60 DAS | **-** | **-** | **-** | **-** | 4 | 3.6  (0.0-9.5) | 4.0  (0.0-9.5) |
| Ergot (%) at 60 DAS | **-** | **-** | **-** | **-** | 2 | 1.8  (0.0-3.5) | 2.5  (2.0-3.0) |

Figures in parenthesis are range

**DM:** 0.1-5.0 % highly resistant; 5.1-10.0% moderately resistant; 10.1-25.0% Susceptible; >25% highly susceptible

**Blast** 1.0-3.0 score resistant; 3.1-5.0 score moderately resistant; 5.1-7.0 score susceptible; > 7 score highly susceptible

**Rust:** 0.0 to 20.00% resistant; 21.0 to 25.0% moderately resistant; >25.0% susceptible

**Table 4: The reaction of insect-pest incidence on pearl millet hybrid GHB 538 Improved in comparison with a check**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Disease** | **State Trials**  **(*Kharif* 2018-2020)** | | | **AICRP on Pearl Millet Trials**  **(*Kharif* 2021 & 2022)** | | |
| **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** | **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** |
| Shoot fly incidence at the vegetative stage (%) | 3 | 2.5  (0.0-5.0) | 8.2  (6.4-11.1) | 5 | 4.4  (0.0-6.7) | 4.7  (0.0-8.2) |
| Shoot fly incidence at the earhead stage (%) | 3 | 3.8  (1.7-5.8) | 5.8  (3.6-8.8) | 5 | 3.5  (0.0-11.9) | 2.8  (0.0-4.9) |
| Stem borer incidence at the vegetative stage (%) | 3 | 4.8  (3.3-10.3) | 13.8  (11.3-22.5) | 2 | 0.0 | 0.4  (0.0-0.8) |
| Stem borer incidence at the earhead stage (%) | 3 | 4.0  (3.5-6.8) | 11.4  (3.8-10.3) | 2 | 2.5  (0.0-5.0) | 1.2  (0.5-1.9) |
| *Helicoverpa* larvae per 5 earheads | 3 | 0.3  (0.0-2.0) | 2.0  (0.0-4.0) | 4 | 0.9  (0.0-1.7) | 2.0  (0.5-3.7) |
| Leaf roller damage score at the earhead stage | **-** | **-** | **-** | 1 | 2.5 | 2.0 |

Figures in parenthesis are range

**Shootfly and stem borer:** 0.0% resistant; 0.1 to 5.0% moderate resistant; 5.1 to 10.0% tolerant; 10.1-20.0% susceptible; > 20.0% highly susceptible

***Helicoverpa* damage:** < 1 larva per 5 ear heads resistant; 1 to 5 larvae per 5 ear heads tolerant; 5.1 to 25 larva per 5 ear heads: susceptible

Table 5 mentions important ancillary traits of GHB 538 Improved with check hybrid at state and AICRP trials. The GHB 538 Improved earhead length increased and recorded 22.3 cm and 24.0 cm, without any change in days to 50% flowering (44 and 45 days).

The GHB 538 Improved, being an EDV version of the original GHB-538, retains its hallmark of early maturity (both improved version and original matures in 78 days) and its recorded plant height (196 and 172 cm), number of productive tillers per plant (3.0 and 2.4), earhead diameter (2.4 and 2.7 cm) and 1000-grain weight (9.2 and 8.8 g) at state and AICRP trials, respectively (Table 4). Additionally, its grain contains iron (53.0 and 43.3 ppm) and zinc (40.0 and 32.6 ppm) in the state as well as AICRP trials, respectively (Table 6), which are higher than the decided minimum benchmark level (Fe 42 ppm and Zn 32 ppm). This Improved hybrid has the same consumer-preferred grain color as the original hybrid. A similar type of work was found in pearl millet, and first successful hybrid was developed. The commercial deployment of a DM-resistant improved version of HHB 67 through MAB was done in India [14,15].

**Table 5: Ancillary traits of pearl millet hybrid GHB 538 Improved along with a check**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Disease** | **State Trials**  **(*Kharif* 2018-2020)** | | | **AICRP on Pearl Millet Trials**  **(*Kharif* 2021 & 2022)** | | |
| **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** | **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** |
| Days to 50% flowering | 10 | 44 | 44 | 15 | 45 | 45 |
| Days to maturity | 10 | 78 | 78 | 14 | 78 | 78 |
| Plant height (cm) | 10 | 196 | 185 | 19 | 172 | 168 |
| No. of productive tillers/plant | 10 | 3.0 | 3.0 | 18 | 2.4 | 2.4 |
| Earhead length (cm) | 10 | 22.3 | 20.5 | 19 | 24 | 22 |
| Earhead diameter (cm) | 10 | 2.4 | 2.5 | 17 | 2.7 | 2.7 |
| 1000-grain weight (g) | 10 | 9.2 | 9.0 | 17 | 8.8 | 8.7 |

**Table 6: Grain biochemical parameters of pearl millet hybrid GHB 538 Improved along with a check**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Disease** | **State Trials**  **(*Kharif* 2018-2020)** | | | **AICRP on Pearl Millet Trials**  **(*Kharif* 2021 & 2022)** | | |
| **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** | **No. of trials** | **GHB 538 Improved** | **GHB-538 (c)** |
| Iron content (ppm) | 4 | 53.0 | 52.0 | 12 | 43.3 | 47.3 |
| Zinc content (ppm) | 4 | 40.0 | 42.0 | 12 | 32.6 | 33.0 |
| Protein (%) | 4 | 8.4 | 7.5 | 2 | 12.2 | 10.7 |
| Fat (%) | 4 | 5.4 | 5.6 | 2 | 5.0 | 4.9 |
| Carbohydrate (%) | 4 | 78.6 | 76.2 | - | - | - |

**4. CONCLUSION**

GHB 538 Improved is a new version of earlier released early segment pearl millet hybrid GHB-538, which becomes susceptible to the DM disease; otherwise, is a very popular and good hybrid for its consumer-preferred grain color and preferable consumer traits. The efforts are taken for the improvement of the original early maturing pearl millet hybrid GHB-538 through marker-assisted backcrossing (MABC) and marker-assisted selection (MAS) by introgressing three downy mildew resistance QTLs from three chromosomes/linkage groups (LGs), *i.e.*, 1, 3 and 4 due to which an improved version that shows resistant to DM. Introgression of additional downy mildew resistance QTLs has not just enhanced downy mildew resistance. Still, it will also impart stability to downy mildew resistance and significantly improve the life span of GHB-538. The GHB 538 Improved shows significant improvement in downy mildew resistance under field conditions and an increase in yield over the original GHB-538 at state and national level trials. Further, it also shows resistance reaction to other diseases of pearl millet. The infestation of major insect-pest, *i.e.,* the stem borer, shoot fly and *helicoverpa,* is less than the check hybrid, so it comes under the resistant category.

**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.

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