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Biofortified pearl millet hybrid: GHB 1231 (Sawaj Shakti)

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Abstract
The Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar (Gujarat) developed the pearl millet biofortified hybrid GHB 1231 (Sawaj Shakti) from a cross combination of ICMA 11222 × J-2597 and released it at the state level for cultivation during the *kharif*, summer, and semi-*rabi* (post rainy) seasons. This hybrid was tested in multi-location trials across all three seasons against recommended national and state level checks for yield, Fe, and Zn and other biotic stresses. During the *kharif* season, this hybrid surpassed checks GHB-558, GHB-732, and Proagro 9444 by 26.18%, 9.22%, and 10.37%, respectively. Furthermore, during the summer, GHB 1231 outperformed the check hybrids GHB-558, GHB-732, and Proagro 9444 by 48.4%, 12.4%, and 5.5%, respectively, and also outperformed GHB-538 by 30.9% during the semi-*rabi* season. Furthermore, its Fe and Zn contents are comparable (Fe >70 ppm and Zn >40 ppm) to the identified biofortified check Dhanshakti. GHB 1231 exhibits a high level of resistance against downy mildew when compared to all of the checks performed throughout the testing period. It's also resists smut, ergot, blast, and rust. This hybrid has appealing panicle characteristics, high-quality stover, attractive grain colour, and lodging resistance. It also found higher resistance to helicoverpa, stem borer, and shoot fly in comparison to controls.

Keywords: GHB 1231, Sawaj Shakti, biofortified, pearl millet, micro-nutrient Fe-Zn

Introduction
Pearl millet is grown on 26 mha globally, of which 7.4 mha are in the most marginal arid and semiarid tropical regions of India, particularly in Maharashtra, Rajasthan, Gujarat, and Uttar Pradesh states (AICRP on Pearl Millet 2019). Pearl millet is mainly grown in *kharif* but in Gujarat it is also grown during summer season. In addition to this state have a large area where farmers grow pearl millet in the semi-*rabi* (Post Rainy). This area actually unrecorded and lays along the west cost of bay of Cambay particularly Gir Somnath and other adjoining districts.
More than two billion people globally are malnourished in terms of micronutrients (Mayer *et al.*, 2008) [5]. The most common types of malnutrition are those caused by iron (Fe), zinc (Zn), vitamin A, and iodine (I) deficiencies, which primarily affect women and children in developing countries. More than 40% of early age children in these nations are stunted due to Zn deficiency, while 30% are anaemic due to Fe deficiency (Belay *et al.*, 2021) [3]. Insufficient intake of any of these nutrients will result in unfavourable metabolic disruptions, resulting in disease, poor health, delayed development in children (Welch *et al.*, 2004) [8].
Pearl millet is a very important staple diet food for millions of people, as well as an essential source of dietary energy and nutritional security for the huge rural communities in these regions (Basavaraj *et al.*, 2010) [2]. Pearl millet is also the cheapest source of Fe and Zn, in addition to calories and protein (Parthasarathy *et al.*, 2006) [6]. Given its high nutritional value, pearl millet can contribute significantly to improve the nutritional status of millions. All of the released and commercially cultivated pearl millet, however, has low amounts of micronutrients, particularly Fe (42 mg kg^{-1}) and Zn (32 mg kg^{-1}) (Govindaraj *et al.*, 2019) [4]. Crop biofortification, which refers to the breeding of cultivars with higher levels of micronutrients, is increasingly being recognized as a cost-effective and sustainable approach to overcome these deficiencies in the food chain. The wide range variations in Fe and Zn content, as well as their genetic inheritance, are well known (Pujar *et al.*, 2020) [7]. These two micronutrients are controlled by additive-effect genes (Govindaraj *et al.*, 2019) [4]. Among the micronutrients, Fe and Zn can be significantly enhanced through biofortification breeding.
Looking to above facts, the work on development of high Fe and Zn content hybrids has been intensified at pearl millet research station, JAU, Jamnagar in collaboration with ICAR and ICRISAT which resulted into GHB 1231 (Sawaj Shakti), a biofortified high Fe and Zn content

hybrid which has been released at state level for three seasons *viz*., *kharif*, summer and semi *rabi*.

Materials and Methods

The pearl millet hybrid GHB 1231 is a biofortified hybrid developed by heterosis breeding at Pearl Millet Research Station, JAU, Jamnagar. It is a cross combination of $ICMA_1$ 11222 × J-2597 and the female line $ICMA_1$ 11222 is developed at ICRISAT. The restorer line has been developed at Pearl Millet Research Station, JAU, Jamnagar by necessary bulking/selection, fertility restoration ability and screening against biotic stresses and designated as a J-2597 in the year 2017. The hybrid GHB 1231 has been tested against national and state level recommended yield and biofortified checks from 2017 to 2019 during rainy (*kharif*) season and 2018 to 2021 during summer as well as semi *rabi* (season at different location of Gujarat. It has been also tested as a testing code MH-2365 at national level under AICRP on Pearl Millet trials during *kharif* 2018 at across the 20 different location of A zone and 17 different locations of B zone of India and during summer 2019, tested with testing code MSH 357 across the 12 different location of India. The recommended package of practices were followed to conduct the trial and to raise the good crop condition.

Fig 1: The grains of this hybrid have higher GHB 1231

Table 1: Yield data of large scale hybrid trial

Name of hybrid	No. of trials/Locations	Average grain yield (kg/ha)	% increase over	Average dry fodder yield (kg/ha)	% increase over
***Kharif* (2017-19)**					
GHB 1231	13	2916	-	7545	-
GHB 1231	20	2760	-	7471	-
GHB 1231	15	2771	-	7277	-
GHB 558 (c)	13	2311	26.18	6123	23.23
GHB 732 (c)	20	2527	9.22	6434	16.12
Proagro 9444 (c)	15	2511	10.37	6272	16.02
Average yield under normal condition			Grain: 2760 kg/ha, Dry fodder: 7471 kg/ha		
Summer (2018-20)					
GHB 1231	12	5737	-	8193	-
GHB 558 (c)	12	3866	48.40	6444	27.10
GHB 732 (c)	12	5102	12.40	7624	7.50
Proagro 9444 (c)	12	5441	5.50	8703	-
Average yield under normal condition			Grain: 5737 kg/ha, Dry fodder: 8193 kg/ha		
Semi *rabi* (2018-20)					
GHB 1231	3	4485	-	8212	-
GHB 538 (c)	3	3426	30.90	7072	16.10
Average yield under normal condition			Grain: 4485 kg/ha, Dry fodder: 8212 kg/ha		

Table 2: Data of Fe and Zn content of GHB 1231 with check hybrids

Name of Hybrid	Fe Content (ppm)			Zn Content (ppm)		
	2018	2019	Mean	2018	2019	Mean
***Kharif* (N=21)**						
GHB 1231	81.0	80.0	80.5	41.0	41.0	41.0
GHB 558 (c)	55.0	-	55.0	37.0	-	37.0
GHB 732 (c)	52.0	55.0	53.5	30.0	35.0	32.5
Proagro 9444 (c)	56.0	53.0	54.5	33.0	35.0	34.0
Dhanshakti (c)	96.0	88.0	92.0	43.0	41.0	42.0
Semi *rabi* (N=3)						
GHB 1231	73.4	75.6	74.5	42.1	43.2	42.7
GHB 558 (c)	40.3	43.5	41.9	30.6	32.7	31.7

Summer (N=3)	2018	2019	2020	Mean	2018	2019	2020	Mean
GHB 1231	64.5	72.0	75.0	70.5	39.5	39.8	44.0	41.1
GHB 558 (c)	49.6	56.8	52.0	52.8	33.6	37.7	32.0	34.4
GHB 732 (c)	43.4	49.5	44.5	45.8	31.3	29.3	29.0	29.8
9444 (c)	40.2	48.4	45.0	44.5	32.8	32.3	34.0	33.0
Dhanshakti (c)	80.1	90.0	88.0	86.0	46.6	46.2	48.0	46.9

Table 3: Data on grain quality parameter of proposed hybrid GHB 1231 in comparison with checks

Name of hybrid	Protein (%)	Fat (%)	Carbohydrate (%)
Kharif			
GHB 1231	11.78	4.78	73.73
GHB 558 (c)	9.74	5.68	69.98
GHB 732(c)	10.07	4.41	71.50
Dhanshakti (c)	11.13	3.42	74.65
Proagro 9444 (c)	10.35	4.95	70.37
Summer			
GHB 1231	10.90	6.30	77.22
GHB-558 (c)	11.73	6.42	75.83
GHB-732(c)	10.30	5.90	74.15
Proagro 9444 (c)	9.94	5.70	80.21
Dhanshakti (c)	9.99	5.93	79.91

Table 4: The reaction of disease incidence under artificially epiphytotic condition

Name of hybrid	Downy mildew (%) at 60 DAS	Blast (Score 0-9)	Rust (%)
***Kharif* (2017-19) Location : 3 (Jamnagar, Anand and S. K. Nagar)**			
GHB 1231	3.0 (1.0-4.5)	1.4 (0.8-2.7)	0.0
GHB 558 (c)	5.3 (2.0-7.6)	1.7 (0.9-4.1)	2.3 (0-5.8)
GHB 732 (c)	6.5 (4.0-11.4)	1.3 (0.8-2.2)	0.0
Dhanshakti (c)	4.0 (1.4-7.2)	7.4 (1.3-15.4)	1.0 (0-2.5)
Proagro 9444 (c)	6.4 (0-11.5)	2.0 (1.5-2.6)	0.0
7042 S-Indicator	94.9 (94.2-96.1)	5.1 (3.7-6.5)	-
Summer (2018-20) Location : 3 (Jamnagar, Anand and S. K. Nagar)			
GHB 1231	0.0	0.0	0.0
GHB 558 (c)	0.6 (0-1.9)	0.0	0.0
GHB 732 (c)	5.6 (0-19.0)	0.0	0.0
Proagro 9444 (c)	0	0.0	0.0
7042 S-Indicator	92.06 (90.8-94.1)	0.0	-
Semi *rabi* Location : 1 (Kodinar under natural condition)			
GHB 1231	0.0	0.0	17.3 (14.1-19.0)
GHB 538 (c)	0.0	0.0	24.9 (12.2-31.3)

Figure in parenthesis range**; DM:** 0.1-5.0% highly resistant, 5.1-10.0% moderately resistant, 10.1-25.0% Susceptible, >25% highly susceptible; **Blast:** 1-3.0 score resistant; 3.1-5.0 score moderately resistant, 5.1-7.0 score susceptible and > 7 score highly susceptible**; Rust:** 0.1 to 33.3% resistant; 33.4 to 55.5% moderately resistant, 55.6 to 77.7% susceptible

Table 5: The reaction of insect-pest incidence of proposed hybrid GHB 1231 comparison with checks

Name of hybrid	Shoot fly at earhead stage (%)	Stem borer at earhead stage (%)	*Helicoverpa* larvae per 5 Earheads
***Kharif* (2017-19) Location : 3 (Jamnagar, Anand and S. K. Nagar)**			
GHB 1231	0	0.9 (0-1.7)	3.7 (0.5-9.0)
GHB 558 (C)	6.9 (4.2-10.3)	11.4 (6.7-16.6)	5.0 (3.0-7.5)
GHB 732(C)	4.4 (1.7-7.1)	6.6 (3.3-10.5)	4.0 (3.0-5.5)
Dhanshakti(C)	9.4 (5.7-12.1)	10.8 (3.3-18.4)	4.2 (2.5-6.5)
9444(C)	7.8 (0.6-15.0)	2.8 (0.6-5.0)	5.5 (5.5-5.5)

Summer (2018-20) Location : 3 (Jamnagar, Anand and S. K. Nagar)			
GHB 1231	0.2 (0-1.3)	0.7 (0-1.3)	0.7 (0-2.0)
GHB 558 (C)	3.8 (1.3-11.7)	1.6 (0-2.7)	0.7 (0.7-2.0)
GHB 732(C)	4.7 (1.3-8.8)	1.3 (0-5.4)	0.7 (0.7-2.0)
9444(C)	2.9 (0-8.9)	0.9 (0-2.7)	1.0 (1.0-2.0)

Figures in parenthesis range; Shootfly and stem borer: Less than 1% resistant, 1.1 to 5.0% tolerant, 5.1 to 10.0% susceptible; Heliothis damage limit: < 1 larva per 5 ear heads: resistant, 1 to 5 larva per 5 ear heads: tolerant and 5.1 to 25 larva per 5 ear heads: susceptible.

Table 6: Morphological traits of proposed hybrid GHB 1231 along with checks (As per DUS guidelines)

Sr.	Characters	GHB 1231	GHB-732(C)	GHB-538(C)
1	Plant anthocynin pigmentation of 1st leaf sheath	Absent	Present	Present
2	Plant: Growth habit (30 DAS)	Erect	Erect	Erect
3	Time of spike emergence (days)	Late	Late	Early
4	Leaf: Sheath pubescence	Absent	Absent	Absent
5	Leaf: Sheath length (cm) (forth leaf from top)	Long	Medium	Short
6	Leaf: Blade length (cm) (forth leaf from top)	Very long	Medium	Medium
7	Leaf: Blade width (cm) (forth leaf from top)	Broad	Medium	Medium
8	Spike: Stigma pigmentation	Absent	Absent	Absent
9	Spike: Anther colour	Purple	Purple	Light brown
10	Plant: Node pubescence	Absent	Present	Absent
11	Plant: Number of node	Medium	Low	Low
12	Plant: Node pigmentation	Green	Green	Green
13	Plant: Internode pigmentation	Green	Green	Green
14	Spike exertion	Complete	Complete	Complete
15	Spike: Length (cm)	Medium	Medium	Medium
16	Spike: Anthocynin pigmentation of glume	Absent	Absent	Absent
17	Spike: Bristle	Absent	Absent	Absent
18	Spike: Bristle colour	NA	NA	NA
19	Spike: Bristle apperance	NA	NA	NA
20	Spike: Diameter (cm)	Thick	Medium	Medium
21	Plant: Number of productive tillers	Low	Medium	Medium
22	Plant: Height(including spike) (cm)	Tall	Medium	Medium
23	Spike: Shape	Conical	Lanceolate	Cylindrical
24	Spike: Tip sterility	Absent	Absent	Absent
25	Spike: Density	Compact	Compact	Compact
26	Seed: Colour	Yellow Brown	Grey brown	Light grey
27	Seed: Shape	Hexagonal	Globular	Globular
28	Seed: Weight of 1000-grains (g)	Bold	Medium	Medium

Results and Discussion

The pearl millet hybrid GHB 1231 (Sawaj Shakti) is a biofortified late maturing group hybrid. It has recorded higher average grain yield over presently recommended relevant group check hybrid GHB-558 (26.18%), latest relevant group hybrid GHB-732 (9.22%) and private sector relevant group check hybrid Proagro 94444 (10.37%) during *kharif* season. It has also recorded 23.23% and 16.12% higher dry fodder yield over relevant checks GHB 558 and GHB 732, respectively and 16.02% higher dry fodder yield over private sector late type check Proagro 9444 during *kharif* season. In the summer season, this hybrid also given 48.4%, 12.4% and 5.5% higher grain yield over check hybrids GHB-558, GHB-732 and Proagro 9444, respectively. The dry fodder increase of GHB 1231 over check hybrids during summer season was to the tune of 27.10% and 7.5% over GHB 558 and GHB 732, respectively. In the coastal region during semi *rabi* (post rainy) season this hybrid given 30.9% and 16.1% higher grain and dry fodder yield, respectively over recommended semi *rabi* check hybrid GHB 538 (Table 1). Additionally, the grains of this hybrid have higher amount of important micronutrient Fe (iron) and Zn (Zinc) over all the public and private sector check and comparable with biofortified check variety Dhanshakti (Table 2).

The pearl millet hybrid GHB 1231 has been tested as a testing code MH 2365 in AICRP on Pearl Millet during *kharif* 2017 across the 20 different location of A zone and 17 different locations of B zone of India. In A zone, it gave 3369 kg/ha average grain yield which was at par with check hybrids 86M86 and MP 7792 and average dry fodder yield 10800 kg/ha which was 6.93% higher than check hybrid MP 7792. This hybrid also tested during summer 2019 as a testing code MSH 357 in AICRP on Pearl Millet SHT across the 12 different location of India. It is recorded 4500 kg/ha average grain yield which was at par with check hybrids 86M64 and proagro 9444 and average dry fodder yield 7950 kg/ha which was 6.6% higher than check hybrid 86M86.

This hybrid found resistant against downy mildew when tested under sick plot condition at different locations during *kharif* as well as summer (Table 4). It is also found resistance against blast, smut and rust. The ergot and smut was not observed during its testing period. This hybrid also found more resistant against pearl millet major insect-pest *viz.*, shoot fly was not observed at earhead stage, stem borer at earhead stage (0.9%) and *helicoverpa* (3.7 larvae/5 earhead) as compared to checks under natural condition during both seasons (Table 5). Further, this hybrid also found resistance against lodging when tested against its checks during three testing season.

This hybrid have more Fe and Zn content to be qualified as high Fe and Zn content biofortified hybrid (Table 2). The grain size of GHB 1231 is medium/bold and the grain colour is attractive having good consumer preference and good quality of chapatti. The grain quality parameters indicated

that, this hybrid possess good or comparable quality parameters when tested against its checks (Table 3).
The mean ancillary data of this hybrid recorded during *kharif*, summer and semi *rabi* seasons was days to 50% flowering (53, 54, 54), days to maturity (82, 84, 104), plant height in cm (212, 187, 183), number of effective tiller per plant (2.5, 3, 5), earhead diameter in cm (3.2, 3.5, 3.8), earhead length in cm (24.5, 27.4, 26.3), 1000-grain weight in g (8.9, 10.2, 10.6) respectively. The distinguish morphological traits of GHB 1231 as per DUS guidelines in comparison with checks hybrids GHB 732 and GHB 538 are mentioned in Table 6.

Conclusion
GHB 1231 has higher grain yield and dry fodder yield over latest relevant public sector and private sector check. Furthermore, its Fe and Zn contents are comparable (Fe >70 ppm and Zn >40 ppm) to those of the identified biofortified check Dhanshakti. The parental lines of this hybrid are well-synchronized, and hence hybrid seed production is not problematic. In comparison to all the checks over the testing period, GHB 1231 has a high level of resistance to downy mildew. Additionally, it is resistant to smut, ergot, blast and rust. This hybrid possesses appealing panicle features, good quality stover, consumers preferred grain colour and lodging resistance trait. In comparison to controls, it also found increased resistance to *helicoverpa*, stem borer and shoot fly. Finally, the dual purpose, high yielding, late type, biofortified hybrid GHB 1231 (Sawaj Shakti) released and recommended for three seasons i.e., *kharif*, summer and semi *rabi* of pearl millet growing farmers of Gujarat.

Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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