



Assessment of Drought Stress of Two Genotypes of Sorghum (*Sorghum bicolor* L.) Using Physiological Parameters

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present experiment conducted in the period of rabi season at Sorghum Improvement Project, M.P.K.V., Rahuri, Maharashtra during the period of 2016 to 2017. During investigation to observed the physiological parameters under non stress and moisture stress condition with cross two genotypes SPV 1830 x IS 6427. In this study of mean performance of the basic generation P1, P2, F1, F2, B1 and B2 of the cross SPV 1830 x IS 6427 was observed various physiological parameters viz. photosynthetic rate, rate of transpiration, stomatal conductance, relative leaf water

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content, SPAD reading, total chlorophyll content and chlorophyll stability index. The present results to observed the B₂ and F₁ generation recorded significantly highest photosynthesis rate (25.98 and 22.47 μ mole CO₂ m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The parent B₁ recorded highest transpiration rate (3.27 and 1.92 mmole H₂O m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The F₁ and B₁ generation recorded significantly the highest mean for stomatal conductance (0.24 and 0.18 mole m⁻² s⁻¹) under non stress condition and moisture stress condition, respectively. The B₁ generation recorded the highest total chlorophyll content (3.30 and 2.08 %) under non stress and moisture stress condition, respectively. The present experimental study to observe physiological parameters of sorghum cross two genotype (SPV 1830 x IS 6427) directly affected in growth and grain yield under non-stress and moisture stress condition. Therefore, present study to find out the drought stress effects on sorghum through the physiological parameters.

Keywords: Non-stress; moisture stress; sorghum; physiological parameters.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important crop in the world. It is a staple food crop of millions of poor people in semi-arid tropics of Africa and Asia. It has gained increasing importance as a fodder (green/dry) and food crop in the last decades. It is cultivated as a major crop in areas with marginal growing conditions such as poor soil fertility and erratic rainfall by Bibi et al. [1]. Dial HL [2] reported that drought reduces production of sorghum crop and risks the wellbeing, livelihood as well as food security in many developing countries. The drought stress effects on the physiology of plants by reducing water content, causing wilting, closing of stomata and decreasing cell enlargement and growth by Taiz and Zeiger [3]. Mostly the effect of drought depends up on its timing of occurrence, duration and intensity, it can accelerate leaf senescence and lead to death of leaf tissue Prasad et al. [4]. Moreover, water deficit results in decreasing leaf expansion and leaf area which results from biophysical effect of turgor pressure Taiz and Zeiger [3]. Drought tolerance mechanism can be studied based on the interpretation of relationship between leaf structure function and stress tolerance reported by Tambe et al. [5] and [6]. As per the IPCC (Intergovernmental Panel on Climate Change-2021) mentioned that rainfall patterns in sorghum growing areas will be highly variable. In addition, Prasad et al [4] reported that the climate change effects would be abrupt change in rainfall patterns in the next four decades combined with the risk of high temperature, which will intensify the drought stress. The extensive adaptability has in sorghum and it can be grown in various series of environment including heat, drought, salinity and flooding mentioned by Ejeta and Knoll [7].

Among the abiotic stress, drought is most important yield limiting factor in *rabi* sorghum. Drought tolerance is a complex trait, expression of which depends on action and interaction of different morphological, physiological and biochemical traits, therefore it is necessary to know the genetics as well as morpho-physiological parameters related with drought tolerance. Despite the progress in sorghum breeding, only limited information is available on inheritance pattern and genetic basis of drought tolerance. During the past three decades high yielding varieties and hybrids have been developed in India. However, the desired increase in production could not be achieved due to erratic rainfall. In recent years research on plant response to water stress is becoming most important aspect Petit et al. [8]. The crop productivity and plant survival are threatening due to water deficit coupled with high temperature. With increasing aridity and growing population water will become an ever limiting factor in near future. A better understanding of effects of drought on plants is an important for management practices and breeding efforts in agriculture. A progress is made on the interpretation of relationship between leaf structure, function by Valladares and Pearcy, [9] and stress tolerance Jackson et al. [10].

Kadam et al., [11] reported that soil moisture content decreased gradually from sowing to harvesting and it was negatively correlated with grain yield. However, some other physiological parameters as like photosynthesis rate, rate of transpiration, stomatal conductance, relative leaf water content, SPAD reading and total chlorophyll content or index are also effects on crops growth and yields. So, above mentioned facts indicate that the irregular water condition, water temperature and physiological properties

are associated with effects on sorghum yield by Kadam et al.[11] and Tambe et al.[6]. For that reason, present study to understanding for mechanism that are directly and indirectly affected by physiological characters in sorghum. Moreover, it will also find out that physiological characters impressive parameter to improve and utilization in the sorghum variety or hybrids of breeding programs. The main aim of any plant breeding programme is to develop high yielding varieties or hybrids. To accomplish this, the breeding programme can efficiently be planned with prior knowledge of the genetic makeup of complex quantitative characters like yield and its attributes. It is therefore necessary to examine the genetic architecture of various quantitative characters in relation to breeding behaviour of the genetic material available. Therefore, present investigation to study the physiological parameters with cross SPV1830 x IS-6427 under two different conditions viz., non stress and moisture drought stress condition in the rabi sorghum. Moreover, it will also find out that physiological characters impressive parameter to improve and utilization in the sorghum variety or hybrids of breeding programs. Overall the main purpose of this study to evaluation of drought stress of sorghum genotypes by using physiological characteristic.

2. MATERIALS AND METHODS

The present research work was carried out in the Sorghum Improvement Project, M.P.K.V., Rahuri Maharashtra during the rabi season 2016-2017 under non stress and moisture stress condition. Present study of mean performance of the basic generations P1, P2, F1, F2, B1 and B2 of the two genotypes cross SPV 1830 x IS 6427 showed physiological parameters viz. photosynthetic rate, rate of transpiration, stomatal conductance, relative leaf water content, SPAD reading, total chlorophyll content and chlorophyll stability index. The experimental design employed a randomized complete block design (RCBD) with three replications and each replication has three rows. Present study following are the methods used for physiological parameters.

Photosynthetic rate, transpiration rate and stomatal conductance was estimated as per Tambe et al. [12]. The photosynthetic rate (μ mole CO₂ m⁻²s⁻¹), transpiration rate (mmole H₂O m⁻²s⁻¹) and stomatal conductance (mole m⁻² s⁻¹) were measured using Infra-Red Gas Analyzer (IRGA; Model Portable Photosynthesis

System LI6400, LI-COR® Inc, Lincoln, Nebraska, USA). Relative leaf water content was estimated as per Barrs and Weatherly, [13] at 50 percent flowering. Twenty leaf discs of third fully expanded leaf from the top were collected and weighted on an electronic balance, and fresh weight was determined. The relative leaf water content (RLWC) was calculated in percentage by using the following formula.

$$\text{Relative Leaf water content (\%)} = \frac{\text{Fresh weight (g)} - \text{dry weight (g)}}{\text{Turgid weight (g)} - \text{dry weight (g)}} \times 100$$

SPAD (Soil Plant Analytical Development) chlorophyll meter reading (SPAD 502; Minolta Company Ltd) measures the greenness or relative chlorophyll content of the leaves. Measurements were taken at three points of each leaf (upper, middle and lower parts). Average of these three readings was considered as SPAD reading of the leaf. SPAD reading was carried out at 50% flowering in the third leaf to the top of the plant. The readings were taken between 10.00 to 12.00 hours of the day. Total chlorophyll content was determined by following DMSO method of Hiscox and Israeltam [14] at 50 percent flowering. The total chlorophyll content was calculated by using the following formula and expressed in mg g⁻¹ fresh weight.

$$\text{Total chlorophyll} = 20.2 (A645) + 8.02 (A663) \times V / 1000 \times W$$

Where,

A645 = Absorbance of the extract at 645 nm

A663 = Absorbance of the extract at 663 nm

W = Fresh weight of the sample (g)

V = Final volume of the chlorophyll extract (ml).

The chlorophyll stability index was computed by using the methodology proposed by Arnon [15].

$$\Delta R = \text{Reading without heating} - \text{Reading after heating at } 560\text{C.}$$

Where, ΔR = CSI

3. RESULTS AND DISCUSSION

In the present investigation to observed the mean performance of the basic generations P1, P2, F1, F2, B1 and B2 of the cross SPV 1830 x IS 6427 showed physiological parameters viz.

photosynthetic rate, rate of transpiration, stomatal conductance, relative leaf water content, SPAD reading, total chlorophyll content, chlorophyll stability index are presented in following Tables 1 to 4. In this study, we find out that this two genotype cross SPV 1830 x IS 6427 of sorghum growing under non stress and moisture stress condition is directly effects on its physiological parameters. So, all details explanation about all physiological parameters are explain in described in below.

3.1 Photosynthetic Rate

The present study for cross SPV 1830 x IS 6427 the photosynthesis rate ranged from 20.97 to 25.98 with the mean of 22.91 μ mole CO₂ m⁻²s⁻¹ and 19.06 to 22.47 with the mean of 20.71 μ mole CO₂ m⁻²s⁻¹ under non stress and moisture stress condition, respectively (Table 1). The B₂ and F₁ generation recorded significantly highest photosynthesis rate (25.98 and 22.47 μ mole CO₂ m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The high yielding generation possessed higher rate of photosynthesis indicating the importance in determining the productivity. Similar findings were also reported by Tambe et al.,[12], Narkhede et al. [16] and Gadakh et al. [17].

3.2 Transpiration Rate

Transpiration rate is an important bio-physical trait which helped to gas exchange. It showed that the stressed leaves showed decline in transpiration rate over non stressed leaves of different *rabi* sorghum generations (Table 1). In the present investigation for cross SPV 1830 x IS 6427 the mean transpiration rate under non

stress condition was 1.43 mmole H₂O m⁻²s⁻¹ and was reduced to 0.89 mmole H₂O m⁻²s⁻¹ under moisture stress condition. The parent B₁ recorded highest transpiration rate (3.27 and 1.92 mmole H₂O m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The F₂ generation was recorded the lowest transpiration rate (2.47 and 1.66 mmole H₂O m⁻²s⁻¹) under moisture stress condition, respectively. It showed that the stressed leaves showed decline in transpiration rate over non stressed leaves of different *rabi* sorghum generations (Table 1). The variations in transpiration rate were also reported by Tambe et al. [6], Narkhede et al. [16] and Shinde et al. [18].

3.3 Stomatal Conductance

The rate of stomatal conductance (Table 2) was observed more in non stress than that in moisture stress condition. The data also indicated that the generations differ significantly in respect of stomatal conductance rate under non-stress stress and moisture stress condition. For cross SPV 1830 x IS 6427, the stomatal conductance ranged from 0.20 to 0.24 and 0.15 to 0.18 mole m⁻² s⁻¹ under non stress and moisture stress condition, respectively. The F₁ and B₁ generation recorded significantly the highest mean for stomatal conductance (0.24 and 0.18 mole m⁻² s⁻¹) under non stress condition and moisture stress condition, respectively. The high yielding generations possessed higher rate of stomatal conductance indicating the importance in determining the productivity. Tambe et al. [12] and Gadakh et al. [19] was observed a similar results in the stomatal conductance under non-stress and moisture stress condition.

Table 1. Rate of Photosynthesis and Rate of Transpiration in the leaves of different generations of *rabi* sorghum cross SPV 1830 x IS 6427 under non stress and moisture stress condition

Sr. No.	Generations	Rate of Photosynthesis (μ mole CO ₂ m ⁻² s ⁻¹)			Rate of Transpiration (mole H ₂ O m ⁻² s ⁻¹)		
		Non Stress	Moisture Stress	Per cent Decrease	Non Stress	Moisture Stress	Per cent Decrease
1	P ₁	21.77	19.73	9.37	2.95	1.90	35.59
2	P ₂	22.25	19.99	10.16	2.75	1.70	38.18
3	F ₁	24.54	22.47	8.43	3.11	1.87	39.87
4	F ₂	20.97	19.06	9.11	2.47	1.66	32.79
5	B ₁	23.06	21.96	4.77	3.27	1.92	41.28
6	B ₂	25.98	19.98	23.09	2.86	1.79	37.00
Mean		22.91	20.71		1.432	0.89	
SE±		0.19	0.21		0.021	0.02	
CD at 5%		0.60	0.67		0.065	0.07	

Table 2. Stomatal Conductance and Relative leaf water content (RLWC) in the leaves of different generations of rabi sorghum cross SPV 1830 x IS 6427 under non stress and moisture stress condition

Sr. No.	Generations	Stomatal Conductance (mole m ⁻² s ⁻¹)			Relative leaf water content (RLWC) (%)		
		Non Stress	Moisture Stress	Per cent Decrease	Non Stress	Moisture Stress	Per cent Decrease
1	P ₁	0.23	0.15	34.78	77.68	67.83	12.68
2	P ₂	0.22	0.14	36.36	71.00	61.59	13.25
3	F ₁	0.24	0.17	29.17	80.42	70.62	12.19
4	F ₂	0.20	0.16	20.00	71.51	62.03	13.26
5	B ₁	0.22	0.18	18.18	81.01	71.13	12.20
6	B ₂	0.20	0.16	20.00	75.02	67.72	9.73
Mean		0.22	0.16		76.11	66.82	
SE±		0.004	0.003		1.97	1.86	
CD at 5%		0.01	0.01		6.22	5.86	

Table 3. SPAD Value and Total Chlorophyll Content in the leaves of different generations of rabi sorghum cross SPV 1830 x IS 6427 under non stress and moisture stress condition

Sr. No.	Generations	SPAD Value			Total Chlorophyll Content (mg g ⁻¹ FW)		
		Non Stress	Moisture Stress	Per Cent Decrease	Non Stress	Moisture Stress	Per Cent Decrease
1	P ₁	50.68	42.01	17.10	2.68	1.72	35.82
2	P ₂	50.45	41.37	17.99	2.66	1.68	36.84
3	F ₁	51.08	42.43	16.93	3.29	2.06	37.39
4	F ₂	53.24	43.35	18.58	2.87	1.83	36.24
5	B ₁	52.01	43.05	17.23	3.30	2.08	36.97
6	B ₂	50.16	39.33	21.59	2.99	1.87	37.46
Mean		51.27	41.92		2.96	1.87	
SE±		0.50	0.59		0.07	0.05	
CD at 5%		1.58	1.87		0.23	0.16	

Table 4. Chlorophyll Stability Index in the leaves of different generations of rabi sorghum cross SPV 1830 x IS 6427 under non stress and moisture stress condition

Sr. No.	Generations	Chlorophyll Stability Index (%)		
		Non stress	Moisture stress	Per cent decrease
1	P ₁	31.99	28.03	12.38
2	P ₂	26.87	23.40	12.91
3	F ₁	32.67	29.65	9.24
4	F ₂	28.90	25.66	11.21
5	B ₁	33.06	30.04	9.13
6	B ₂	28.66	25.59	10.71
Mean		30.36	27.56	
SE±		0.61	0.73	
CD at 5%		1.92	2.30	

3.4 Relative Leaf Water Content (%)

The mean relative leaf water content for the cross SPV 1830 x IS 6427 the parents and different generations of sorghum under non stress was 76.11 % and it reduced to 66.82 %

under moisture stress condition. The B₁ generation recorded significantly the highest relative leaf water content (81.74 and 71.74 %) and in different generations highest relative leaf water content was recorded in F₁ and B₂ generations (81.01 and 74.42 %) under non

stress and moisture stress condition, respectively. Among the segregating generation, the per cent reduction in RLWC varied from as low as 9.73 % in B₂ generation to as high as 13.26 % in F₂ generation. The control of stomatal aperture is one of the major mechanism by which plant regulates water status. Water status of a plant is a measure of drought tolerance and it could be conveniently studied in term of relative leaf water content (RLWC). Relative leaf water potential is very important phenomenon as retention of water in the leaf under moisture stress condition is a major indication of drought tolerance. The present investigation (Table 2), revealed that in crosses SPV 1830 x IS 6427 the moisture stressed plant has lower relative water content than non- stressed. These finding are in agreement with the findings of Tambe et al [12], Narkhede et al [20] and Kachare [19].

3.5 Spad Reading

In cross SPV 1830 x IS 6427, the mean SPAD reading at 50% flowering was recorded 51.27 and 41.92 under non stress and moisture stress condition, respectively (Table 3). The segregating generation F₂ recorded significantly the highest SPAD reading (53.24 and 43.35) under non stress condition and moisture stress condition, respectively. Amongst the segregating generations, the per cent reduction in SPAD reading varied from as low as 16.93 per cent in F₁ generation to as high as 21.59 per cent in B₂ generation. The variation in SPAD chlorophyll reading is depends on greenness of leaves. The stay green genotypes recorded higher reading than non-stay green. Tambe et al [5] was reported as exact SPAD reading in cross RSV 1237 x RSV 1703. Similar result was also reported by Subudhi et al., [21].

3.6 Total Chlorophyll Content (MG G⁻¹FW)

Mean total chlorophyll content was less in water stress condition than non stress condition which may be due to adverse effect of water stress on plant metabolic processes (Table 3). In cross SPV 1830 x IS 6427, the mean total chlorophyll content at 50 per cent flowering was estimated 2.96 mg g⁻¹FW and 1.87 mg g⁻¹FW under non stress and moisture stress condition, respectively. Amongst the parents and different generations, the percent reduction in total chlorophyll content varied from as low as 35.82 per cent in P₁ (SPV 1830) to as high as 37.46 per cent in B₂ generation. The B₁ generation recorded the highest total chlorophyll content

(3.30 and 2.08 %) under non stress and moisture stress condition, respectively. According to Tambe et al., [5], Vinita et al., [22] and Deshmukh et al., [23] water stress leads to decline in total chlorophyll content. Their findings were in agreement with the observations recorded in the present investigation.

3.7 Chlorophyll Stability Index (%)

Chlorophyll stability is a function of temperature and found to correlate with drought tolerance. Chlorophyll stability index is a measure of integrity of membrane or heat stability of pigments under stress condition by Koleyoreas, [24]. The chlorophyll destruction commences rapid at control temperature of 55 to 56° C. Chlorophyll stability is an important trait which indicate an ability of genotype to survive under stress condition. The lower chlorophyll stability index is desirable parameter for drought tolerance in *rabi* sorghum genotypes. In the present investigation (Table 4), for cross SPV 1830 x IS 6427, the chlorophyll stability index (CSI) varied from 26.87 to 33.06 % under non stress and 23.40 to 30.04 % under moisture stress condition. Amongst the parents and different generations, the percent reduction in total chlorophyll content varied from as low as 35.82 per cent in P₁ (SPV 1830) to as high as 37.46 per cent in B₂ generation, indicate its drought tolerance capacity. The parent P₂ (IS 6427) recorded significantly the lowest chlorophyll stability index (26.87 and 23.40 %) under non stress and moisture stress condition respectively. Amongst the different generations, the percent reduction in chlorophyll stability index varied from as low as 9.13 per cent in B₁ generation to as high as 12.91 per cent in parent P₂ (IS 6427). Similar findings were also reported by Shinde and Narkhede [20] and Awari et al, [25,26].

4. CONCLUSION

In the present results, we concluded the some significant observation in this research work. We found that the B₂ and F₁ generation recorded significantly highest photosynthesis rate (25.98 and 22.47 μ mole CO₂ m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The parent B₁ recorded highest transpiration rate (3.27 and 1.92 mmole H₂O m⁻²s⁻¹) under non stress and moisture stress condition, respectively. The F₂ generation was recorded the lowest transpiration rate (2.47 and 1.66 mmole H₂O m⁻²s⁻¹) under moisture stress

condition, respectively. The F₁ and B₁ generation recorded significantly the highest mean for stomatal conductance (0.24 and 0.18 mole m⁻² s⁻¹) under non stress condition and moisture stress condition, respectively. The B₁ generation recorded significantly the highest relative leaf water content (81.74 and 71.74 %) and in different generations highest relative leaf water content was recorded in F₁ and B₂ generations (81.01 and 74.42 %) under non stress and moisture stress condition, respectively. The segregating generation F₂ recorded significantly the highest SPAD reading (53.24 and 43.35) under non stress condition and moisture stress condition, respectively. The B₁ generation recorded the highest total chlorophyll content (3.30 and 2.08 %) under non stress and moisture stress condition, respectively. The parent B₂ generation recorded the highest chlorophyll stability index (34.49 and 32.08 %) under non stress and moisture stress condition, respectively. The parent P₂ (IS 6427) recorded significantly the lowest chlorophyll stability index (26.87 and 23.40 %) under non stress and moisture stress condition respectively. Amongst the different generations, the percent reduction in chlorophyll stability index varied from as low as 9.13 per cent in B₁ generation to as high as 12.91 per cent in parent P₂ (IS 6427).

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bibi A, Sadaqat HA, Tahir MHN, Akram HM. Screening of sorghum (*Sorghum bicolor* var Moench) for drought tolerance at seedling stage in polyethylene glycol. The J. of Animal and Plant Sci. 2012;22: 671-678.
2. Dial HL. Plant Guide for Sorghum (*Sorghum bicolor* L.). USDA-Natural Resources Conservation Service, Tucson Plant Materials Center. Tucson, AZ, USA; 2012.
3. Taiz L, Zeiger E. Plant Physiology. Sinauer Associates, Inc. Sunderland, UK. 2006: 591-602.
4. Prasad VR, Govindaraj M, Djanaguiraman M, Djalovic I, Shailani A, Rawat N. Drought and high temperature stress in sorghum: Physiological, genetic, and molecular insights and breeding approaches. International Journal of Molecular Sciences. 2021;22(18):9826.
5. Tambe SA, Kusalkar DV, Shinde GC, Jondhale AS. Heterosis Studies for Grain Yield and Yield Components in Rabi Sorghum [*Sorghum bicolor* (L.) Moench]. Int. J Plant Soil Sci. 2022;34(23):1706-1719.
6. Tambe SA, Kusalkar DV, Shinde GS, Shinde MS. Inheritance of morphological traits for drought tolerance in rabi sorghum [*Sorghum bicolor* (L.) Moench]. Int. J. Curr. Res. Biosci. Plant Biol. 2019;6(9):24-32.
7. Ejeta G, Knoll JE. Marker-assisted selection in sorghum. In Genomics-assisted crop improvement. Springer, Dordrecht. 2007;187-205.
8. Petit JR, Jouzel J, Raynaud D, Barkov NI, Barnola JM, Basile I, Bender M, Chappellat J, Davis M, Delaygue G, Delmotte M, Kotlyakov VM, Legrand M, Lipenkov VY, Lorius C, Depin, L, Ritz C, Saltzman E, Stievenard M. Climate and atmospheric history of the past 420,000 years from the Vostok ice Core, Antarctica. Nature. 1999;399:429-436.
9. Valladares F, Pearcy RW. Interaction between water stress, sun-shade acclimation, heat tolerance and photo inhibition in the Sclerophyll. *Heteromeles arbutifolia* plant cell and Environment., 1997;20:25-36.
10. Jackson RB, Sperry JS, Dawson TE. Root water uptake and transport: using physiological processes in global predictions. Trends in Plant Sci. 2000;5 :482-488.
11. Kadam GN, Gadakh SR, Awari VR. Physiological analysis of Rabi sorghum genotypes for shallow soil. Journal of Maharashtra Agricultural Universities. 2002;27(3):274-276.
12. Tambe SA, Jondhale AS, Wagh BD. Evaluation of Physiological Efficiency in Sorghum (*Sorghum bicolor* (L.) Moench) Genotypes under Drought Stress. Int. J Plant Soil Sci. 2024;36(7):309-316.
13. Barrs HD, Weatherly PE. Re-examination of relative turgidity for estimating water

- deficits in leaves. Australian J. of Bio. Sci. 1962;15:413-428.
14. Hiscox and Israeltam. A method for extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany., 1979;57:1332-1334.
 15. Arnon OI. Copper enzymes in isolated chloroplasts, polyphenol oxidase in *Beta vulgaris*. Plant Physiol. 1949;24: 1-15.
 16. Narkhede BN, Shinde MS, Gadakh SR. Phule Maulee (RSLG 262) a new rabi sorghum variety for shallow to medium soil of Maharashtra state. J. Maharashtra Agric. Univ. 2004;29(1):12-16.
 17. Gadakh SR, Shinde MS, Gaikwad AR, Nirmal SV, Chavan UD. Phule Suchitra : A new rabi sorghum variety for medium soil. Crop Res. 2013;45(1, 2, 3):136-140.
 18. Shinde MS, Gaikwad AR, Patil VR, Gadakh SR. Phule Anuradha (RSV 458) :A new drought tolerant rabi sorghum variety for shallow soils of Maharashtra. Ann. Plant Physiol. 2011;25(1):66-69.
 19. Kachare, GP. Significance of morphological characters in rabi sorghum genotypes. M.Sc. (Agri.) Thesis, M.P.K.V., Rahuri (India); 1998.
 20. Narkhede BN, Shinde MS, Patil SP. Association of physiological parameters with grain yield of rabi sorghum. Ann. of Pl. Physiol. 1998;12(1):65-66.
 21. Subudhi PK, Magpantay GG, Rosenow Enow DT, Nguyen HT. Mapping of marker-assisted selection to improve the stay Green Trait for drought Tolerance in Sorghum. 1991;183-191.
 22. Vinita J, Sujata B, Streb PFJ, Jagtap V, Bhargava S. Comparative effect of water, heat and light stress on photosynthetic reactions in *Sorghum biolor* (L.) Moench. Journal of Experimental Botany. 1998;49 (327):1715-1721.
 23. Deshmukh RU, Launara SL, Dhuman KN. Metabolic alterations on *Sorghum bicolor* under water stress. J. of Maharashtra Agricultural Universities. 2001;26(1):50 – 53.
 24. Koleyoreas SA. A new method of determination of drought resistance. Plant Physiol. 1958;33:232-233.
 25. Awari VR, Gadakh SR, Shinde MS, Kusalkar DV. Correlation study of morpho-physiological and yield contributing characters with grain yield in sorghum. Ann. of Plant Physiol. 2003;17(1):50-52.
 26. Shinde MS, Narkhede BN. Association of physiological parameters with grain yield of rabi sorghum. Ann. Plant Physiol. 1998;12 (1):65-66.

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