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Effect of Seed Priming on Seed Quality in Parental Lines of Hybrid Maize (*Zea mays* L.) MAH 15 - 84

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ABSTRACT

The laboratory experiment was conducted to standardize the seed priming techniques for enhancement of seed yield and quality in parental lines of hybrid maize (*Zea mays* L.) MAH 15-84 at Department of Seed Science and Technology, CoA, UAS, GKVK, Bengaluru during 2022. The seeds of both male (MAI-19-20) and female (MAI-19-117) parents were primed with KNO_3 and $ZnSO_4$ at 0.5 and 1 per cent, gibberellic acid (GA_3) and salicylic acid (SA) at 50 and 100 ppm and hydroprimed for 12 and 24 h and unprimed seeds were used as control. The results revealed that, among treatments, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded highest seed germination (99.33 and 99.00%), root length (29.70 and 27.33 cm), shoot length (25.26 and 26.02 cm), seedling dry weight (93.31 and 92.33 mg), SVI-I (5459 and 5282), SVI-II (9268 and 9141), total dehydrogenase activity (2.456 and 2.348 at A_{480} nm) and least electrical conductivity (0.262 and 0.228 dSm^{-1}), less duration for radicle emergence (70.93 and 69.07 h) and T_{50} value (3.08 and 3.24 days) respectively, which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7) compared to control (89.33 and 90.67%, 20.40 and 20.42 cm, 18.09 and 18.01 cm, 78.41 and 82.00 mg, 3438 and 3484, 7004 and 7435, 0.974 and 0.724 at A_{480} nm 0.610 and 0.650 dSm^{-1}, 80.83 and 82.27 h and 5.04 and 4.78 days respectively). Thus, seed priming with 50 ppm GA_3 for 12 h and 1 per cent $ZnSO_4$ for 12 h found to be the best treatments to enhance the seed quality of hybrid maize compared to other priming treatments and control. Hence, these two treatments could be utilised for commercial exploitation of maize hybrid seed production to get better seed yield.

Keywords : Maize hybrid, Seed priming, KNO_3, $ZnSO_4$, GA_3, Salicylic acid, Hydropriming

MAIZE, scientifically known as *Zea mays* L. belonging to the Poaceae family is having a chromosome number with 2n=20. It holds a significant stature among cereal crops globally, closely trailing rice and wheat in both production and consumption. It is originated in Central America and hailed as the 'Miracle crop' or the 'Queen of cereals' for its remarkable genetic yield potential. It is one of the most versatile emerging crops having wider adaptability due to its C_4 plant status making it a linchpin in sustainable agricultural practices (Kumar and Jhariya, 2013). With approximately 9.9 per cent protein, 4 per cent oil and 70 per cent starch, maize serves as a vital source of nutrients including vitamins A and E, riboflavin and nicotinic acid addressing the dietary requirements of a growing population (Gami *et al.,* 2018). Beyond its role as a staple food crop, maize exhibits versatility across various domains, including feed, fodder, industrial raw materials and biofuel production. This diverse range of applications has led to its designation as a '4F crop' (Food, Feed, Fuel and Fodder).

Globally, maize stands out as a leading cereal crop, cultivated on an area of 201 million hectares with a production of 1162 million tonnes and productivity of 5.75 tonnes per hectare (Anonymous, 2021). In India, maize ranks third position among cereals with the production of 33.73 million tonnes from an area of 9.95 million hectares with productivity of 3.38 t / hectare. Andhra Pradesh, Karnataka, Maharashtra, Rajasthan and Bihar together account for about 2/3rd of the total maize production in India (Anonymous, 2022). Among all states, Karnataka holds first place in maize production with 1.68 million hectares of area. This is about 17.0 per cent of India's total area under cultivation, producing around 5.18 million tonnes which is 16.45 per cent of all India production with a yield of 3092 kg / hectare (Anonymous, 2020).

Seed Priming

The recent surge in maize production and utilization has garnered significant national and international interest from researchers. This emphasis aims to tackle issues such as poor genetic potential, low seed yield and inadequate adaptation to diverse agro-ecologies, particularly focusing on improving the performance of certain varieties (Deepak and Vasudevan, 2023). To suffice the utmost requirement of breeders, development of high-yielding maize hybrids necessitates access to top-quality seeds. Among the array of seed enhancement technologies available, seed priming stands out as a notable approach (Subedi & Ma, 2005 and Dutta, 2018).

Seed priming involves controlled hydration to enhance pre-germinative metabolism without initiating radicle emergence. It encompasses alterations in water content, regulation of the cell cycle, ultrastructural changes, management of oxidative stress and mobilization of reserves. Imbibition triggers protein synthesis and respiratory activities utilizing existing mRNA, thus kickstarting germination processes. Known for its cost-effectiveness and efficacy, seed priming ensures uniform emergence, enhances growth and stress resistance, improves nutrient and water efficiency and suppresses weeds, leading to synchronization of flowering and enhancement of seed yield and quality (Raj and Raj, 2019). Diverse seed-priming techniques have been established, including hydro-priming, osmo-priming, nutrient priming, chemical priming, bio-priming and priming with plant growth regulators, extracts, nanoparticles and physical agents (Dawood, 2018).

Halo-priming, involving the immersion of seeds in solutions of inorganic salts such as zinc sulphate, sodium chloride, potassium nitrate and calcium chloride which promotes uniform germination and enhances crop performance, even under challenging conditions like temperature extremes and oxygen deprivation (Raj and Raj, 2019). Optimal levels of potassium nitrate notably enhance the seed quality parameters *viz.,* germination time and emergence in parental plants of maize facilitating synchronized flowering (Krishna *et al.,* 2019 and Karmore & Tomar, 2015). Hormopriming with gibberellic acid (GA_3) optimizes seedling growth and development, enhancing vegetative and reproductive traits by regulating crucial physiological processes across diverse crop species (Pawar and Laware, 2018). Additionally, salicylic acid (SA) as a silicon source effectively mitigates abiotic and biotic stresses, maintaining plant water balance, photosynthetic activity, leaf erectness and xylem vessel structure under high transpiration rates. It notably enhances germination percentage, shoot and root length as well as relative water content in salt-stressed maize (Ullah *et al.,* 2023). Critical factors in hydropriming include the duration of seed soaking, water volume and priming temperature. Taylor *et al.* (1998) noted that water freely enters the seed during hydropriming, contributing to increased final germination percentage and vigour in maize seeds (Dezfuli *et al.,* 2008).

Optimizing seed priming conditions, including the choice of priming agent and treatment duration, is pivotal for achieving the desired response. Given the variability among crop species, determining the most effective treatment often requires experimentation.

This study aims to standardize priming treatments, considering factors such as soaking duration and temperature to investigate their effects on seed quality in parental lines of hybrid maize (*Zea mays* L.) MAH 15-84.

Material and Methods

Freshly harvested seeds of MAI-19-117 (female parent) and MAI-19-20 (male parent) of single cross hybrid maize MAH 15-84 were obtained from Zonal Agricultural Research Station (ZARS), UAS, GKVK, Bengaluru. The laboratory experiments were carried out at the Department of Seed Science and Technology, GKVK and Seed Technology Research Unit, NSP, UAS, GKVK, Bengaluru, during June-July 2022. The seed material was dried to maintain safe moisture level (< 9-10%) and graded to uniform size by using 18/64" round perforated sieves.

Table 1

Treatment details of the experiment

Priming material used	Concentration	Duration (h)
Control (Unprimed)	Nil	Nil
Hydro priming	Nil	12 & 24
Priming with KNO_3	0.5 % & 1%	12 & 24
Priming with $ZnSO_4$	0.5 % & 1%	12 & 24
Priming with GA_3	@ 50 & 100 ppm	12 & 24
Priming with Salicylic Acid (SA)	@ 50 & 100 ppm	12 & 24

Preparation of Priming Solutions

KNO_3 (0.5% and 1%) : 5.06 and 10.11 grams crystalline solid form of KNO_3 was added to a small volume of distilled water in two separate one-liter volumetric flasks, stirred until it gets dissolved completely in water and made the volume to one-liter each with distilled water to get 0.5 and 1 per cent KNO_3 respectively.

$ZnSO_4$ (0.5% and 1%) : 2.88 and 5.76 grams of colorless crystalline solid form of $ZnSO_4$ was added to100 ml of distilled water in two separate, cleaned and dried one-liter volumetric flask, stirred until it gets dissolved completely in water and made the volume to one-liter each with distilled water and allow to cool to room temperature to get 0.5 and 1 per cent $ZnSO_4$ respectively.

Table 2

Treatment combinations of the experiment

T_1 : Seed Priming with 0.5 % KNO_3 for 12 h
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h
T_3 : Seed Priming with 1 % KNO_3 for 12 h
T_4 : Seed Priming with 1 % KNO_3 for 24 h
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12 h
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h
T_9 : Seed Priming with 50 ppm GA_3 for 12 h
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{17} : Hydropriming for 12 h
T_{18} : Hydropriming for 24 h
T_{19} : Control

GA_3 and Salicylic Acid (50 and 100 ppm) : 50 mg and 100 mg each of GA_3 and Salicylic Acid was added to two separate one-liter volumetric flasks by adding small quantity of ethanol prior to dilution with distilled water. Then distilled water was added to make the volume 1 liter to get 50 and 100 ppm GA_3 and Salicylic Acid solution respectively.

Procedure of Seed Priming : Seeds of both male (MAI-19-20) and female (MAI-19-117) parental lines of hybrid maize MAH 15-84 were subjected to respective priming treatments for 12 h and 24 h specific durations during experimentation by utilising solutions prepared as mentioned above. After priming, the seeds were removed from the solutions, rinsed in distilled water and redried to its original moisture content under shade at room temperature. The unprimed seeds were used as control.

Seed Quality Testing : Seed quality parameters *viz.,* seed germination (%), radicle emergence (h), T_{50} value (days), seedling length (cm), seedling dry weight (mg), seedling vigour index I & II, electrical conductivity (dSm^{-1}) and total dehydrogenase activity (A_{480} nm) were determined for primed seeds along with unprimed control as per the methods prescribed by ISTA (2021) at the Department of Seed Science and Technology, GKVK and Seed Technology Research Unit, NSP, UAS, GKVK, Bengaluru.

Data Analysis : The experimental data on seed priming treatments were subjected to completely randomized design (CRD) statistical analysis as suggested by Gomez and Gomez (1984). Critical difference (CD) values were computed at 1 per cent level wherever 'F' test was significant.

Results and Discussion

In the present investigation, effect of different seed priming technique for standardization showed that the seeds primed with gibberellic acid (GA_3) and zinc sulphate ($ZnSO_4$) with different concentration and durations performed better as compared to other treatments and control through initial improvement in seed quality attributes *viz.,* seed germination (%), radicle emergence (h), T_{50} value (days), seedling length (cm), seedling dry weight (mg), vigour indices, electrical conductivity (dSm^{-1}) and total dehydrogenase activity (at A_{480}nm) and are presented in Table 3-6, Fig. 1-3 and discussed in the following paragraph.

Table 3

Influence of different seed priming treatments on seed germination, radicle emergence and T_{50} value in parental lines of maize hybrid MAH 15-84

Treatments	Seed germination (%)		Radicle emergence (h)		T_{50} value (Days)	
	Male	Female	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	92.00	93.33	78.27	79.10	4.26	4.49
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	93.00	94.00	76.37	75.37	3.92	3.65
T_3 : Seed Priming with 1 % KNO_3 for 12 h	93.33	93.67	76.10	76.67	3.66	3.60
T_4 : Seed Priming with 1 % KNO_3 for 24 h	94.00	95.33	75.33	75.57	3.51	3.43
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	92.33	93.67	77.73	78.13	3.92	3.83
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	93.67	94.67	76.47	76.53	4.01	3.83
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	98.00	98.33	72.07	70.30	3.38	3.40
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	94.00	95.33	73.03	74.50	3.47	3.54
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	99.33	99.00	70.93	69.07	3.08	3.24
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	95.00	96.67	73.63	73.70	3.63	3.84
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	96.00	96.33	72.50	72.67	3.63	3.74
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	94.67	95.33	72.97	73.03	3.92	3.90
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	93.00	93.67	76.83	76.63	4.14	4.02
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	95.00	94.00	74.83	74.57	4.00	3.82
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	94.00	95.33	76.13	76.47	4.20	4.18
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	95.33	96.00	73.00	73.10	4.08	3.68
T_{17} : Hydropriming for 12 h	92.00	91.67	75.57	75.50	4.14	4.21

Continued....

TABLE 3 Continued....

Treatments	Seed germination (%)		Radicle emergence (h)		T_{50} value (Days)	
	Male	Female	Male	Female	Male	Female
T_{18} : Hydropriming for 24 h	92.33	93.00	76.37	75.90	3.95	4.25
T_{19} : Control	89.33	90.67	80.83	82.27	5.04	4.78
Mean	94.02	94.74	75.21	76.14	3.82	3.96
S. Em ±	0.91	0.95	0.39	0.37	0.16	0.14
CD (P=0.01)	2.61	2.71	1.12	1.06	0.45	0.38
CV (%)	1.69	1.74	1.90	1.85	2.04	2.41

TABLE 4

Influence of different seed priming treatments on root length and shoot length in parental lines of maize hybrid MAH 15-84

Treatments	Root length (cm)		Shoot length (cm)	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	22.77	22.27	19.80	19.13
T_3 : Seed Priming with 1 % KNO_3 for 12 h	23.56	24.08	20.47	19.18
T_4 : Seed Priming with 1 % KNO_3 for 24 h	22.14	22.66	20.72	20.20
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	22.42	21.69	19.60	18.40
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	23.96	25.10	20.65	19.93
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	27.62	26.63	23.44	24.86
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	23.09	23.88	21.71	20.93
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	29.70	27.33	25.26	26.02
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	26.24	24.34	22.35	21.69
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	26.68	25.97	23.27	23.80
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	25.27	24.01	22.76	22.14
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	23.62	23.83	20.84	19.00
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	24.23	23.95	21.19	20.80
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	26.28	24.52	22.15	21.42
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	25.48	25.28	22.84	22.68
T_{17} : Hydropriming for 12 h	25.20	24.15	22.26	20.71
T_{18} : Hydropriming for 24 h	24.35	25.30	21.07	20.43
T_{19} : Control	20.40	20.42	18.09	18.01
Mean	24.52	24.06	21.48	20.94
S. Em ±	0.50	0.47	0.39	0.25
CD (P=0.01)	1.43	1.35	1.11	0.72
CV (%)	3.54	3.40	3.14	2.09

TABLE 5

Influence of different seed priming treatments on mean seedling length and seedling dry weight in parental lines of maize hybrid MAH 15-84

Treatments	Mean seedling length (cm)		Seedling dry weight (mg)	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	40.85	40.03	80.97	83.99
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	42.57	41.40	81.60	83.80
T_3 : Seed Priming with 1 % KNO_3 for 12 h	44.03	43.26	84.15	85.57
T_4 : Seed Priming with 1 % KNO_3 for 24 h	42.86	42.86	82.83	83.77
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	42.02	40.09	80.98	84.41
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	44.61	45.03	84.20	84.79
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	51.06	51.49	91.53	90.71
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	44.80	44.81	84.80	89.58
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	54.96	53.35	93.31	92.33
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	48.59	46.03	89.13	89.32
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	49.95	49.77	89.17	89.60
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	48.03	46.15	88.40	90.35
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	44.46	42.83	83.40	85.70
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	45.42	44.75	85.54	87.55
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	48.43	45.94	88.07	88.53
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	48.32	47.96	89.13	89.63
T_{17} : Hydropriming for 12 h	47.46	44.86	88.70	88.03
T_{18} : Hydropriming for 24 h	45.42	45.73	85.03	87.57
T_{19} : Control	38.49	38.43	78.41	82.00
Mean	46.00	45.00	85.78	87.22
S. Em ±	1.87	0.79	0.43	0.41
CD (P=0.01)	5.37	2.27	1.24	1.18
CV (%)	3.22	3.05	1.34	1.12

TABLE 6

Influence of different seed priming treatments on seedling vigour index (SVI) I and II in parental lines of maize hybrid MAH 15-84

Treatments	Vigour index-I		Vigour index-II	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	3758	3736	7449	7839
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	3959	3892	7589	7877
T_3 : Seed Priming with 1 % KNO_3 for 12 h	4109	4052	7854	8015
T_4 : Seed Priming with 1 % KNO_3 for 24 h	4029	4086	7786	7986
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	3880	3755	7477	7907
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	4179	4263	7887	8027
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	5009	5063	8970	8920
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	4211	4272	7971	8540

Continued....

TABLE 6 Continued....

Treatments	Vigour index-I		Vigour index-II	
	Male	Female	Male	Female
T_{9} : Seed Priming with 50 ppm GA_3 for 12 h	5459	5282	9268	9141
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	4606	4450	8467	8635
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	4795	4794	8560	8631
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	4547	4399	8369	8613
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	4135	4012	7756	8028
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	4315	4207	8126	8230
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	4552	4379	8279	8440
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	4616	4604	8497	8604
T_{17} : Hydropriming for 12 h	4534	4131	8160	8070
T_{18} : Hydropriming for 24 h	4194	4253	7851	8144
T_{19} : Control	3438	3484	7004	7435
Mean	4332	4269	8070	8267
S. Em ±	56.94	100.24	122.80	107.73
CD (P=0.01)	163.03	286.97	351.58	308.42
CV (%)	2.28	4.07	2.63	2.27

SVI- I= Germination (%) × Mean seedling length (cm); SVI- II = Germination (%) × Seedling dry weight (mg)

$$\text{Per cent increase (\%)} = \frac{\text{Highest value - Lowest value}}{\text{Lowest value}} \times 100$$

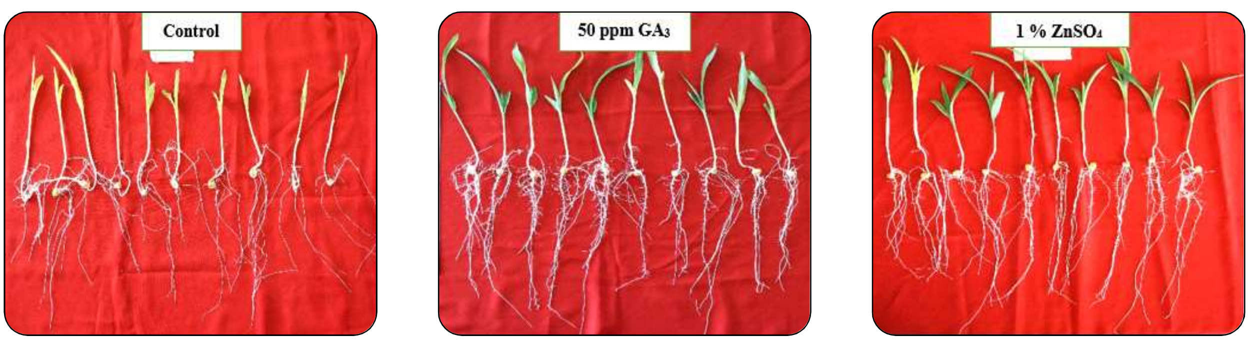


Fig. 1 : Seedling length of male parental line primed with 50 ppm GA_3 (12 h) and 1 % $ZnSO_4$ (12 h) in comparison to control in maize hybrid (MAH 15-84)

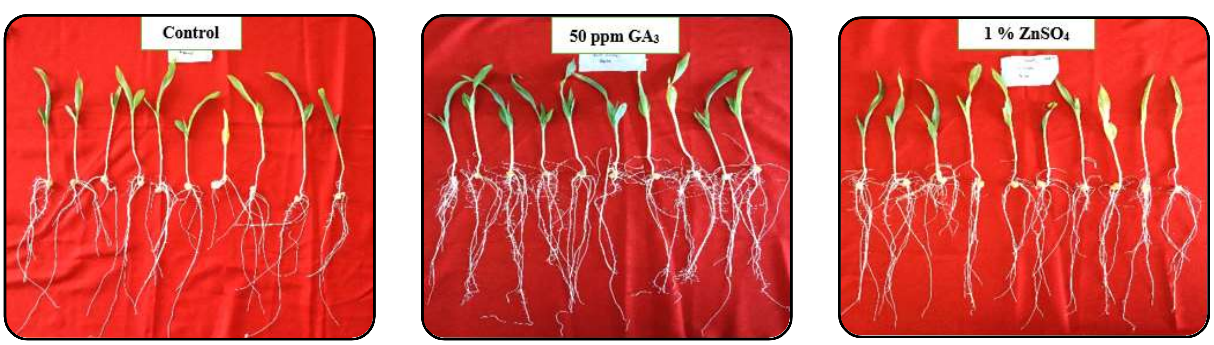
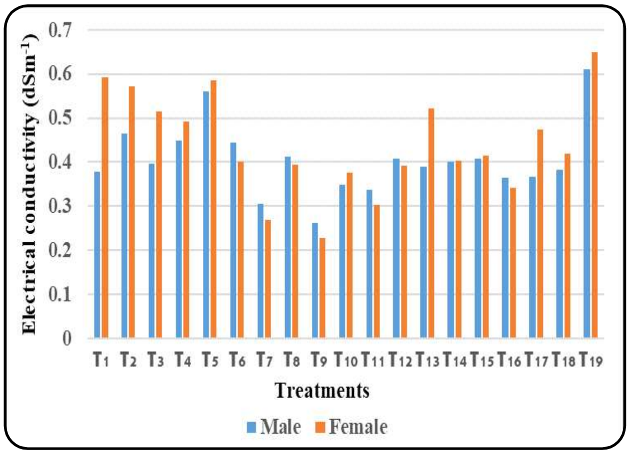


Fig. 2 : Seedling length of female parental line primed with 50 ppm GA_3 (12 h) and 1 % $ZnSO_4$ (12 h) in comparison to control in maize hybrid (MAH 15-84)



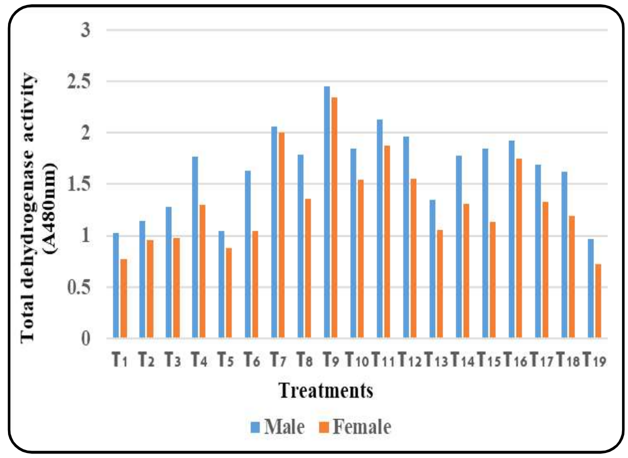


Fig. 3 : Influence of different seed priming treatments on electrical conductivity and total dehydrogenase activity in parental lines of maize hybrid MAH 15-84

Treatments : [T_1: Seed Priming with 0.5 % KNO_3 for 12 h, T_2: Seed Priming with 0.5 % KNO_3 for 24 h, T_3: Seed Priming with 1 % KNO_3 for 12 h, T_4: Seed Priming with 1 % KNO_3 for 24 h, T_5: Seed Priming with 0.5 % $ZnSO_4$ for 12 h, T_6: Seed Priming with 0.5 % $ZnSO_4$ for 24 h, T_7: Seed Priming with 1 % $ZnSO_4$ for 12 h, T_8: Seed Priming with 1 % $ZnSO_4$ for 24 h, T_9: Seed Priming with 50 ppm GA_3 for 12 h, T_{10}: Seed Priming with 50 ppm GA_3 for 24 h, T_{11}: Seed Priming with 100 ppm GA_3 for 12 h, T_{12}: Seed Priming with 100 ppm GA_3 for 24 h, T_{13}: Seed Priming with 50 ppm Salicylic Acid for 12 h, T_{14}: Seed Priming with 50 ppm Salicylic Acid for 24 h, T_{15}: Seed Priming with 100 ppm Salicylic Acid for 12 h, T_{16}: Seed Priming with 100 ppm Salicylic Acid for 24 h, T_{17}: Hydropriming for 12 h, T_{18}: Hydropriming for 24 h, T_{19}: Control]

Seed Germination (%)

Significant variations were observed among the parental lines of maize hybrid MAH 15-84 in response to different seed priming treatments concerning seed germination percentage (Table 3). The germination percentages ranged from 89.33 per cent to 99.33 per cent for male parental lines and from 90.67 per cent to 99.00 per cent for female parental lines, with mean values of 94.02 per cent and 94.74 per cent respectively. However, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded highest seed germination (99.33 and 99.00%) which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 98.00 and 98.33%) compared to control (T_{19}: 89.33 and 90.67%) which showed lowest germination percentage respectively. Treatment T_9 increased germination by 11 and 9 per cent, while T_7 increased it by 10 and 8 per cent over the control for male and female parents respectively.

This highlights the effectiveness of GA_3 and $ZnSO_4$ seed priming treatments in enhancing seed germination performance compared to untreated seeds. This enhancement in seed germination can be attributed to the heightened activity of enzymes such as amylase, protease and lipase which are pivotal in breaking down macromolecules for embryo growth and development, consequently leading to increased seedling emergence. Similar findings were reported by Hidayat *et al.* (2008) and Manjunatha *et al.* (2018) in maize genotypes. Kumari *et al.* (2017) also reported the positive impact of GA_3 on maize germination, further supporting our findings and emphasizing the significance of seed priming techniques in optimizing seedling establishment and crop productivity.

Radicle Emergence (h)

Seeds of male and female parents of maize hybrid MAH 15-84 exhibited significant differences in response to diverse seed priming treatments concerning radicle emergence. It ranged from 70.93 and 69.07 to 80.83 and 82.27 with a mean of 75.21 and 76.14 hours for male and female parents respectively (Table 3). Remarkably, the treatment T_9 (50 ppm GA_3 for 12 h) resulted in the shortest time for radicle emergence (70.93 and 69.07 h) which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 72.07 and 70.30 h) compared to the control

(T_{19}: 80.83 and 82.27 h) which took longest time for radicle emergence in male and female parents respectively. Treatment T_9 decreased time taken for radicle emergence by 14 and 19 per cent, while T_7 decreased it by 12 and 17 per cent over the control for male and female parents, respectively.

GA_3 and $ZnSO_4$ seed priming treatments accelerate radicle emergence in maize by stimulating the enzymatic breakdown of stored reserves like starch and proteins facilitating rapid embryo growth and enhancing cell elongation by regulating gibberellin, auxin and cytokinin signalling pathways, ultimately leading to quicker and more efficient germination leading to enhanced seedling establishment. Similar results were reported by Farooq *et al.* (2010) for GA_3 in rice and by Shakirova *et al.* (2018) for $ZnSO_4$ in maize.

T_{50} Value (Days)

Significant differences were noted among the parental lines of maize hybrid MAH 15-84 subjected to various seed priming treatments with respect to T_{50} value. It ranged from 3.08 to 5.04 days for male parental lines and from 3.24 to 4.78 days for female parental lines, with mean durations of 3.82 and 3.96 days respectively (Table 3). However, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded lowest T_{50} value (3.08 and 3.40 days), which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 3.38 and 3.40 days). In contrast, the control (T_{19}) showed higher T_{50} values, with durations of 5.04 and 4.78 days for male and female parents respectively. Treatment T_9 decreased T_{50} value by 64 and 48 per cent, while T_7 decreased it by 45 and 36 per cent over the control for male and female parents, respectively.

This is due to stimulative activity of pivotal enzymes, notably amylase and protease, involved in seed metabolism by breaking down of complex starches and proteins into readily available forms, thus energizing the germination process. By accelerating the hydrolysis of these reserves, GA_3 and $ZnSO_4$ hasten the metabolic processes necessary for germination leading to a quicker attainment of the T_{50} value. Similar findings were reported by Wang *et al.* (2015) and Rajput *et al.* (2018) in maize.

Root and Shoot length (cm)

Significant variations in root and shoot length were observed among treatments (Table 4 and Fig. 1 & 2). The most notable enhancements were observed in treatment T_9 (50 ppm GA_3 for 12 h) resulting in the highest root length (29.70 and 27.33 cm) and shoot length (25.26 and 26.02 cm) followed by treatment T_7-1 per cent $ZnSO_4$ for 12 h exhibited considerable root length (27.62 and 26.63 cm) and shoot length (23.44 and 24.86 cm) for seeds of male and female parental lines respectively. Additionally, treatment T_{16} - 100 ppm salicylic acid for 24 h and T_{11}- 100 ppm GA_3 for 12 h demonstrated substantial root length measuring 25.48 and 25.28 cm and 26.68 and 25.97 cm shoot length of 22.84 and 22.68 cm and 23.27 and 23.80 cm for seeds of male and female parental lines respectively. In contrast, the control (T_{19}) exhibited the lowest root length (20.40 and 20.42 cm) and shoot length (18.09 and 18.01 cm) compared to all other seed priming treatments. Treatment T_9 increased root length by 44 and 34 per cent and shoot length by 40 and 44 per cent, while T_7 increased it by 35 and 30 per cent and 30 and 38 per cent over the control for male and female parents respectively.

The improvements in root and shoot length were facilitated by GA_3, which stimulated cellular growth through the promotion of cell elongation and division by activating α-amylase. Mean while, $ZnSO_4$ contributed to hormonal balance by synthesizing auxins and enhancing enzyme activity involved in essential processes like protein, nucleic acid and chlorophyll synthesis. These combined effects played a crucial role in enhancing root and shoot development. Similar findings were reported by Krishna *et al.* (2023) and Soumya *et al.* (2021) in maize.

Mean Seedling Length (cm)

Significant variations were evident in mean seedling length across the treatments (Table 5 and Fig. 1 & 2). It ranged from 38.49 to 54.96 cm for male parental lines and from 38.43 to 53.35 cm for female parental lines, with mean of 46.00 and 45.00 cm respectively. The most notable enhancements were observed in treatment T_9 (50 ppm GA_3 for 12 h), resulting in the highest mean seedling length (54.96 and 53.35 cm) followed by treatment T_7-1 per cent $ZnSO_4$ for 12 h (51.06 and 51.49 cm) exhibited considerable improvements compared to the control (T_{19}: 38.49 and 38.43 cm) for seeds of male and female parental lines respectively. Treatment T_9 increased mean seedling length by 43 and 39 per cent, while T_7 increased it by 33 and 34 per cent over the control for male and female parents, respectively.

GA_3 stimulates the synthesis of enzymes responsible for loosening and expanding cell walls, promoting elongation in roots and shoots. In parallel, $ZnSO_4$ enhances photosynthetic efficiency and supports root and shoot system development. These synergistic effects culminate in superior growth and development of maize seedlings. Similar findings were reported by Wang *et al.* (2019) and Menaka *et al.* (2019) in maize.

Seedling Dry Weight (mg)

Significant variations were noted in mean seedling dry weight among the treatments, as indicated in Table 5. It ranged from 78.41 to 93.31 mg for male parental lines and from 82.00 to 92.33 mg for female parental lines, with mean values of 85.78 mg and 87.22 mg respectively. Highest seedling dry weight was recorded in the treatment T_9 (93.31 and 92.33 mg) followed by T_7 (91.53 and 90.71 mg). Additionally, treatments T_{16} (100 ppm salicylic acid for 24 h) and T_{11} (100 ppm GA_3 for 12 h) demonstrated substantial seedling dry weights measuring 89.53 and 89.63 mg, and 89.17 and 89.60 mg for seeds of male and female parental lines respectively. In contrast, the control (T_{19}) exhibited the lowest seedling dry weight, measuring 78.41 and 82.00 mg compared to all other seed priming treatments. Treatment T_9 increased seedling dry weight by 19 and 13 per cent, while T_7 increased it by 17 and 11 per cent over the control for male and female parents, respectively.

GA_3 promotes cell elongation and division, salicylic acid induces stress tolerance *via.,* stimulation of gibberellic and auxin signalling pathways and $ZnSO_4$ enhances nutrient uptake resulting in robust seedling growth and biomass accumulation. This aligns with findings of Adhikari and Subedi (2022), Shatpathy *et al.* (2018) and Soumya *et al.* (2021) in maize.

Seedling Vigour Indices

The study on seed priming treatments revealed significant differences in seedling vigour index I and II among the treatments (Table 6). The results showed that, T_9 (50 ppm GA_3 for 12 h) recorded highest vigour index I (5459 and 5282) and vigour index II (9268 and 9141) which was followed by T_7 (5009 and 5063; 8970 and 8920) for seeds of male and female parental lines respectively. Additionally, treatments T_{16} (100 ppm salicylic acid for 24 h) and T_{11} (100 ppm GA_3 for 12 h) demonstrated substantial vigour index I and II measuring (4616 & 4604 and 8497 & 8604) and (4795 & 4794 and 8560 & 8631) respectively. In contrast, the control (T_{19}) exhibited the lowest vigour index I and II measuring 3438 and 3484; 7004 and 7435 respectively compared to all other seed priming treatments. Treatment T_9 increased vigour index I by 59 and 52 per cent and vigour index II by 32 and 23 per cent meanwhile, T_7 increased vigour index I by 46 and 45 per cent and vigour index II by 28 and 20 per cent over the control for male and female parents, respectively.

The results highlight the efficacy of diverse seed priming treatments in enhancing seedling vigour compared to the untreated control. GA_3 and salicylic acid accelerates and standardizes germination, enhances seedling growth through increased metabolic activity, while $ZnSO_4$ promotes hormonal balance and nutrient uptake augmenting stress resistance against drought and diseases. Similar findings were reported by Khan *et al.,* 2015; Li *et al.,* 2020 and Sastry & Divakara, 2011 in maize.

Electrical Conductivity (dSm^{-1})

The parental lines exhibited significant variation on electrical conductivity of seed leachate for different seed priming treatments (Fig. 3). It ranged from 0.262 to 0.610 dSm^{-1} for male parental lines and from 0.228 to 0.650 dSm^{-1} for female parental lines, with mean values of 0.406 and 0.440 dSm^{-1}, respectively. The results revealed that seeds of male and female parental lines primed with 50 ppm GA_3 for 12 h (T_9) recorded significantly lower electrical conductivity of seed leachate (0.262 and 0.228 dSm^{-1}) followed by the treatment 1 per cent $ZnSO_4$ for 12 h (T_7: 0.305 and 0.269 dSm^{-1}) whereas, the control (T_{19}) recorded highest (0.610 and 0.650 dSm^{-1}) electrical conductivity respectively.

The reduction in the value of electrical conductivity of seed leachate was due to critical maintains of structural integrity and cell membrane permeability, hormonal regulation and genetic factors. The results were in accordance with the findings of Kiran and Channakeshava (2017) and Omar *et al.* (2022) in maize.

Total Dehydrogenase Activity (A_{480} nm)

Seeds of male and female parents of maize hybrid MAH 15-84 exhibited significant differences in response to diverse seed priming treatments concerning total dehydrogenase activity (Fig. 3). It ranged from 0.971 & 0.724 to 2.456 & 2.348 with a mean of 1.646 & 1.321 $A_{480\ nm}$ for male and female parents respectively. The treatment T_9 showed highest total dehydrogenase activity (2.456 and 2.348 $A_{480\ nm}$) which was followed by T_7 (2.061 and 2.005 $A_{480\ nm}$) whereas, the control (T_{19}) recorded the lowest (0.971 and 0.724 $A_{480\ nm}$) for male and female parental lines respectively.

The results indicated that GA_3 and $ZnSO_4$ as seed priming agents boosts seed germination and early seedling growth by activating genes linked to cell elongation and by stimulating dehydrogenase enzymes crucial for cellular respiration and energy metabolism, ultimately elevating total dehydrogenase activity. Similar findings were reported by Wang *et al.,* 2019 and Wu *et al.,* 2017.

The experiment demonstrated significant improvements in seed quality parameters in parental lines of maize hybrid MAH 15-84 through seed priming with various methods, concentrations and durations compared to the control. Priming with GA_3 and $ZnSO_4$ effectively enhanced seedling growth and vigour by promoting mechanisms such as cell elongation, stress tolerance and nutrient uptake. T_9 (50 ppm GA_3 for 12 h) and T_7 (1% $ZnSO_4$ for 12 h) emerged as optimal priming treatments which enhances overall seed quality and suitable for commercial exploitation of maize hybrid production. These findings offer practical pathways to enhance seedling establishment, vigour and yield in commercial maize seed production.

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