



RESEARCH ARTICLE

Atmospheric plasma exposure strengthens germination, seedling vigour and enzymatic activity for improved wheat establishment

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Abstract

Atmospheric plasma treatment markedly improved germination, early growth and biochemical activation in three wheat varieties (UP 2565, UP 2425, UP 2338) compared with hydropriming and untreated control. Plasma increased final germination from 91–92 % (control) to 94.7–96.0 %, translating into more reliable crop establishment. Emergence speed rose from 16.8–17.3 to 20.3–20.9 seedlings·day⁻¹ and shorten germination indicating faster and more uniform seedling emergence. The increase in seedling length dry weight by 18 % over control reflect stronger early growth and establishment potential. Vigour indices were substantially higher, underscoring the capacity of plasma treatment to produce robust seedlings capable of better field performance. Biochemically, plasma-treated seeds showed lower electrical conductivity, signifying improved membrane integrity, alongside higher dehydrogenase activity and greater α -amylase activity, which support rapid reserve mobilisation. Correlation analysis confirmed that superior germination and vigour were strongly associated with elevated enzyme activities (dehydrogenase, $r = 0.93$; α -amylase 24 hr $r = 0.99$) and inversely with electrical conductivity (EC) and mean germination time (MGT). These results demonstrate that plasma treated seeds by strengthening physiological processes critical for early establishment, offering a promising, scalable dry seed treatment to enhance wheat productivity pending optimisation of dosimetry and validation under field conditions.

Keywords: enzyme activities; membrane integrity; plasma treatment; seed germination; seed priming

Introduction

Wheat is central to global food security, supplying a major share of dietary protein and calories. Despite extensive research to improve its cultivation, productivity in key systems such as the rice–wheat cycle has declined over the past decade, threatening food security (1, 2). Declining productivity is aggravated by biotic, abiotic and management stresses, including poor soil health, water scarcity, salinity, pest pressure and climatic variability that often delay sowing and reduce germination (3, 4). Additionally, meteorological and non-climatic fluctuations in places like India often result in deviations from optimal sowing periods due to variables such as prolonged kharif crops, postponed harvesting, labour shortages and inadequate soil moisture (5). These challenges exacerbate temperature stress, delaying sowing and impairing seed germination and emergence, ultimately reducing overall crop productivity.

High germination rates and strong plant stand help wheat and other crops thrive in varied conditions. Water, physical or chemical treatments like sodium hypochlorite and sodium nitroprusside improve seed performance before sowing (6, 7). Seed priming affects cell function before germination, expanding the radicle and coleoptile (8). One of the most popular procedures for fast and even germination in poor conditions is hydropriming, which includes soaking seeds in water for a specified time and drying them in the shade (9). Hydropriming speeds up cellular, biochemical and metabolic processes, increases plant population density, germination rate and reduces chemical inputs. Hydropriming works, but it's time-consuming and difficult to scale up.

Due to these restrictions, exposing seeds to atmospheric plasma has become a new and promising way to improve seed technology by increasing the percentage of seeds that sprout and the vigour of seedlings (10). Plasma is an ionised gas with charged

particles. Sometimes dubbed the fourth condition of matter. It reduces microorganisms on seed surfaces, makes them water-loving and promotes germination and seedling growth. Plasma treatment hydrophilises the seed coat, allowing nutrients to pass through it for germination (11). Plasma's physical etching makes seeds more wettable, helping them absorb more water and restart metabolism (12, 13). Reactive species formed at ambient temperature and atmospheric pressure can contact biological tissues without thermal harm (14). Non-thermal plasma has attracted much interest as a novel pre-sowing method that can improve seed performance by reducing germination time and promoting overall plant growth (10). Plasma priming efficacy depends on osmotic and water potentials, priming agents, duration, temperature and aeration (15).

This study aims to comprehensively evaluate the effects of plasma exposure on wheat seed germination, biochemical activity, seedling vigour and productivity in both controlled laboratory and open-field environments, given its significant potential to enhance seed germination and overall production. Research on plasma technology in wheat is limited and this study is distinctive as it examines several aspects and employs multiple methodologies. The innovation involves combining laboratory findings with actual agricultural applications by examining the effects of low-pressure air plasma on germination, emergence and seedling performance in different wheat cultivars. This study aims to clarify the molecular relationships between plasma-induced changes and their practical implications for crop establishment by integrating physiological data with biochemical assays and correlation analysis. The objective of the experiment is to demonstrate that plasma priming may serve as a scalable, enduring seed treatment that enhances wheat growth and accelerates establishment.

Materials and Methods

Seed collection

Wheat was selected because of its high consumption and marketable importance. Seeds of late-sown wheat varieties, UP 2565, UP 2425 and UP 2338, were obtained from the Breeder Seed Production Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The seeds were visually scanned for any physical adulteration and pest damage and only seeds without defects were selected for plasma exposure. One seed lot of each variety was packed in a polyline cloth bag and sent to the Institute of Plasma Research, Ahmedabad, for plasma exposure. After treatment, the seeds were packed properly for further studies.

Exposure of seeds to plasma and hydro-priming

A schematic of the experimental apparatus used for seed treatment is shown in Fig. 1. The apparatus comprised a capacitive coupled plasma reactor containing a stainless steel (SS) chamber with a rotary pump to create the necessary sub-atmospheric vacuum. Seeds were treated with air plasma at a coupled power of 50 W and 0.7 m bar pressure for 6 min. All three wheat varieties were treated with plasma exposure to observe the impact of plasma on seed behavior. Hydropriming was performed by soaking the seeds in normal tap water at a seed-to-water ratio of 1 : 2 for 12 hr, followed by shade drying until the seeds reached their original moisture content.

Seed water uptake test

Seed moisture content was determined gravimetrically as per a previous study (16). About 10 g of treated seeds were placed in Petri dishes and removed at 12, 18 and 24 hr after initiation of imbibition, drained, blotted with absorbent paper and weighed. Seed moisture was determined as follows:

Seed moisture (%) =

$$\frac{\text{Total weight} - \text{Initial weight}}{\text{Initial weight}} \times 100$$

Seed germination and emergence

Seed germination was assessed following ISTA guidelines (ISTA, 2004). Radicle protrusion of 2 mm was considered germination. Seed germination percentage was calculated using standard formulas:

Germination percentage (%) =

$$\frac{\text{Number of normal seedlings}}{\text{Total number of seeds placed}} \times 100$$

Speed of emergence was calculated by following formula as suggested from a previous study (17):

$$\text{Speed of emergence} = \sum \frac{n}{d_i}$$

Where, n = No. of seeds newly germinated on day d_i ; d_i = i^{th} day after incubation

For calculating the mean germination time taken by seeds during the germination test was computed by following formula.

$$\text{Mean germination time} = \sum \frac{(n \times d_i)}{\sum n}$$

Where,

n = number of seeds newly germinated on day d_i ; and d_i = i^{th} day after incubation

Shoot-root length and seedling vigour

Shoot and root lengths were measured from normal seedlings obtained in the germination test. Five seedlings per sample were randomly selected and their root and shoot lengths were recorded, averaged and combined to calculate total seedling length. After measurement, samples were oven-dried at $70 \pm 2^\circ\text{C}$ for 48 hr until constant weight and dry weights were expressed as mg/seedling. Seedling vigour was calculated using following formula:

Vigour index I =

$$\text{Germination \%} \times \text{seedling length (cm/seedling)}$$

Vigour index II =

$$\text{Germination \%} \times \text{seedling dry weight (mg/seedling)}$$

Enzyme activities

The dehydrogenase activity was assessed via the tetrazolium reduction method outlined by Kittock and Law (18). Ten seeds from each treatment were soaked for 16 hr, embryos were removed, incubated in a 0.5 % tetrazolium solution and optical density was assessed at 480 nm using a spectrophotometer. Results were shown

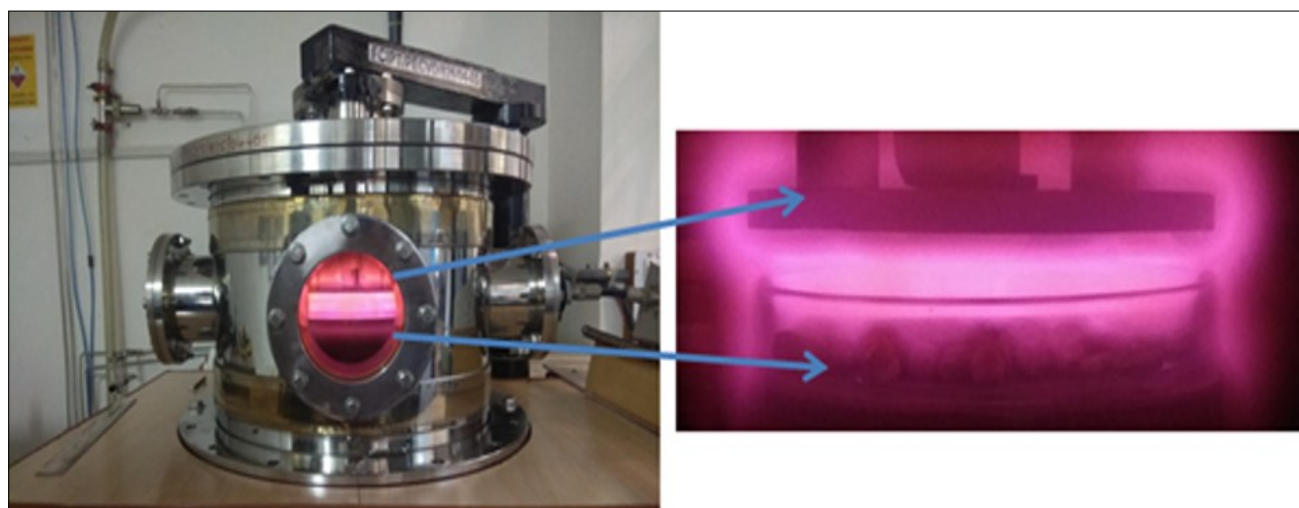


Fig. 1. Plasma system for wheat seed treatment (in-set shows closer view of plasma).

as OD per 10 seeds. α -Amylase activity was evaluated according to the methodology of Majumdar & Majumdar (19). Seeds undergoing germination were homogenised in Tris-HCl solution and the enzyme extract was incubated with a starch substrate. The reaction mixture was quenched with iodine reagent and absorbance was measured at 620 nm. Enzyme activity was measured using a starch standard curve and reported as mg of starch hydrolysed per g of seed.

Statistical analysis

Analysis of variance was used to analyse experimental data and the critical difference at 5 % significance was determined to examine the significance of any two means when the *F*-test was significant (20). Data from the inquiry were analysed using OPSTAT, created by CCS Haryana Agricultural University, Hisar, India to evaluate the statistical difference between treatments and make conclusions (21). Critical differences between treatments were examined at 5 %.

Results and Discussion

Speed of emergence and germination

Wheat emergence was considerably improved by atmospheric plasma exposure. UP 2565's emergence rate increased by 24 % above the control, although hydropriming improved it by 13 %. Compared to 3.0 days (control), 2.5 days (plasma) showed faster and more synchronised germination (Table 1). Plasma treatment improves early seed performance in all studied varieties. Compared to hydro-priming and untreated controls, plasma treatment boosted emergence rates, seedling length, dry weight and vigour indicators. These phenotypic improvements were supported by lower electrical conductivity, increased dehydrogenase and α -

amylase activity, indicating enhanced membrane integrity and faster metabolic activation during imbibition (6, 17). Our studies show that plasma priming can boost crop productivity and early establishment without chemicals.

Seedling growth and vigour index

Plasma treatment resulted in the greatest improvement in seedling growth and biomass accumulation. Seedling length was enhanced by ~16 % compared to control and a lower gain was observed with hydropriming (Table 1). Similarly, seedling dry weight was ~19 % greater following plasma treatment showing its stronger influence on early establishment. These improvements were also evident in vigour indices viz., SVI-1 was ~21 % higher and SVI-2 ~24 % higher in plasma exposure than in the control. Plasma always resulted in highest improvement in emergence, development and vigour whilst hydropriming was intermediate. Correlation analysis also supports these findings by correlating physiological and biochemical variables (17). The germination percentage was strongly and positively correlated with emergence ($r = 0.86$), seed dry weight ($r = 0.94$) and vigour indices (SVI-1 $r = 0.99$; SVI-2 $r = 0.99$) demonstrating that the improvement in germination immediately transferred to better establishment measures (Table 2). These improvements were also connected with biochemical parameters such as dehydrogenase activity ($r = 0.93$) and early α -amylase activity ($r = 0.99$) being favourably correlated with germination and vigour and mean germination time ($r = -0.96$) and electrical conductivity ($r = -0.98$) being negatively correlated. Such patterns demonstrate a coordinated response where reduced membrane leakage and increased metabolic activity (22) are the basis of the noted enhancements in seedling growth and vigour following plasma priming (13, 15).

Table 1. Germination and seedling growth and vigour indices of wheat under atmospheric plasma and conventional priming treatments

Treatment	Germination (%)	Speed of emergence (seeds/days)	Mean germination time (days)	Seedling length (cm)	Seedling dry weight (mg)	SVI-1	SVI-II
V1	Control	92.0	16.8	3.0	18.9	1,742.67	1,534.00
	Hydropriming	93.3	19.0	2.7	21.3	1,989.00	1,815.67
	Plasma treatment	96.0	20.9	2.5	22.0	2,112.00	1,900.00
V2	Control	91.3	17.1	3.0	18.9	1,727.67	1,681.33
	Hydropriming	93.3	19.2	2.6	20.7	1,927.67	1,801.00
	Plasma treatment	95.3	20.3	2.5	22.3	2,122.33	1,882.00
V3	Control	92.0	17.3	3.0	18.7	1,720.00	1,645.67
	Hydropriming	93.3	18.6	2.8	21.0	1,959.33	1,819.67
	Plasma treatment	94.7	20.3	2.5	21.9	2,069.33	1,859.67
C.D. ($p = 0.05$)	N/A	1.041	0.2	0.9	0.9	91.364	100.82

Table 2. Correlation matrix of germination, seedling vigour and biochemical traits in wheat

	Germination %	Seedling emergence	Mean germination time	Seedling length	Seed dry weight	SVI-1	SVI-2	Electrical conductivity	Dehydrogenase	α-Amylase (24h)	α-Amylase (48h)
Germination %	1.000***										
Seedling emergence	-0.861***	1.000***									
Mean germination time	-0.958***	0.931***	1.000***								
Seedling length	-0.619*	0.813**	0.775**	1.000***							
Seed dry weight	-0.939***	0.928***	0.986***	0.803**	1.000***						
SVI-1	0.991***	-0.897***	-0.978***	-0.690*	-0.966***	1.000***					
SVI-2	0.993***	-0.896***	-0.978***	-0.690*	-0.966***	0.998***	1.000***				
Electrical conductivity	-0.975***	0.929***	0.992***	0.759***	0.986***	-0.990***	-0.991***	1.000***			
Dehydrogenase	-0.932***	0.937***	0.986***	0.812**	0.994***	-0.962***	-0.962***	0.985***	1.000***		
α-Amylase (24 hr)	-0.990***	0.899***	0.983***	0.708*	0.972***	-0.995***	-0.996***	0.994***	0.967***	1.000***	
α-Amylase (48 hr)	0.333	0.500	-0.455	0.658*	0.204	0.621*	0.275	-0.196	0.728*	0.325	1.000***

Membrane stability and enzyme activities

Plasma-treated seeds exhibited lower electrical conductivity (EC) values (0.182–0.186 dS m⁻¹ across plasma types), indicating reduced membrane leakage during imbibition (Table 3). Plasma increased dehydrogenase activity to 0.25 OD/10 seeds in V1, but α-amylase activity increased quickly in a time-dependent manner, with plasma achieving the maximum starch hydrolysis rates (24, 25 mg g⁻¹ seed at 24 hr; up to 35.2mg g⁻¹ seed at 48 hr). Significant differences showed that plasma priming promotes respiratory activation and reserve mobilisation compared to hydropriming and control. Correlation analysis confirmed these results (Table 2). The germination percent was substantially correlated with emergence (r = 0.86), seed dry weight (r = 0.94), vigour indicators (SVI-1 r = 0.99; SVI-2 r = 0.99), dehydrogenase (r = 0.93) and early α-amylase activity (r in contrast, performance attributes were inversely linked with mean germination time (r = -0.96) and EC (r = -0.98). These patterns show that plasma exposure lowers membrane permeability and promotes metabolic activation, accelerating germination and seedling growth.

The empirical findings support plasma-mediated mechanisms hypothesised in the literature. Plasma-activated water and non-thermal plasma can alter seed surface characteristics and produce reactive species that communicate redox changes and enzyme activation (9, 15). Increased dehydrogenase activity and α-amylase levels indicate increased starch mobilisation and ATP synthesis for cell growth and radicle protrusion (1). Lower EC values indicate membrane compartmentation, promoting enzyme function and metabolite flux (23). Plasma had greater and more consistent advantages than hydropriming, possibly due to surface etching, improved wettability and transient reactive oxygen/nitrogen species signalling (8, 14). The correlation structure highlights important trait linkages but does not establish causality. Exposure to plasma produces reactive oxygen and nitrogen species (RONS) which serve as redox signals that activate downstream pathways such as MAPK cascades. These signalling events lead to the upregulation of α-amylase gene expression, which accelerates starch hydrolysis and energy release for radicle protrusion (24). The improvement of cereal α-amylase activity and germination performance by plasma-induced oxidative signalling has been confirmed by recent investigations (24, 25).

Table 3. Effect of atmospheric plasma and priming treatments on membrane stability and key enzyme activities in wheat seeds

Treatment	Membrane stability (EC)	Dehydrogenase activity	α-amylase (24 hr)	α-amylase (48 hr)
Control	0.209	0.225	22.033	30.523
V1 Hydropriming	0.188	0.234	23.433	33.213
V1 Plasma treatment	0.182	0.25	24.667	35.163
Control	0.213	0.23	22.3	27.067
V2 Hydropriming	0.193	0.239	23.3	28.7
V2 Plasma treatment	0.186	0.248	24.767	30.103
Control	0.218	0.217	20.433	25.423
V3 Hydro-priming	0.196	0.237	22.6	29.497
V3 Plasma treatment	0.185	0.248	24.067	31.243
C.D. (p = 0.05)	0.015	0.018	2.545	2.882

Conclusion

Atmospheric plasma treatment significantly enhanced germination and emergence velocity, decreased mean germination duration and resulted in longer seedlings of wheat types with increased dry weight, hence yielding considerably higher vigour indices. Biochemical studies indicated reduced electrical conductivity, heightened dehydrogenase activity and higher α -amylase levels at initial time points, correlating greater membrane integrity and expedited metabolic activation with improved germination and establishment. Atmospheric plasma is a highly promising and scalable pre-sowing treatment that enhances wheat establishment. However, targeted manipulation investigations, such as enzyme inhibition, reactive oxygen species scavenging and time-resolved metabolomics or transcriptomics, are necessary to ascertain whether membrane stabilisation or metabolic activity is the immediate factor enhancing germination. Field trials are crucial for assessing the persistence of early vigour increases under agronomic circumstances and their translation into yield advantages. Subsequent research should evaluate long-term seed viability, effects on seed microbiome and subsequent influences on plant growth.

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Authors' contributions

RS carried out the study, performed the alignment and drafted the manuscript. STP provided resources and guided the experiment. OV provided laboratory facilities and resources for the study. AP carried out formal analysis and manuscript review, writing and editing. MSP participated in statistical analysis and drafting. PK contributed to visualisation and manuscript review, writing and editing. SK was involved in manuscript review, writing and editing and formal analysis. AKR contributed to formal analysis and manuscript review, writing and editing. SVS was involved in formal analysis, data curation and manuscript review, writing and editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

- Rahman MM, Sajib SA, Rahi MS, Tahura S, Roy NC, Parvez S, et al. Mechanisms and signaling associated with LPDBD plasma mediated growth improvement in wheat. *Sci Rep.* 2018;8:10498. <https://doi.org/10.1038/s41598-018-28960-3>
- Nirmal NP, Anyimadu CF, Khanashyam AC, Annamalai S, Ramasamy S, Chinnasamy A, et al. Alternative protein sources: Addressing global food security and environmental sustainability. *Sustain Dev.* 2024;33:3958–76. <https://doi.org/10.1002/sd.3338>
- Anbukkani P, Shaloo S, Pal S. Adoption and impact of technology in the rice-wheat system. *Indian J Agric Sci.* 2020;90:31–6. <https://doi.org/10.56093/ijas.v90i1.98523>
- Dormatey R, Sun C, Ali K, Coulter JA, Bi Z, Bai J. Gene pyramiding for sustainable crop improvement against biotic and abiotic stresses. *Agronomy.* 2020;10:1255. <https://doi.org/10.3390/agronomy10091255>
- Kumar MVN, Ramya V, Govindaraj M, Dandapani A, Maheshwaramma S, Ganapathy KN, et al. India's rainfed sorghum improvement: Three decades of genetic gain assessment for yield, grain quality, grain mold and shoot fly resistance. *Front Plant Sci.* 2022;13:1056040. <https://doi.org/10.3389/fpls.2022.1056040>
- Błaszczak W, Doblado R, Frias J, Vidal-Valverde C, Zieliński H, Kaczmarek M. Microstructural and biochemical changes in raw and germinated cowpea seeds upon high pressure treatment. *Food Res Int.* 2007;40:415–23. <https://doi.org/10.1016/j.foodres.2006.10.018>
- Zhang SJ, Li L, Zhang CL, Li GM. ALA altered ABA content of winter oilseed rape (*Brassica napus* L.) seedling. *Agric Sci Technol.* 2011;12:484–7.
- Pereira AES, Oliveira HC, Fraceto LF, Santaella C. Nanotechnology potential in seed priming for sustainable agriculture. *Nanomaterials.* 2021;11:267. <https://doi.org/10.3390/nano11020267>
- Noreen S, Saleem MH, Ali B, Zafar H, Aqeel M, Rizwan M, et al. Advancing plant resilience against microplastics and metals through nanotechnology. *BioNanoScience.* 2024;14:2065–83. <https://doi.org/10.1007/s12668-024-01301-7>
- Randeniya LK, de Groot GJJB. Non-thermal plasma treatment of agricultural seeds for stimulation of germination, removal of surface contamination and other benefits: A review. *Plasma Process Polym.* 2015;12:608–23. <https://doi.org/10.1002/ppap.201500042>
- Ahmed N, Siow KS, Wee MFMR, Jamaludin N, Ab Rahim R, Mohd Zain Z, et al. A study to examine the ageing behaviour of cold plasma treated agricultural seeds. *Sci Rep.* 2023;13:2223. <https://doi.org/10.1038/s41598-023-28811-w>
- Wanyera R, Owuochi J. Wheat improvement, management and utilization. In: Bonjean AP, Angus WJ, van Ginkel M, editors. *The World Wheat Book.* 2017. p. 1105–42. <https://doi.org/10.5772/63694>
- Kumar P. Biostimulatory effects of plasma on seeds and plants. *Int J Res Appl Sci Eng Technol.* 2015;13:1101–8. <https://doi.org/10.22214/ijraset.2025.73152>
- Fatelnig LMM, Chanyalew S, Tadesse M, Abebe A, Assefa K, Alemu D, et al. Seed priming with gas plasma activated water in Ethiopia's "orphan" crop tef (*Eragrostis tef*). *Planta.* 2024;259:83. <https://doi.org/10.1007/s00425-024-04359-5>
- Adhikari B, Adhikari M, Ghimire B, Adhikari BC, Park G, Choi EH, et al. Cold plasma seed priming modulates growth, redox homeostasis and stress response by inducing reactive species in tomato (*Solanum lycopersicum*). *Free Radic Biol Med.* 2020;156:57–69. <https://doi.org/10.1016/j.freeradbiomed.2020.06.003>
- Chen HH, Chang HC, Chen YK, Hung CL, Lin SY, Chen YS. An improved process for high nutrition of germinated brown rice production: Low-pressure plasma. *Food Chem.* 2016;191:120–7. <https://doi.org/10.1016/j.foodchem.2015.01.083>
- Maguire JD. Speed of germination aid in selection and evaluation for seedling emergence and vigour. *Crop Sci.* 1962;2:176–7. <https://doi.org/10.2135/cropsci1962.0011183X000200020033x>
- Kittcock PA, Law AG. Relationship of seedling vigour to respiration and tetrazolium chloride reduction of germinating wheat seeds. *Agron J.* 1968;60:286–8. <https://doi.org/10.2134/agronj1968.00021962006000030012x>
- Majumdar BC, Majumdar K. Methods on physicochemical analysis of fruits. Kolkata: University College of Agriculture, Calcutta University; 2003. p. 140–65.
- Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; 1984. p. 680.
- Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. Statistical software package for agricultural research workers. In: Hooda DS, Hasija RC, editors. *Recent advances in information theory, statistics & computer applications.* Hisar: CCS HAU, Department of Mathematics

Statistics; 1998. p. 139–43.

22. Gouribhai P, Yashaswini S, Ramakrishna H, Nawalagatti C. Evaluation of seed storability and pre-sowing treatments to enhance germination and seedling performance in cinnamon (*Cinnamomum verum* J Presl). *Plant Sci Today*. 2026;13(sp1):1–7. <https://doi.org/10.14719/pst.11965>
23. Liu B. Non-thermal atmospheric pressure plasma interacting with water for biological applications. HAL (Le Centre pour la Communication Scientifique Directe); 2019.
24. Starič P, Mravlje J, Mozetič M, Zaplotnik R, Šetina Batič B, Junkar I, et al. The influence of glow and afterglow cold plasma treatment on biochemistry, morphology and physiology of wheat seeds. *Int J Mol Sci*. 2022;23:7369. <https://doi.org/10.3390/ijms23137369>
25. Jatana BS, Grover S, Ram H, Baath GS. Seed priming: Molecular and physiological mechanisms underlying biotic and abiotic stress tolerance. *Agronomy*. 2024;14:2901. <https://doi.org/10.3390/agronomy14122901>

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