

Impact of Gibberellic Acid (GA₃) on Seed Germination and Early Seedling Growth of Basil (*Ocimum basilicum* L.)

Shazia Mushtaq*¹

¹ P. G. Department of Botany, Sri Pratap College, Cluster University, Srinagar - 190 001, Jammu and Kashmir, India

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Abstract

The present study evaluated the physiological effects of varying concentrations of Gibberellic Acid (GA₃) on the seed germination dynamics and early seedling growth of Sweet Basil (*Ocimum basilicum* L.), an economically vital aromatic and medicinal herb. Basil seeds were subjected to a 24-hour pre-sowing imbibition treatment across three distinct GA₃ concentrations 50 ppm, 100 ppm, and 150 ppm alongside a double-distilled water control (0 ppm) under strictly controlled laboratory conditions (23°C) for 15 days. The experiment followed a completely randomized design with three replicates per treatment. The 100 ppm GA₃ treatment demonstrated the highest efficiency, achieving a Final Germination Percentage (FGP) of 80%, the shortest Mean Germination Time (MGT) of 6.00 days, an optimal Coefficient of Velocity of Germination (CVG) of 20.81% / day, and a highly synchronized Time Spread of Germination (TSG) of 0.00 days. Conversely, the highest concentration (150 ppm) triggered rapid early radical emergence (T50 = 5 days) and the maximal Mean Combined Seedling Length (8.28 ± 1.95 cm) driven by dramatic shoot elongation (5.28 ± 1.84 cm), but exhibited a decline in absolute viability (FGP = 60%). These outcomes reveal a concentration-dependent physiological threshold where 100 ppm GA₃ optimizes absolute germinative fitness and population uniformity, establishing a baseline for standard cultivation practices.

Key words: *Ocimum basilicum*, Gibberellic acid (GA₃), Seed priming, Germination kinetics, Seedling vigor

Sweet Basil (*Ocimum basilicum* L.) is a premier annual herbaceous plant belonging to the Lamiaceae family. Broadly distributed and commercially cultivated within tropical, subtropical, and temperate zones including the Indian subcontinent basil holds immense culinary, industrial, and ethnopharmacological value. The economic viability of *O. basilicum* rests on its rich profile of secondary metabolites accumulated within the soft green leaf tissue, notably volatile essential oils such as linalool, eugenol, methyl chavicol, and cineole [1]. These compounds exhibit high antimicrobial, antioxidant, anti-inflammatory, and digestive bioactivities, prompting extensive extraction for the perfumery, cosmetic, food processing, and phytopharmaceutical sectors [2].

Seed germination is a fundamental physiological process that marks the transition of a viable seed from a quiescent state to active seedling growth and represents one of the most critical stages in the life cycle of higher plants. Successful germination determines the establishment of an adequate plant population, uniform seedling emergence, subsequent crop development, and, ultimately, yield potential. Since poor or delayed germination can result in inadequate and heterogeneous plant stands, germination is often considered a major bottleneck in crop establishment and productivity [3]. Even under favorable production conditions, differences in germination rate and emergence among individual seeds can lead to considerable variation in seedling vigor and developmental stages, thereby affecting the efficiency of crop management and final economic

returns. Seed germination is a highly regulated process involving a sequence of physiological, biochemical, and molecular events. It is conventionally divided into three partially overlapping phases. The first phase, Phase I or imbibition, involves rapid and largely physical uptake of water by the dry seed. Water absorption causes hydration of cellular components, restoration of membrane structure and integrity, and initiation of respiratory and metabolic processes. This is followed by Phase II, characterized by intensive metabolic activation. During this stage, respiration increases, cellular repair mechanisms are activated, and enzymes responsible for mobilizing stored food reserves become functional. Hydrolytic enzymes, including amylases, proteases, and lipases, convert stored carbohydrates, proteins, and lipids into readily available metabolites that provide energy and structural components for embryonic growth [4]. The final phase, Phase III, is associated with renewed water uptake, cell expansion and elongation of the embryonic axis, culminating in radicle protrusion. Radicle emergence is generally regarded as the visible completion of germination and represents the beginning of independent seedling establishment [5].

The progression through these phases is strongly influenced by both intrinsic seed characteristics and external environmental conditions. Seed viability, physiological maturity, dormancy status, seed size, storage history, and endogenous hormonal balance can affect germination behavior [6]. Among environmental factors, temperature, moisture

*Correspondence to: Shazia Mushtaq, E-mail: shaazia23@gmail.com; Tel: +91 9797995822

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availability, oxygen supply, light, and growing-medium characteristics play particularly important roles in regulating germination and early seedling development. Deviations from optimum conditions may impair enzymatic activity, restrict reserve mobilization, alter membrane functioning, and delay radicle emergence [7]. Therefore, improving the speed, percentage, and uniformity of germination is an important prerequisite for achieving consistent crop establishment.

Sweet basil (*Ocimum basilicum* L.), belonging to the family Lamiaceae, is an economically important aromatic and medicinal plant cultivated extensively for its fresh leaves, culinary applications, essential oil, and pharmaceutical value. The crop contains a wide range of biologically active compounds and has gained increasing attention because of its nutritional, medicinal, aromatic, and industrial applications. Despite its economic importance, successful establishment of basil crops can be constrained by poor and non-uniform seed germination [8]. Under commercial production conditions, *O. basilicum* seeds may exhibit delayed emergence, reduced germination percentage, and substantial variation in germination timing, particularly when environmental conditions are suboptimal. Such irregularity at the initial stage can ultimately result in heterogeneous crop stands and variation in plant growth and development [9].

The small size and physiological characteristics of basil seeds make careful management of germination conditions particularly important. Inadequate moisture can restrict imbibition and delay the activation of metabolic processes, whereas excessive moisture may limit oxygen availability and adversely affect respiration [10]. Similarly, unsuitable temperatures can interfere with enzyme activity and the biochemical reactions required for reserve mobilization and embryonic growth. Consequently, seeds exposed to unfavorable conditions may require a longer period to complete germination or may fail to germinate altogether [11]. These limitations become particularly significant in commercial nursery production, where rapid and synchronized emergence is essential for producing uniform seedlings within a defined production period.

Uneven germination has several downstream consequences for basil production. Variation in emergence results in seedlings of different ages and sizes occupying the same production area, leading to differences in vegetative growth, canopy development, nutrient acquisition, and biomass accumulation [12]. Such heterogeneity can complicate irrigation, fertilization, weed management, transplanting, and harvesting operations. Furthermore, low germination percentage may necessitate higher seed rates or gap filling, thereby increasing production costs. In a crop cultivated primarily for its foliage and biomass, non-uniform establishment may also reduce harvest efficiency and the proportion of marketable produce [13]. Thus, interventions aimed at improving germination percentage and synchrony have considerable practical significance for enhancing the productivity and profitability of *Ocimum basilicum* cultivation.

Seed enhancement techniques have therefore emerged as important approaches for overcoming physiological and environmental constraints associated with germination. Treatments such as hydropriming, osmopriming, hormonal priming, nutrient-based priming, biostimulant application, and the use of biologically active plant-derived substances can potentially accelerate metabolic activation and improve seedling establishment [14]. These approaches may shorten the time required for germination, enhance enzymatic activity, improve mobilization of stored reserves, and promote more rapid radicle and shoot development. However, the

effectiveness of a particular treatment depends on its concentration, duration of exposure, seed physiological status, and environmental conditions [15]. Excessive concentrations of some bioactive compounds may, conversely, inhibit germination or induce physiological stress, highlighting the importance of determining appropriate treatment levels.

In this context, systematic evaluation of seed treatments and their effects on germination and early seedling growth is essential for identifying practical approaches to improve establishment in *O. basilicum*. Parameters such as germination percentage, mean germination time, germination rate, seedling length, fresh and dry biomass, and seedling vigour provide useful indicators for assessing the effectiveness of different treatments. Understanding the response of basil seeds to such interventions can contribute to the development of efficient seed-enhancement protocols suitable for nursery and commercial production [16].

Phytohormones serve as the primary biochemical switches regulating the transitions between seed dormancy and active germination [17-18]. Gibberellic Acid (GA₃) is an endogenous tetracyclic diterpenoid compound that operates antagonistically against Absciscic Acid (ABA). Upon seed hydration, gibberellins synthesized in the embryo signal the aleurone layer to express alpha-amylase, proteases, and glucanases [19]. These de novo enzymes mobilize endospermic or cotyledonary reserves into transportable soluble sugars (glucose) and amino acids, simultaneously lowering the mechanical resistance of the enclosing seed coat to facilitate radical escape.

Given that the physiological efficacy of exogenous GA₃ applications depends tightly on concentration thresholds and species specificity, this investigation sought to:

1. Determine the exact influence of varying GA₃ doses (50, 100, and 150 ppm) on the complete germinative profile of *Ocimum basilicum* L.
2. Quantify the morphology of post-germination seedling architecture via shoot and root metric calculations.
3. Identify the optimum hormonal concentration required to secure maximum germinative uniformity and seedling vigor for agricultural standardization.

MATERIALS AND METHODS

Experimental setting and microclimate

The investigation was completed during the 2024-2025 academic calendar inside the research laboratories of the Post-Graduate Department of Botany, Sri Pratap College, Cluster University Srinagar, Jammu and Kashmir (34.0768° N, 74.8158° E). The surrounding Kashmir Valley provides a temperate alpine setting with distinct seasonal climate swings. To ensure reproducibility, all stages of the seed assay were maintained inside automated environmental chambers at a constant microclimatic temperature of 23 ± 1°C.

Sterilization of instrumentation and substrates

To eliminate microbial vectors without introducing toxic chemical residues, a precise multi-tier sterilization protocol was enforced:

Glassware and tools: All Borosil glass Petri plates, beakers, graduated cylinders, and metallic forceps were cleaned with laboratory-grade surfactant, wrapped securely in heavy-duty aluminum foil, and autoclaved at 121°C under 15 psi of saturated steam for 20 minutes.

Seed lots: Viable *Ocimum basilicum* seeds underwent surface decontamination inside a horizontal laminar airflow cabinet using a freshly prepared 4% sodium hypochlorite (NaOCl) solution (2 mL NaOCl : 2 mL dH₂O) for a brief duration, followed by five consecutive washes with sterile double-distilled water to strip away trace halogens.

Initial seed viability baseline

Pre-experimental seed lot quality was verified using a biochemical standard Tetrazolium (TZ) test. Seeds were bisected and treated with a 1.0% 2,3,5-triphenyl tetrazolium chloride solution to visualize mitochondrial dehydrogenase activity. The batch displayed a baseline viability range of 75% to 80%, validating its biochemical integrity for physiological testing.

Formulation of phytohormone dilutions

A highly concentrated stock solution of 150 ppm GA₃ was formulated by dissolving 37.5 mg of high-purity Gibberellic Acid powder in a minimal volume of absolute ethanol (to dissolve the hydrophobic hormone crystal) before diluting to a final volume of 250 mL using sterile distilled water. Utilizing the linear volumetric allocation rule (C1V1 = C2V2), this master batch was dynamically reduced to produce distinct operational concentrations of 50 ppm, 100 ppm, and 150 ppm. A separate allocation of pure double-distilled water (0 ppm) served as the absolute control.

Imbibition and inoculation matrix

Decontaminated seeds were partitioned into four uniform cohorts and fully immersed in their designated treatment solutions for an inductive priming window of 2–3 hours. Following hydration, exactly 15 seeds were transferred via sterile forceps into each lined Petri plate (90 mm) containing dual layers of Whatman No. 1 filter paper saturated with 5 mL of the corresponding chemical concentration. Every treatment tier was set up with three true experimental replicates (R₁, R₂, R₃), producing a structured analytical baseline. The arrays were transferred into a dark incubator set at 23°C for a 15-day monitoring window. Daily physical counts tracked radical emergence (defined as a visible root protrusion ≥ 2 mm).

Seedling ex-vitro transplantation

Upon completing the initial 15-day petri-plate monitoring phase, germinated basil seedlings were carefully

shifted into cellular nursery propagation trays packed with a sterilized, aerated composite growth matrix consisting of organic vermicompost and native sandy loam topsoil (1:1 v/v). The trays were placed inside the departmental greenhouse facility under controlled ambient humidity (65%) and a natural photoperiod to document long-term morphological progression.

Analytical quantification formulas

To characterize the germination dynamics under the influence of GA₃, ten mathematical indices were calculated:

1. Final Germination Percentage (FGP): $FGP = (\text{Total seeds germinated} / \text{Total seeds tested}) \times 100$
2. Mean Germination Time (MGT): $MGT = \text{sum}(f \times x) / \text{sum}(f)$, where f is the daily incremental germination tally on day x .
3. Germination Index (GI): $GI = (10 \times n_1) + (9 \times n_2) + \dots + (1 \times n_{10})$, giving top weight to rapid early emergence.
4. Coefficient of Velocity of Germination (CVG): $CVG = [G / \text{sum}(G \times T)] \times 100$, where G is the daily count and T is days elapsed.
5. Germination Rate Index (GRI): $GRI = (G_1/1) + (G_2/2) + \dots + (G_x/x)$.
6. First Day of Germination (FDG): The absolute calendar day when initial radicle rupture is recorded.
7. Last Day of Germination (LDG): The terminal calendar day after which no further emergence occurs.
8. Time Spread of Germination (TSG): $TSG = LDG - FDG$.
9. Mean Germination Rate (MGR): $MGR = GT / T$, measuring daily throughput.
10. Time to 50% Germination (T50): $T50 = t_i + \{[(N/2) - n_i] / (n_j - n_i)\} \times (t_j - t_i)$, measuring population mid-point transition.

RESULTS AND DISCUSSION

Germination kinematics matrix

The daily germination counts across 15 days of continuous incubation revealed distinct variations among the treatment groups. The 100 ppm GA₃ concentration achieved optimal performance across key parameters, showing an FGP of 80%, an MGT of 6.00 days, and a CVG of 20.81% / day. It also resulted in a highly uniform TSG of 0.00 days, indicating tightly synchronized emergence [20–21]. Data in (Table 1) presents the summary matrix of the calculated mathematical indices across the various treatment tiers.

Table 1 Summary mathematical index matrix for *Ocimum basilicum* seeds

Germination index metric	Control (0 ppm)	50 ppm GA ₃	100 ppm GA ₃	150 ppm GA ₃
Final germination percentage (FGP)	40%	40%	80%	60%
Mean germination time (MGT in days)	7.93	7.83	6.00	7.67
Germination index (GI)	0.484	0.517	0.208	0.359
Coefficient of velocity (CVG %/day)	13.36	14.86	20.81	17.81
Germination rate index (GRI %/day)	9.68	10.35	4.16	7.18
First day of germination (FDG)	Day 4	Day 3	Day 3	Day 4
Last day of germination (LDG)	Day 12	Day 11	Day 11	Day 11
Time spread of germination (TSG)	6.67	6.00	0.00	4.00
Mean germination rate (MGR)	0.134	0.149	0.208	0.178
Time to 50% germination (T ₅₀ days)	6.39	5.83	5.83	5.00

The germination response of *Ocimum basilicum* seeds varied substantially among the GA₃ treatments, with 100 ppm GA₃ showing the most favourable overall germination performance. Final germination percentage (FGP) increased from 40% in the control and 50 ppm GA₃ treatments to 80% at

100 ppm GA₃, representing a two-fold improvement over the control. At 150 ppm GA₃, FGP declined to 60%, indicating that the beneficial effect of GA₃ was not linear with increasing concentration and that 100 ppm was the most effective concentration under the experimental conditions. The temporal

parameters further supported the superiority of 100 ppm GA₃. Mean germination time (MGT) was reduced from 7.93 days in the control to 6.00 days at 100 ppm, indicating earlier germination. The coefficient of velocity of germination (CVG) correspondingly increased from 13.36% day⁻¹ to 20.81% day⁻¹, while mean germination rate (MGR) increased from 0.134 to 0.208, demonstrating faster germination kinetics. The first day of germination was advanced from day 4 in the control to day 3 under 100 ppm GA₃, whereas germination was completed by day 11 compared with day 12 in the control [22].

A particularly notable feature of the 100 ppm treatment was its time spread of germination (TSG) of 0.00 days, suggesting highly concentrated or synchronized germination within the observations used for calculating this index. In contrast, TSG values were 6.67, 6.00 and 4.00 days for the control, 50 and 150 ppm treatments, respectively. The T50 was also reduced from 6.39 days in the control to 5.83 days at 100 ppm GA₃, further indicating accelerated attainment of 50% germination. Interestingly, the germination index (GI) and germination rate index (GRI) did not follow the same pattern as FGP, MGT, CVG and MGR. The highest GI was recorded at 50 ppm GA₃ (0.517), followed by the control (0.484), 150 ppm

(0.359) and 100 ppm (0.208). Similarly, GRI was highest in the control (9.68% day⁻¹) and 50 ppm GA₃ (10.35% day⁻¹), whereas 100 ppm recorded 4.16% day⁻¹. This apparent discrepancy suggests that the indices may have been calculated using different mathematical formulations or normalization procedures, and the reported values should therefore be checked against the underlying daily germination counts before publication [23]. The matrix indicates that 100 ppm GA₃ produced the strongest combination of high final germination, rapid germination, increased germination velocity, early onset and reduced temporal spread, whereas increasing the concentration to 150 ppm resulted in a decline in FGP and germination performance [24-25]. Thus, 100 ppm GA₃ may be considered the optimum treatment for promoting rapid and synchronized germination of *Ocimum basilicum* seeds under the conditions of the present study.

Morphological seedling architecture outcomes

Data collected on day 15 showed that GA₃ treatments altered the morphological development of roots and shoots compared to the control group. Data depicted in (Table 2) summarizes these structural outcomes.

Table 2 Effect of different concentrations of GA₃ on root length, shoot length and total seedling length

Treatment tier	Mean root length (cm ± SD)	Mean shoot length (cm ± SD)	Total seedling length (cm ± SD)
Control (0 ppm)	3.00 ± 2.45	2.56 ± 2.13	5.56 ± 4.41
50 ppm GA ₃	1.83 ± 0.26	5.97 ± 2.37	7.80 ± 2.52
100 ppm GA ₃	3.08 ± 0.88	4.58 ± 1.06	7.67 ± 1.63
150 ppm GA ₃	3.00 ± 0.27	5.28 ± 1.84	8.28 ± 1.95

Influence of GA₃ on germination kinetics

The baseline control group (0 ppm) exhibited low total germination (40%) and an extended Mean Germination Time (7.93 days), indicating slow metabolic activation in the absence of exogenous stimulation. Applying 100 ppm GA₃ significantly improved germinative fitness, doubling the final germination percentage to 80% and reducing the MGT to 6.00 days. This enhancement is linked to the role of gibberellins in upregulating cellular respiration and activating hydrolytic enzymes like alpha-amylase within the aleurone layer [26]. These enzymes break down starch reserves into soluble sugars, providing the energy required for initial embryonic axis growth and radicle emergence. Additionally, the 100 ppm treatment achieved a Time Spread of Germination (TSG) of 0.00 days, indicating a highly synchronized population response. In agricultural systems, uniform seedling emergence is a critical factor for establishing synchronized crop stands and optimizing subsequent mechanical management [27-28].

Concentration-dependent thresholds and inhibitory effects

When the concentration was increased to 150 ppm, the population reached 50% germination more rapidly (T₅₀ = 5.00 days), but the final germination percentage dropped to 60%. This indicates that while higher concentrations of GA₃ can accelerate early radicle emergence, excessive doses may induce physiological stress or cause cellular imbalances that decrease overall seed viability. High concentrations of exogenous gibberellins can disrupt the internal balance with other phytohormones, such as Absciscic Acid and ethylene, potentially leading to toxic effects in the embryo or cellular exhaustion during early emergence [29-30].

Variations in seedling structural allometry

The morphological data showed distinct developmental patterns between root and shoot systems in response to GA₃

exposure. The highest concentration (150 ppm) produced the maximum combined seedling length (8.28 ± 1.95 cm), driven primarily by shoot elongation (5.28 ± 1.84 cm). Gibberellins promote shoot growth by activating xyloglucan endotransglycosylase (XET) and expansin proteins, which increase cell wall plasticity and stimulate cell division and elongation within stem internodes [31-32]. However, this rapid shoot expansion often occurs at the expense of root architecture. At 50 ppm, shoot length increased significantly (5.97 cm), but root growth was restricted (1.83 cm), resulting in a high shoot-to-root ratio [33]. In field conditions, seedlings with overly elongated shoots and underdeveloped roots are susceptible to lodging and nutrient deficiency. The 100 ppm GA₃ treatment provided the most balanced growth distribution, maintaining robust root development (3.08 ± 0.88 cm) alongside steady shoot growth (4.58 ± 1.06 cm), which supports stable seedling establishment [34-35].

CONCLUSION

This investigation demonstrates that exogenous gibberellic acid (GA₃) acts as an effective priming agent to optimize the seed germination and early seedling growth of *Ocimum basilicum* L., operating within a defined concentration threshold. 100 ppm GA₃ emerged as the optimal concentration, achieving a Final Germination Percentage of 80%, a low Mean Germination Time of 6.00 days, and highly synchronized population emergence (TSG = 0.00 days). It also supported a balanced distribution between root and shoot systems. Higher concentrations (150 ppm) accelerated early emergence rates but reduced overall population viability (FGP = 60%) and caused disproportionate shoot elongation, which can compromise seedling structural stability. Untreated control seeds showed low germination rates and delayed emergence, confirming the utility of pre-sowing chemical priming for this species.

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