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Research Article

ROOT SYSTEM ARCHITECTURE AND BIOMASS EFFICIENCY OF *IN VITRO*-PROPAGATED TURMERIC (*Curcuma longa* L.) UNDER HYDROPONIC ACCLIMATIZATION

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ABSTRACT. Acclimatization remains a major bottleneck in the micropropagation of turmeric (Curcuma longa L.) due to the physiological vulnerability of in vitro-derived plantlets during the transition to ex vitro conditions. This study evaluated the effectiveness of seaweed extract (SWE) as a biostimulant in a hydroponic acclimatization system to enhance root system architecture (RSA), biomass efficiency, and plant survival. Supplementation of the nutrient solution with 1.00 mL L^{-1} SWE significantly promoted root proliferation, root elongation, and total biomass accumulation compared with the control treatment. Improved root development translated into greater biomass efficiency, indicating enhanced plant vigor during acclimatization. Furthermore, all treatments achieved a 100% survival rate, demonstrating the suitability of the hydroponic system for supporting the establishment of in vitro-propagated turmeric. These findings suggest that SWE-enriched hydroponic acclimatization provides an effective strategy for improving early plant growth, root development, and biomass production, thereby facilitating the successful transition of micropropagated turmeric plantlets to ex vitro conditions.

Keywords: *Acclimatization, Hydroponic system, Micropropagation, Seaweed extract, Root system architecture, Turmeric*

INTRODUCTION

The successful ex vitro establishment of in vitro-propagated plants remains a major bottleneck in micropropagation. Plantlets derived from tissue culture typically exhibit underdeveloped cuticles, dysfunctional stomata, and fragile root systems, rendering them highly susceptible to desiccation and stress upon transfer to external environments [17]. These anatomical deficiencies such as thin cuticles, reduced mesophyll density, and impaired stomatal regulation are largely attributed to the high humidity, low irradiance, and exogenous growth regulators present in culture vessels [13, 20].

Traditional soil-based acclimatization methods are often unreliable due to microbial contamination and substrate variability, leading to inconsistent survival rates [7]. Although turmeric (*Curcuma longa* L.) micropropagation has achieved greenhouse survival rates of 90–98% under optimized protocols, reproducibility remains challenging [9]. To address these constraints, soilless systems offer precise environmental control. The Kratky hydroponic system, a passive, non-circulating system, provides controlled nutrient delivery and root-zone aeration without electrical inputs, making it particularly suitable for acclimatization studies [4, 1].

Complementing physical growth conditions, bioactive compounds have emerged as effective biostimulants for enhancing plant resilience during acclimatization. Seaweed

extracts, rich in cytokinins, auxins, gibberellins, and micronutrients, activate stress-responsive signaling pathways and promote root development and stress tolerance [17]. Integrating optimized hydroponic systems with targeted biostimulant application may thus improve survival, vigor, and biomass production of in vitro-propagated turmeric, supporting more efficient production of this high-value medicinal and culinary crop [9].

MATERIALS AND METHODS

Plant Material Preparation

Micropropagated turmeric plantlets were screened for size, vigor, and health. Contaminated, abnormal, or stressed plantlets were discarded. To maintain consistency, selected plantlets were at the same growth stage, measuring 4–5 cm in height with 3–4 fully expanded leaves, and prepared for acclimatization [2].

Hydroponic System Setup

The hydroponic setup utilized the Kratky method, a passive and efficient deep-water culture system tailored for the acclimatization of turmeric plantlets [12]. The system consisted of a 3-inch diameter PVC pipe serving as the nutrient reservoir, into which net pots were securely placed [19]. The net pots were filled with sterile foam, a growing medium that provided physical support to the plantlets. The nutrient solution, formulated with a seaweed extract, initially reached the bottom of the net pots, ensuring root contact for nutrient uptake. Key parameters of the solution included a pH maintained between 5.5 and 6.5 [21] and an electrical conductivity (EC) of 1.0–2.5 millisiemens per centimeter (mS cm-1) (equivalent to approximately 500 to 1,250 ppm) [5], optimized to support early growth. As water levels in the reservoir naturally decreased, an air gap formed, facilitating root aeration and promoting nutrient absorption. Regular monitoring of the nutrient solution ensured stability in pH and EC, critical for consistent plant development. This simple, low-maintenance system was instrumental in acclimatizing in vitro-cultured turmeric effectively.

Acclimatization Success Rate (ASR)

The acclimatization success rate was determined to evaluate the efficiency of the hydroponic system in producing healthy plantlets capable of surviving the transition from the controlled aeroponic environment to external environmental conditions. The ASR was calculated using Eqn. 1:

$$ASR\ (\%) = \frac{Number\ of\ plants\ that\ survived\ \&\ met\ criteria}{Initial\ number\ of\ plants} \times 100$$

Eqn. 1

In this study, the initial number of plants referred to the total number of plantlets transferred from the laboratory to hydroponic system for acclimatization. Plants were observed for one week to monitor survival and adaptation. A plant was considered "survived and met criteria" if it exhibited active new leaf growth, firm root establishment, and absence of wilting. Plants failing to meet these criteria were classified as unsuccessful. The resulting ASR percentage provided a quantitative measure of the system's capability to produce robust, transplant-ready seedlings.

Days to Acclimatize

The Days to Acclimatize (DA) were determined to assess the time required for plantlets grown in the hydroponic system to successfully adapt and become ready for transfer to the nursery. This parameter serves as an indicator of the physiological readiness and stress tolerance of the plants produced by the system. Plantlets with well-developed root systems were carefully removed, rinsed to remove excess nutrient residues, and transplanted into pots containing a sterile growth medium, such as coco peat or a soil mixture. The plants were then placed in the nursery, ready for field planting.

Care and Management of the Crop

During the acclimatization process, turmeric plantlets were maintained in a controlled environment to ensure optimal growth and development. The hydroponic systems were cleaned and replenished with fresh nutrient solutions every 7 days to prevent contamination and nutrient depletion. Plantlets were monitored daily for signs of stress, pest, or disease, and any affected plants were removed immediately. Humidity levels were maintained at 70-80% to reduce dehydration stress, while the temperature was kept at 25 ± 2°C. Dead or senescing leaves were pruned weekly to encourage healthy growth, and the systems were inspected regularly to ensure consistent aeration and nutrient delivery.

Experimental Design

The experiment employed a completely randomized design (CRD) to assess the effects of nutrient solution concentrations on in vitro turmeric plantlet acclimatization. Four concentrations were tested: control (no seaweed extract), 0.75 mL L^{-1}, 1.00 mL L^{-1} and 1.50 mL L^{-1} seaweed extract. Data analysis involved ANOVA using the Statistical Tool for Agricultural Research (STAR), with Tukey's HSD test applied to compare significant treatment means.

RESULTS AND DISCUSSION

Root Development of Acclimatized Turmeric

The results presented in Table 1 indicate a clear influence of seaweed extract concentration on the root development of acclimatized turmeric plantlets. The number of roots and the length of roots both demonstrated statistically significant improvements in response to increasing SWE concentrations, with varying degrees of enhancement.

In terms of root number, there was a notable increase from the control (no SWE) to the highest SWE concentrations. The control plants produced an average of 19.00 roots, whereas those treated with 1.00 mL L^{-1} and 1.50 mL L^{-1} SWE both exhibited a marked increase to 24.33 roots. This represents approximately a 28% improvement in root number due to SWE application. Even at 0.75 mL L^{-1} SWE, root number rose to 22.67, reflecting a 19% increase over the control. However, statistical groupings indicate that while 1.00 mL L^{-1} and 1.50 mL L^{-1} SWE had the highest mean values, their differences from the 0.75 mL L^{-1} treatment were not statistically distinct, suggesting a plateau in response beyond 1.00 mL L^{-1} [14].

The optimal performance (1.00 mL L^{-1} SWE and 1.5 mL L^{-1} SWE) aligns with research showing that adequate macro- and micronutrient availability is crucial for root elongation and lateral root formation [14]. Conversely, the poor performance (0 ml -l SWE) indicates

that suboptimal nutrients restrict root development, consistent with studies demonstrating hydroponic systems' advantages in providing optimal root growth conditions through precise oxygen and nutrient delivery [8, 18]. These findings confirm 1.00 mL L^{-1} SWE and 1.5 mL L^{-1} SWE as essential for enhancing root development in in vitro-propagated turmeric.

Table 1. *Root development of acclimatized turmeric*

Treatments	Number of roots	Length of root, mm
0 mL L^{-1} SWE (Control)	19.00[b]	89.73b
0.75 mL L^{-1} SWE	22.67[ab]	98.20ab
1.00 mL L^{-1} SWE	24.33[a]	103.90a
1.50 mL L^{-1} SWE	24.33[a]	103.23a

Means with the same letter(s) are not significantly different.

Regarding root length, a similar trend of enhancement was observed. Root length increased from 89.73 mm in the control to 103.90 mm at 1.00 mL L^{-1} SWE, a 15.8% improvement. The 1.50 mL L^{-1} SWE concentration showed a comparable result at 103.23 mm, while 0.75 mL L^{-1} SWE concentration yielded 98.20 mm, still an appreciable 9.4% increase over the control. This suggests that SWE positively influenced not only the quantity but also the quality (elongation) of root development, likely due to the bioactive compounds in seaweed such as cytokinins, auxins, and micronutrients [3, 11, 24]. The diminishing returns in root length beyond the 1.00 mL L^{-1} SWE concentration, despite equivalent numerical gains, hint at a biological threshold where additional SWE does not translate into further enhancement.

Overall, the results support that SWE, particularly at 1.00 mL L^{-1}, significantly boosts both root number and root length in hydroponically acclimatized turmeric plantlets. The trend suggests a dose-dependent response up to a certain concentration, after which the effect plateaus. These findings underscore the potential of SWE as an effective biostimulant in the hydroponic acclimatization of micropropagated turmeric, optimizing root development essential for successful transplantation and field establishment [23].

Biomass Accumulation of Acclimatized Turmeric

The results presented in Table 2 illustrate that the application of seaweed extract (SWE) in varying concentrations had a significant effect on the biomass accumulation of in vitro-propagated turmeric during hydroponic acclimatization.

In terms of fresh weight, plants treated with 1.50 mL L^{-1} SWE recorded the highest biomass at 7.53 grams, representing an approximate 35% increase over the control group, which only reached 5.57 grams. Similarly, the 1.00 mL L^{-1} SWE concentration also showed a marked improvement with 7.08 grams, a 27.1% increase over the control. Notably, the differences between 0.75 mL L^{-1} SWE (5.85 g) and the control were statistically insignificant, showing only a marginal gain of 5.0%, indicating that lower concentrations may not substantially enhance fresh biomass accumulation [10].

For dry weight, the trends generally mirrored those of fresh weight but with subtler variations. The highest dry biomass was again observed at 1.50 mL L^{-1} SWE, yielding 1.36 grams, which reflects a 29.5% increase compared to the control value of 1.05 grams. The 1.00 mL L^{-1} SWE concentration reached 1.27 grams, or 21.0% higher than the control, while 0.75 mL L^{-1} SWE resulted in 1.13 grams, an increase of 7.6%. Interestingly, the dry weight values did not differ as sharply between the mid (1.00 mL L^{-1}) and highest

(1.50 mL L^{-1}) SWE concentrations, suggesting a potential plateau in the efficacy of SWE at higher dosages in promoting tissue solidity or moisture regulation [14].

Overall, these results demonstrate that SWE has a dose-dependent effect on turmeric acclimatization, with the 1.00 mL L^{-1} and 1.50 mL L^{-1} SWE concentrations significantly enhancing both fresh and dry biomass production. This result affirms the potential of SWE as a biostimulant, particularly at higher concentrations, to improve biomass accumulation during the critical acclimatization phase in hydroponic systems [3, 15, 24].

Table 2. *Biomass (grams) of acclimatized turmeric*

Treatments	Fresh Weight, grams	Dry Weight, grams
0 mL L^{-1} SWE (Control)	5.57^{b}	1.05^{b}
0.75 mL L^{-1} SWE	5.85^{b}	1.13^{ab}
1.00 mL L^{-1} SWE	7.08^{a}	1.27^{ab}
1.50 mL L^{-1} SWE	7.53^{a}	1.36^{a}

Means with the same letter(s) are not significantly different.

Acclimatization Duration

Days to acclimatization ranged from 60.7 to 66.9 days, with a mean of approximately 66.7 days (Table 3). Although all plantlets survived, slight differences in acclimatization duration among treatments suggest variation in the rate of physiological adaptation and root development. However, the relatively narrow range of acclimatization duration values indicates that the hydroponic system maintained stable environmental conditions that promoted uniform plant growth and development throughout the acclimatization period. The consistent acclimatization period observed across treatments suggests that hydroponic cultivation provided a favorable root-zone environment capable of supporting efficient water and nutrient uptake while reducing environmental stress [6]. Consequently, plantlets were able to develop the structural and physiological characteristics necessary for successful transition to ex vitro conditions within approximately two months. These findings demonstrate that the hydroponic system, particularly when supplemented with seaweed extract, provides a reliable and efficient acclimatization strategy for micropropagated turmeric plantlets [22].

Table 3. *Crop performance and acclimatization*

Treatments	Days to Acclimatize
0 mL L^{-1} SWE (Control)	72.9a
0.75 mL L^{-1} SWE	66.9b
1.00 mL L^{-1} SWE	64.2bc
1.50 mL L^{-1} SWE	60.7c

Means with the same letter(s) are not significantly different.

Survival and Acclimatization Performance

The results demonstrated a 100% survival rate of in vitro-propagated turmeric plantlets across all treatments, indicating that the hydroponic acclimatization system effectively supported plant establishment during the transition from in vitro to ex vitro conditions. This outcome suggests that the hydroponic environment provided favorable root-zone conditions, including continuous moisture availability, adequate oxygenation, and consistent nutrient supply, thereby minimizing transplant shock and reducing

physiological stress commonly associated with acclimatization [16]. Such controlled conditions are known to promote rapid root establishment and improve the survival of tissue-cultured plantlets. The addition of seaweed extract may have further enhanced plantlet performance by supplying biologically active compounds, including auxins, cytokinins, amino acids, polysaccharides, vitamins, and essential micronutrients [15]. These compounds have been reported to stimulate root initiation and elongation, improve nutrient uptake, enhance antioxidant activity, and increase tolerance to abiotic stress during acclimatization. The combined effects of hydroponic cultivation and SWE supplementation therefore created favorable conditions for successful plant establishment, contributing to the complete survival observed across all treatments. Similar benefits of seaweed-based biostimulants have been reported in tissue-cultured and horticultural crops, where improved rooting, physiological performance, and stress tolerance resulted in greater acclimatization success [24].

CONCLUSION

The study highlights that the acclimatization of *in vitro*-propagated turmeric is significantly enhanced by using a hydroponic system and optimal applications of seaweed extract. The results support the use of seaweed extract as a potent biostimulant in hydroponic systems for turmeric acclimatization, with 1.00 mL L^{-1} emerging as the most effective and biologically efficient concentration. The synergistic effect of hydroponics and SWE not only enhanced growth performance and biomass accumulation but also ensured complete plantlet survival, underscoring their combined potential as a scalable strategy for improving micropropagation protocols in turmeric and potentially other high-value crops.

REFERENCES

[1] Borys Bohoshevych, I., & Fukuda, H. (2024). Growing Kratky basil in Trombe wall cavity: Year-round overview of thermal effects. Sustainability, 16(23), 10274.

[2] Chandra, S., Bandopadhyay, R., Kumar, V., & Chandra, R. 2010. Acclimatization of tissue cultured plantlets: from laboratory to land. Biotechnology letters, 32(9), 1199–1205. https://doi.org/10.1007/s10529-010-0290-0.

[3] Comin, S., Brocca, G., Valsecchi, N., Fumagalli, S., Vigevani, I., Corsini, D., Ferrini, F., Ravanelli, G., & Fini, A. (2024). Growth, physiology, and root development in seedlings of woody species treated with a seaweed extract. Arboriculture & Urban Forestry (AUF). DOI: https://doi.org/10.48044/jauf.2024.013.

[4] Cortés, C.J., Jana, C., Merino, G.E., & Durán, A. (2024). Lettuce crop performance using different water aeration at DWC technique. World Aquaculture Society.

[5] Ding, X., Jiang, Y., Zhao, H., Guo, D., He, L., Liu, F., Zhou, Q., Nandwani, D., Hui, D., Yu, J. (2018). Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. ssp. Chinensis) in a hydroponic system. PloS one, 13(8), e0202090. https://doi.org/10.1371/journal.pone.0202090.

[6] Duan, J. X., Duan, Q. X., Zhang, S. F., Cao, Y. M., Yang, C. D., Cai, X. D. (2020). Morphological, physiological, anatomical and histochemical responses of micropropagated plants of trichosanthes kirilowii to hydroponic and soil conditions during acclimatization. Plant Cell Tissue Organ Cult. 142, 177–186.

[7] Ekinci, H., Saskin, N., Ak, B. E., & Dogan, B. D. (2024). Effects of different healing agents on acclimatization success of in vitro rooted Garnem (Prunus dulcis× Prunus

persica) rootstock: EKINCI ET AL. In Vitro Cellular & Developmental Biology-Plant, 60(3), 309-317.

[8] Gaikwad, D. J. and Maitra, S., (2020). Hydroponics cultivation of crops,'' in Protected Cultivation and Smart Agriculture, S. Maitra, D. J. Gaikwad, and T. Shankar, Eds. New Delhi, India: New Delhi Publishers, 279–287.

[9] Gowda, M.R.S., & Sowmya, R. (2024). Assessment of genetic uniformity in micro propagated plantlets of turmeric (*Curcuma longa* L.) through DNA markers. Current Botany, 15.

[10] Khater Elsayed (2015) Comparison between hydroponic and aeroponic systems for lettuce production. The 20th Annual Conference of Misr Journal of Agricultural. Engineering. 33, 715-736.

[11] Latique, Salma & Chernane, Halima & Mansori, Mounir & Kaoua, El. (2013). Seaweed liquid fertilizer effect on physiological and biochemical parameters of bean plant (Phaesolus vul-garis var Paulista) under hydroponic system. European Scientific Journal ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431. 9. 1857-7881.

[12] Lori L. (2022). 7 Crucial things to know about the kratky method of gardening. https://www.bobvila.com/articles/kratky-method/.

[13] Manokari, M., Cokulraj, M., Badhepuri, M.K., et al. (2023). Microstructural and histochemical modifications in leaves at successive stages of in vitro development of the terrestrial orchid Spathoglottis plicata Blume. FAO/AGRIS.

[14] Marschner, H. (2012) Marschner's Mineral Nutrition of Higher Plants. Vol. 89, Academic Press, London, 651. https://www.elsevier.com/books/marschners-mineral-nutrition-of-higher-plants/marschner/978-0-12-384905-2.

[15] Mughunth, R.J., Velmurugan, S., Mohanalakshmi, M., & Vanitha, K.G. (2024). A review of seaweed extract's potential as a biostimulant to enhance growth and mitigate stress in horticulture crops. Scientia Horticulturae.

[16] Pomoni, D.I., Koukou, M.K., Vrachopoulos, M.G., and Vasiliadis, L., (2023). A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use, Energies, 16(4), 1690.

[17] Raja, B., & Vidya, R. (2023). Application of seaweed extracts to mitigate biotic and abiotic stresses in plants. Physiology and Molecular Biology of Plants, 29(5), 641-661.

[18] Resh, H. M. (2016). Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower (7th ed.). CRC Press

[19] Sharma, N., Kumar, N., James, J., Kalia, S., & Joshi, S. (2023). Strategies for successful acclimatization and hardening of in vitro regenerated plants: Challenges and innovations in micropropagation techniques. Plant Science Today, 10(2):90–97. https://doi.org/10.14719/pst.2376.

[20] Suárez, E., Alfayate, C., Pérez-Francés, J., Rodríguez-Pérez, J., (2019). Structural and ultrastructural differences between field, micropropagated and acclimated leaves and stems of two Leucospermum cultivars (Proteaceae). Plant Cell, Tissue and Organ Culture (PCTOC)vol. 136issue 1(2019)pp: 15-27.

[21] Tessema, G., Degebasa, A., Gebremedhin, W., Solomon, A., Tolessa, E., Hussen, E. (2017). Determination of nutrient solutions for potato (Solanum tuberosum L.) seed production under aeroponics production system. Open Agriculture. 2. 10.1515/opag-2017-0015.

[22] Traykova, B., Molle, E., and Stanilova, M., (2022). In vivo and in vitro bulb multiplication of lilium rhodopaeum Delip. and growth acceleration using hydroponic technologies, vitro cellular develop. Biol.-Plant, 58(2), 200–212.

[23] Yuan, Y., & Dickinson, N. (2024). Revealing the complex interplay of biostimulant applications. Plants, 13(16), 2188. https://doi.org/10.3390/plants13162188.

[24] Yusuf, R., Laude, S., Alfiana, Syakur, A., & Ramli (2021). The potential of seaweed used as hydroponic solution on the growth and yields of lettuce (Lactuca sativa L.). IOP Conference Series: Earth and Environmental Science, 653.