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Krishna G Choli
College of Horticulture, UHS Campus, Bengaluru, Karnataka, India

Manjunath R
College of Horticulture, UHS Campus, Bengaluru, Karnataka, India

B Doddabasappa
Regional Horticultural Research and Extension Centre, UHS Campus, Bengaluru, Karnataka, India

Shivanna M
College of Horticulture, UHS Campus, Bengaluru, Karnataka, India

Anil Kumar S
Krishi Vigyan Kendra, Kolar, Karnataka, India

Corresponding Author:
Manjunath R
College of Horticulture, UHS Campus, Bengaluru, Karnataka, India

Standardized nutrient management for profitability and storability in arc-derived potato seed tubers

Krishna G Choli, Manjunath R, B Doddabasappa, Shivanna M and Anil Kumar S

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Abstract
Potato (*Solanum tuberosum* L.) seed production is often constrained by slow multiplication rates and disease accumulation. Apical rooted cuttings (ARC) offer a rapid, disease-free alternative for early generation seed (EGS) multiplication, but nutrient requirements for maximizing both yield and post-harvest performance remain poorly defined. This study was conducted to standardize nutrient inputs in ARC-derived seed tubers with special reference to yield attributes, storability, and cost economics.
Six nutrient regimes (T_1-T_6), varying in NPK intensity and secondary/micronutrient supplementation, were evaluated in a randomized block design. Growth parameters, yield components, seed-size tuber recovery (30-55 mm), tuber quality indices, and shelf-life traits under ambient storage (physiological weight loss, sprouting percentage, rosette/shriveling) were recorded. Cost economics were calculated based on input use, gross returns, net returns, and benefit-cost (B:C) ratio.
Balanced nutrient application (T_1) produced the most favorable outcome, with vigorous canopy development, higher seed-size tuber recovery, and superior storability. T_1 also achieved the highest B:C ratio (1.48), whereas the excessive-input treatment (T_6) recorded the lowest (0.68), largely due to higher input costs and poor storability. Nutrient regimes including Ca, Mg, S, and foliar micronutrients significantly reduced physiological weight loss and sprouting during storage, enhancing seed tuber integrity compared with high-salt treatments.
The study demonstrates that profitability in ARC potato seed systems depends more on optimizing seed-size yield and storability than on maximizing gross yield. Standardized nutrient management tailored to ARC physiology thus provides a practical, cost-effective approach to strengthening seed potato supply chains by improving both economic returns and post-harvest performance.

Keywords: Potato, apical rooted cuttings, nutrient standardization, seed tuber, cost economics, shelf life

Introduction
Potato (*Solanum tuberosum* L.) is one of the most important food crops worldwide, serving as a staple for millions and contributing significantly to food and nutritional security. In India, potato plays a key role in both food consumption and processing industries. Production of healthy seed tubers is critical for maintaining yield and quality. Conventional methods of seed potato multiplication are often slow, resource-intensive, and prone to degeneration due to viral and other pathogen infections. Apical rooted cuttings (ARC) offer an efficient alternative, ensuring genetic fidelity, rapid multiplication, storage and high-quality seed tuber production. The importance of potato storage lies in maintaining tuber quality, minimizing post-harvest losses, and ensuring a continuous supply for food, processing, and seed purposes. Since potato is a perishable crop with high moisture content and a living, respiring organ, proper storage plays a critical role in the value chain. Freshly harvested potatoes are seasonal, but proper storage allows them to be available year-round for consumption, processing, and planting. Without proper storage, potatoes quickly sprout, shrivel, or rot, leading to heavy losses. Scientific storage methods can reduce weight and quality losses significantly. Good storage conditions (temperature, humidity, and ventilation) help maintain, firmness, nutritional value, and taste. For seed potato production, storage is crucial to preserve viability, dormancy, and health of tubers until the next planting season.

The cost economics of potato cultivation is highly important because it directly influences the profitability, sustainability, and adoption of production technologies by farmers. This helps farmers and researchers determine whether the investment in ARC potato cultivation for seed tuber gives sufficient economic returns. By calculating gross returns, net returns, and the benefit-cost ratio (B\:C ratio), it becomes clear which cultivation practices are most viable. Rapid multiplication and fewer field generations are made possible by ARC technique, which preserves the quality of the seed (Sharma and Pandey, 2013) [5]. To produce mini-tubers, in-vitro-generated plantlets are first acclimated to the field before being transplanted (Tadesse *et al*., 2001). [6] Apical cuttings, on the other hand, are rooted transplants made from tissue culture. Though they are vegetatively propagated and disease-free, these cuttings resemble seedlings cultivated in nurseries. A cost-effective and efficient technique of propagating potatoes, ARCs have the potential for fast regeneration and genetic integrity. According to Tsoka *et al*. (2012) [7], they have great potential for the preservation and generation of superior potato seed tubers.

Material and Methods

The study was conducted at the Regional Horticultural Research and Extension Centre (RHREC) on the UHS campus at GKVK, Bengaluru in the Rabi season of 2023. Apical Rooted Cuttings ((ARC) of Kufri Karan potato produced at RHREC Bengaluru tissue cultured planting material was used under RCBD experimental design with the following10 treatments and 03 replications with spacing of 60 cm x 20 cm and plot size of 2.4 m x 2m.

Treatment details

- **T_1:** 125:100:125 kg ha^{-1} N:P:K + Potato special (UHSB Package)
- **T_2:** 125:100:125 kg ha^{-1} N:P: K
- **T_3:** 156: 125:156 kg ha^{-1} N: P: K+ Potato special
- **T_4:** 156: 125: 156 kg ha^{-1} N: P: K
- **T_5:** 93.5: 75: 93.5 kg ha^{-1} N: P: K+ Potato special
- **T_6:** 93.5: 75: 93.5 kg ha^{-1} N: P: K
- **T_7:** 93.5: 100: 125 kg ha^{-1} N: P: K + Potato special
- **T_8:** 125: 100: 93.5 kg ha^{-1} N: P: K + Potato special
- **T_9:** 156: 100: 125 kg ha^{-1} N: P: K + Potato special
- **T_{10}:** 125: 100: 156 kg ha^{-1} N: P: K + Potato special

The potato special of UHSB-3 micronutrient formulation for foliar spray 3 g L-1 contains zinc, manganese, iron, boron, and copper in the ppm of 200, 75, 100, 75, and 25 respectively.
The tubers were harvested once they achieved the desired stage of physiological maturity. The plants from each plot were then uprooted, and data were collected for each treatment. To gather observations, five plants were randomly chosen and tagged from the net plot in each treatment and observations for plant height(cm), number of branches per plant, number of leaves per plant, plant spread(cm^2), leaf area(cm^2), number of tubers per plant, average tuber size of 20 tubers(g), average weight of 20 tubers (g)

Cost economics (Rs ha^{-1})

Following the cropping season, a financial study was performed to evaluate cost-effectiveness and establish benefit-cost ratios. This entailed comparing entire cultivation expenditures to the revenue obtained from tuber sales.

Cost of cultivation (Rs ha^{-1})

The overall cost of cultivation was computed by summing all expenses incurred from land preparation to harvest, including seed tubers, fertilizers, weeding, chemical treatments, and labour pay. These expenses, outlined in Appendix II, are expressed in rupees per hectare.

Gross income (Rs ha^{-1})

The gross income for each treatment was calculated based on the market price of tubers and expressed in rupees per hectare. (https://agmarknet.gov.in/).

Net income

The net income per hectare was calculated by subtracting the cost of cultivation per hectare from the gross income.
Net Income (Rs ha^{-1}) = Gross income (Rs ha^{-1}) - Cost of cultivation (Rs ha^{-1})

Benefit: cost ratio

The benefit-cost ratio was calculated using the following formula.

$$\text{B: C Ratio} = \frac{\text{Net return (Rs ha}^{-1})}{\text{Total cost of cultivation (Rs ha}^{-1})}$$

Shelf life

Physiological loss in weight (PLW) (%)

The initial weight of tubers in each treatment was determined using an electric weighing scale. The tuber weights for each treatment were then recorded at intervals of 15, 30, 45, 60, 75 and 90 days following storage. The cumulative weight reduction was determined and expressed as a percentage of physiological weight loss.
Following is the formula used in calculating PLW

$$\text{PLW (\%)} = \frac{P_0 - P_1}{P_0} \times 100$$

Where,
P_0**:** Initial weight and P_1**:** Final weight

Results

Cost economics

The data on the cost of cultivation, gross returns, net returns, and benefit-cost ratio (B:C ratio) for different nutrient doses on apical rooted cuttings are detailed in Table 1. The highest B:C ratio of 1:48 was achieved with treatment T_1. Conversely, the lowest B:C ratio 1:41 was observed in treatment T_6.

Table 1: Cost economics for production of seed tubers from apical rooted cuttings from different fertilizer doses (Rs ha^{-1})

Particulars	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
Land preparation and seedling material	32300	32300	32300	32300	32300	32300	32300	32300	32300	32300
FYM	57500	57500	57500	57500	57500	57500	57500	57500	57500	57500
Urea+SSP+MOP+Micronutrient (varies treat to treat)	7773	6963	4336	3526	6118	5308	7773	6118	8039	9428

Plant protection chemicals	3548	3548	3548	3548	3548	3548	3548	3548	3548	3548
Expenditure on labour wages	27150	27150	27150	27150	27150	27150	27150	27150	27150	27150
Harvesting, grading and transportation	32500	32500	32500	32500	32500	32500	32500	32500	32500	32500
Total cost of cultivation	160771	159961	157334	156524	159116	158306	160771	159116	161037	162426
Seed tuber yield (t ha^{-1})	6.28	5.83	6.89	6.08	3.66	3.81	5.94	6.45	6.61	8.11
Marketable tuber yield (t ha^{-1})	11.91	9.31	9.71	8.69	9.17	8.62	8.19	9.53	9.31	8.37
Returns from seed tuber	188400.00	174900.00	206700.00	182400.00	109800.00	114300.00	178200.00	193500.00	198300.00	243300.00
Returns from marketable tuber	210926.10	164880.10	171964.10	153899.90	162400.70	152660.20	145044.90	168776.30	164880.10	148232.70
Gross returns	399326.10	339780.10	378664.10	336299.90	272200.70	266960.20	323244.90	362276.30	363180.10	391532.70
Net return	238555.10	179819.10	221330.10	179775.90	113084.70	108654.20	162473.90	203160.30	202143.10	229106.70
B:C ratio	1.48	1.12	1.40	1.14	0.71	0.68	1.01	1.27	1.25	1.41

Shelf life

Physiological loss in weight (%)

The data on physiological loss in weight of apical rooted cuttings under various nutrient treatments showed significant differences during the storage period at ambient conditions, as detailed in Table 22. After 15 days of storage, varied significantly with an average of 8.07%, ranged from 5.56 to 9.23%. The highest physiological loss in weight was recorded in T_4at 9.23%, which was on par with T_9, T_7, T_3, T_8, T_2, T_6 and T_1 with 8.99, 8.93, 8.64, 8.46, 8.44, 8.29 and 8.14% loss respectively. In contrast, the lowest physiological loss in weight was observed in $T_{10}$and T_5at 5.56 and 6.11% respectively.

After 30 days of storage, non-significantly varied across treatment with an average of 15.70% ranged from 14.19% to 17.73%. The highest physiological loss in weight was recorded in T_1at 17.73%. On the other hand, the lowest physiological loss in weight was observed in T_{10}, which had a loss of 14.19%. After 45 days of storage, there were no significant difference with an average of 17.84 varies from 16.50 to 19.10%. The highest physiological loss in weight was observed in T_1 at 19.10%. In contrast, the lowest physiological loss in weight was noted in T_{10}, which had a loss of 16.50%. 60 days after storage, non-significantly with a mean of 20.82% ranged from 19.63 to 21.79%. The highest physiological weight loss was observed in the $T_3$with a loss of 21.79%. On the other hand, the T_{10} treatment experienced the lowest physiological weight loss, at 19.63%.

Table 2: Performance of apical rooted cuttings of potato at different doses of nutrients for physiological loss in weight (%)

Treatments	15 DAS	30 DAS	45 DAS	60 DAS
T_1	8.14	17.73	19.10	20.65
T_2	8.44	15.78	18.69	19.94
T_3	8.64	16.72	18.57	21.79
T_4	9.23	16.39	17.05	21.57
T_5	6.11	15.23	16.79	20.56
T_6	8.29	15.15	17.74	20.98
T_7	8.93	15.39	17.81	21.05
T_8	8.46	15.07	17.35	21.46
T_9	8.99	15.39	18.85	20.66
T_{10}	5.56	14.19	16.50	19.63
Mean	8.07	15.70	17.84	20.82
S.Em±	0.56	0.87	0.68	0.76
C.D at 5%	1.66	2.61	2.04	2.27

Discussion

Cost economics: Table 1 provide information on the cost of culture, gross returns, net returns, and benefit-cost ratio (B:C ratio) for different nutrient dosages on apical rooted cuttings. Treatment T_1 produced the greatest B:C ratio, 1.48. In treatment T_6, on the other hand, the lowest B:C ratio (0.68) was noted. The varying quantities of fertilizer utilized in each treatment are responsible for these changes in B:C ratios, which in turn affected the outcomes. In comparison to other treatments, the greatest B:C ratio was linked to a better tuber yield, which resulted in an enhanced net return per hectare. These results are in line with the findings of research on sweet potatoes published by Kumar *et al*. (2017) and Agyarko *et al*. (2012) [1, 4].

Shelf life

Physiological loss in weight (%)

Table 2 presents the findings of this investigation, which indicated that there were substantial variations in the physiological weight loss among the 10 treatments of potato apical rooted cuttings. T_4 had the most physiological weight loss after 15 days of storage, coming in at 9.23%. Conversely, T_{10} showed the least physiological weight reduction, at 5.56%. Following thirty days of storage, T_1 had the most physiological weight reduction (17.73%). Conversely, T_{10} had the least physiological weight loss, gaining only 14.19% of its initial weight. Following 45 days of storage, T_1 showed the most physiological weight reduction (19.10%). T_{10}, on the other hand, saw the least physiological weight reduction a decrease of 16.50%. The T_3 showed the greatest physiological weight reduction, with a drop of 21.79%, 60 days following storage. However, with a physiological weight reduction of only 19.63%, the T_{10} therapy had the least amount of weight loss. According to Imas and Bansal (2002) [3], it is widely known that a high potassium dosage improves potato tubers' capacity for storage by raising their dry matter content and lowering their vulnerability to pests and illnesses. Furthermore, potassium is essential for lowering the activity of the enzyme's peroxidase and catalase, which reduces tuber storage losses. These results are consistent with those of Biswas *et al*. (2018) [2].

Conclusion

The highest benefit-to-cost (B:C) ratio of 1.48 was achieved with treatment T1 followed by T10 with a ratio of 1.41. Since seed tuber of D-grade T_{10} has the second highest B: C ratio and the highest shelf-life, that depicted presence of the highest tuber yield in T_{10} among different treatments. However, when considering all factors, including growth and yield parameters, economic costs, and mainly seed tuber production, the differences between T_3 and T_1 are minimal. The smallest weight losses at 15, 30, 45, and 60 days after storage (DAS) were recorded for treatment T_{10} with losses of 9.34%, 17.73%, 19.37%, and 21.96%, respectively, compared to other treatments. The cost economics for producing seed tubers using ARC plantlets with the T_{10} treatment is highly favorable, offering strong profitability and good shelf life compared to other treatments.

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