

MODULATING CYTOKININ LEVELS FOR EFFICIENT *IN VITRO* CLONAL PROPAGATION OF POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS

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ABSTRACT: *In vitro* micropropagation has emerged as an efficient strategy for producing disease-free and genetically uniform potato (*Solanum tuberosum* L.) planting materials. The present study was conducted to evaluate the varietal response of two potato cultivars, BARI Alu-41 and BARI Alu-72, to *in vitro* regeneration under different concentrations of 6-benzylaminopurine (BAP). Shoot tip explants were cultured on Murashige and Skoog (MS) medium supplemented with varying BAP concentrations to assess their effects on shoot multiplication, node formation, leaf number, shoot length, and root traits. Significant differences were observed between the two varieties for most regeneration traits. BARI Alu-72 exhibited superior performance, producing a higher number of nodes (11.05), leaves (10.60), longer shoots (71.56 mm), and longer roots (26.07 mm) compared to BARI Alu-41. In contrast, shoot number and root number did not differ significantly between the varieties. BARI Alu-41 performed slightly better in *ex vitro* conditions than BARI Alu-72, reflecting genotypic differences in acclimatization. These findings indicate that BAP plays a critical role in stimulating shoot proliferation and plantlet growth. The differential varietal responses highlight that *in vitro* regeneration efficiency in potato is genotype-dependent, and thus, optimization of hormone combinations is essential for each cultivar. This study provides a reliable framework for variety-specific micropropagation, enabling rapid multiplication of disease-free seed potatoes to enhance productivity and ensure a sustainable seed supply in regions where viral and other systemic infections pose a major threat to crop production.

KEYWORDS: Potato, shoot tip culture, cytokinin BAP, *in vitro* regeneration, genotype-specific response.

INTRODUCTION

Potato (*Solanum tuberosum* L.), a tetraploid ($2n = 4x = 48$) herbaceous dicotyledon belonging to the Solanaceae family, is a vegetatively propagated crop that originated from the Peru-Bolivian Andes and southern Chile (Swamy, 2023). Globally recognized as the fourth most important food crop, it serves as a staple in more than 40 countries and contributes nearly 45% of the total world production of tuber crops (Chandrasekara and

Kumar, 2016; Hu *et al.*, 2025). It thrives best in cool climates, with tuber production optimal at around 20°C but severely hampered when temperatures rise above 30°C (Nasif *et al.*, 2018; Liu *et al.*, 2025).

In Bangladesh, potatoes are primarily cultivated as a winter crop and rank third in terms of total cultivated area after rice and wheat, while being the leading vegetable crop in both area and production (Rahim *et al.*, 2023). Among the improved cultivars

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developed by the Bangladesh Agricultural Research Institute (BARI), BARI Alu-41 and BARI Alu-72 are notable for their yield potential. BARI Alu-41 is more suited to northern regions, while BARI Alu-72 performs well in saline-prone coastal areas (Rahman *et al.*, 2021). Despite their promising agronomic traits, both cultivars are vulnerable to a wide range of pathogens, especially viruses such as PVX, PVY, PVA, PVS, PVM, and PLRV (Kenzhebekova *et al.*, 2025), which can reduce yields by up to 80-90% (Masum *et al.*, 2011). A major factor contributing to disease prevalence in Bangladesh is the widespread use of infected tubers due to the unavailability of clean planting material. Using disease-free seed tubers can boost potato yield by 20-30% (Karim *et al.*, 2011; Yayeh *et al.*, 2025). However, diagnosing and treating pathogen-infected tubers is costly and often ineffective, highlighting the urgent need for a reliable alternative propagation method.

In vitro tissue culture techniques, particularly shoot tip or meristem culture, offer a sustainable solution by enabling large-scale production of disease-free planting materials. Meristem culture is proven to eliminate systemic pathogens, including viruses, and is more practical and cost-effective compared to other tissue culture methods. Cytokinins, especially BAP (6-benzylaminopurine), play a central role in shoot initiation and proliferation *in vitro* (Adu Donyina *et al.*, 2025). While BAP promotes cell division and axillary bud development, it may also inhibit root formation (Dilshad *et al.*, 2021; Vaičiukynė *et al.*, 2025). Therefore, precise modulation of cytokinin levels is critical for optimizing micropropagation protocols.

Although a few attempts have been made in Bangladesh to produce virus-free potato plants through tissue culture (Nasif

et al., 2018; Azad *et al.*, 2020; Rahman *et al.*, 2021), there is a noticeable research gap regarding the *in vitro* propagation of specific high-yielding cultivars like BARI Alu-41 and BARI Alu-72. These cultivars are yet to be extensively studied for their responses to cytokinin-mediated shoot tip culture, which is essential for establishing a reliable and genotype-specific propagation protocol. Considering the aforementioned context, the present study was undertaken with the following specific objectives:

1. To assess the effect of different concentrations of cytokinin (BAP) on the shoot proliferation of potatoes.
2. To explore the potentialities of two potato cultivars responding to *in vitro* shoot tip culture.

MATERIALS AND METHODS

Experimental site and duration

The study was carried out at the Plant Breeding and Biotechnology Laboratory, Agrotechnology Discipline, Khulna University, Khulna, Bangladesh, from February to November 2024.

Plant materials

Two potato cultivars, BARI Alu-41 and BARI Alu-72, were used in the experiment. These were collected from the Bangladesh Agricultural Research Institute (BARI), Gazipur. Shoot tips of the sprouts, developed under laboratory conditions, were used as the source material for *in vitro* culture.

Culture media and hormonal treatments

All *in vitro* cultures were initiated and maintained on Murashige and Skoog (MS) medium (Murashige and Skoog, 1962), supplemented with 30 g L⁻¹ sucrose and solidified with 8 g L⁻¹ agar. The media were fortified with different concentrations of BAP

(0.0, 1.5, 2.0, 2.5, and 3.0 mg L⁻¹), each in combination with 0.2 mg L⁻¹ NAA. The pH of the medium was adjusted to 5.6 before autoclaving at 121°C and 1.5 kg cm⁻² pressure for 20 minutes. The prepared medium was poured into test tubes, each containing 10 ml media.

Sterilization procedures

All glassware were sterilized by autoclaving at 121°C for 30 minutes at 1.5 kg cm⁻² pressure. Metal instruments were sterilized through dry heat and by dipping in 100% ethanol followed by flaming prior to use. The culture room and laminar airflow cabinet were disinfected with 70% ethanol and formaldehyde prior to use.

Surface sterilization of explants

Sprouts were first rinsed with tap water, then surface sterilized in 70% ethanol for 30 seconds, followed by treatment in 0.1% HgCl₂ for 10 minutes. They were then rinsed three times with sterile distilled water and dried on autoclaved tissue paper in the laminar airflow cabinet.

Inoculation of explants and incubation

Using aseptic techniques, 2 cm shoot tips were excised and inoculated individually onto the prepared media in test tubes. The tubes were incubated at 25±1°C with a 16-hour photoperiod, light intensity of ~3000 lux, and relative humidity of approximately 65%. Shoot proliferation was first observed after 15 days of culture and further sub-culturing was done for two times to facilitate shoot multiplication and plantlet development each after 4 weeks interval.

Experimental design

The experiment was laid out in a two-factor factorial completely randomized design (CRD) with three replications. Factor A was variety (BARI Alu-41 and BARI Alu-72) and

factor B was BAP concentrations (0.0, 1.5, 2.0, 2.5, and 3.0 mg L⁻¹). Each replication consisted of seven test tubes, with one explant cultured per tube.

Data collection

Quantitative data were recorded at three different intervals (30, 60, and 90 days after culture) on the following parameters:

- Shoot length (cm)
- Number of shoots explant⁻¹
- Number of nodes plantlet⁻¹
- Number of leaves plantlet⁻¹
- Number of roots plantlet⁻¹
- Root length (cm)
- *Ex vitro* survivability (%)

Statistical analysis

Collected data were analyzed using Analysis of Variance (ANOVA) in the R programming environment (R Core team, 2024). Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

RESULTS

Effect of BAP concentration on *in vitro* multiplication efficiency of potato

BAP concentration significantly influenced shoot number, node number, leaf number, and shoot length, while root number and root length remained unaffected (Table 1). The highest number of shoots (2.98), nodes (11.39), and leaves (9.40) plantlet⁻¹ was recorded at 2.0 mg L⁻¹ BAP, which was significantly superior to the lowest values observed at control as well as 3.0 mg L⁻¹ for shoots and nodes, and at 2.5 mg L⁻¹ for leaves. Shoot length was also highest at 1.5 mg L⁻¹ (68.96 mm) and 2.0 mg L⁻¹ (66.46 mm), which were significantly greater than the shortest length in control

Table 1. Effect of BAP concentration on *in vitro* multiplication efficiency of potato

BAP (mg L ⁻¹)	Shoots plant ⁻¹	Nodes plant ⁻¹	Leaves plant ⁻¹	Roots plant ⁻¹	Shoot length (mm)	Root length (mm)
0	1.35 ^c	5.42 ^c	3.15 ^c	14.25	39.62 ^c	18.73
1.5	2.55 ^{ab}	8.87 ^{ab}	7.46 ^{ab}	15.73	68.96 ^a	20.84
2.0	2.98 ^a	11.39 ^a	9.4 ^a	16.60	66.46 ^a	22.54
2.5	2.97 ^a	8.37 ^{ab}	5.47 ^b	11.17	43.77 ^b	22.52
3.0	2.2 ^b	7.93 ^b	7.6 ^{ab}	16.60	57.44 ^{ab}	26.41
LS	*	*	*	NS	*	NS

followed by 43.77 mm shoot length at BAP 2.5 mg L⁻¹. Root number and root length did not differ significantly among treatments, although slightly longer roots were observed at 3.0 mg L⁻¹ (26.41 mm).

Varietal effect on *in vitro* regeneration of potato

The two potato varieties exhibited notable differences in several regeneration parameters under *in vitro* conditions (Fig. 1). BARI Alu-72 significantly outperformed BARI Alu-41 in terms of number of nodes (11.05 vs. 7.23) and number of leaves plantlet⁻¹ (10.60 vs. 4.37), both at the 1% level of significance. Similarly, BARI Alu-72 produced significantly longer shoots (71.56 mm) and roots (26.07 mm)

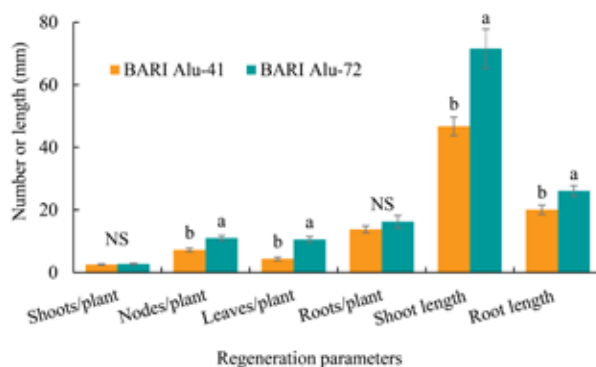


Fig. 1. Regeneration efficiency of two potato varieties in *in vitro* conditions

compared to BARI Alu-41 (46.76 mm and 20.08 mm, respectively), with shoot length differing at the 1% level and root length at the 5% level of significance. However, no significant varietal differences were observed in the number of shoots plantlet⁻¹ and number of roots plantlet⁻¹.

Interaction effect of variety and BAP concentration on *in vitro* multiplication efficiency of potato

The interaction between variety and BAP concentration had significant effects on all evaluated parameters except shoot number, which was significant at the 5% level (Table 2). The highest number of shoots

Table 2. Interaction of variety and BAP concentration on *in vitro* multiplication efficiency of potato

Variety	BAP (mg L ⁻¹)	Shoots plant ⁻¹	Nodes plant ⁻¹	Leaves plant ⁻¹	Roots plant ⁻¹	Shoot length (mm)	Root length (mm)
BARI Alu- 41	0	1.22 ^c	4.35 ^c	2.10 ^d	7.05 ^{bc}	32.84 ^d	15.21 ^b
	1.5	2.64 ^{ab}	6.12 ^b	2.51 ^d	9.79 ^{bc}	44.80 ^{cd}	16.40 ^b
	2.0	3.32 ^a	10.03 ^{ab}	6.71 ^c	13.72 ^{abc}	54.18 ^{cd}	23.81 ^{ab}
	2.5	2.45 ^{ab}	6.67 ^b	3.80 ^{cd}	13.89 ^{abc}	37.40 ^d	17.39 ^b
	3.0	1.91 ^b	6.08 ^b	4.47 ^{cd}	17.78 ^{ab}	50.68 ^{cd}	22.73 ^{ab}
BARI Alu- 72	0	1.48 ^c	6.27 ^{bc}	3.56 ^{cd}	12.84 ^{bc}	40.15 ^d	18.64 ^b
	1.5	2.46 ^{ab}	11.62 ^a	12.42 ^a	21.66 ^a	93.12 ^a	25.28 ^{ab}
	2.0	2.64 ^{ab}	12.74 ^a	12.11 ^a	19.48 ^a	78.74 ^{ab}	21.26 ^{ab}
	2.5	3.50 ^a	10.06 ^{ab}	7.14 ^{bc}	8.45 ^c	50.15 ^{cd}	27.66 ^a
	3.0	2.50 ^{ab}	9.78 ^{ab}	10.74 ^{ab}	15.42 ^{abc}	64.21 ^{bc}	30.08 ^a
Level of significance		*	*	**	**	**	*

** = Significant at 1% level of significance; * = Significant at 5% level of significance

plantlet⁻¹ (3.50) was recorded in BARI Alu-72 at 2.5 mg L⁻¹ BAP, followed closely by BARI Alu-41 at 2.0 mg L⁻¹ (3.32). Node number was significantly higher in BARI Alu-72 at both 2.0 mg L⁻¹ (12.74) and 1.5 mg L⁻¹ (11.62) BAP, while the lowest was in BARI Alu-41 at control (4.35).

Leaf number varied significantly across treatments. The maximum was observed in BARI Alu-72 at 1.5 mg L⁻¹ (12.42), statistically similar to 2.0 mg L⁻¹ (12.11), while the lowest was in BARI Alu-41 at control (2.10) followed by BAP 1.5 mg L⁻¹ (2.51). Root number also showed significant interaction effects, with the highest value in BARI Alu-72 at 1.5 mg L⁻¹ (21.66), and the lowest in variety BARI Alu-41 at control (7.05) followed by BAP 2.5 mg L⁻¹ (8.45) in BARI Alu-72. Shoot length differed markedly across combinations, with the longest shoots produced by BARI Alu-72 at 1.5 mg L⁻¹ (93.12 mm), while the shortest was observed in BARI Alu-41 at control (32.84 mm). Root length was also significantly affected, with BARI Alu-72 at 3.0 mg L⁻¹ showing the highest value (30.08 mm), and the lowest being recorded in BARI Alu-41 at control followed by BAP 1.5 mg L⁻¹ (16.40 mm).

Relationships between BAP concentrations and shoot production efficiency of potato varieties

The regression analysis showed that shoot production efficiency in BARI Alu-41 increased slightly with rising BAP concentration, following the equation $y = 0.3192x + 1.7321$ with a coefficient of determination of $R^2 = 0.1896$. This indicates that 18.96% of the variation in shoot production was explained by BAP concentration.

For BARI Alu-72, shoot production exhibited a stronger positive linear relationship with BAP concentration, described by the equation $y = 0.4857x + 1.6417$ with $R^2 = 0.3797$. In this case, 37.97% of the variation

in shoot production was explained by BAP concentration (Fig. 2).

Ex vitro hardening

Ex vitro hardening of regenerated potato plantlets revealed notable differences between the tested substrates for both varieties (Table 3). In BARI Alu-41, the highest survival rate (94.2%) was obtained in cocopeat + vermicompost, followed by 87.5% in soil +

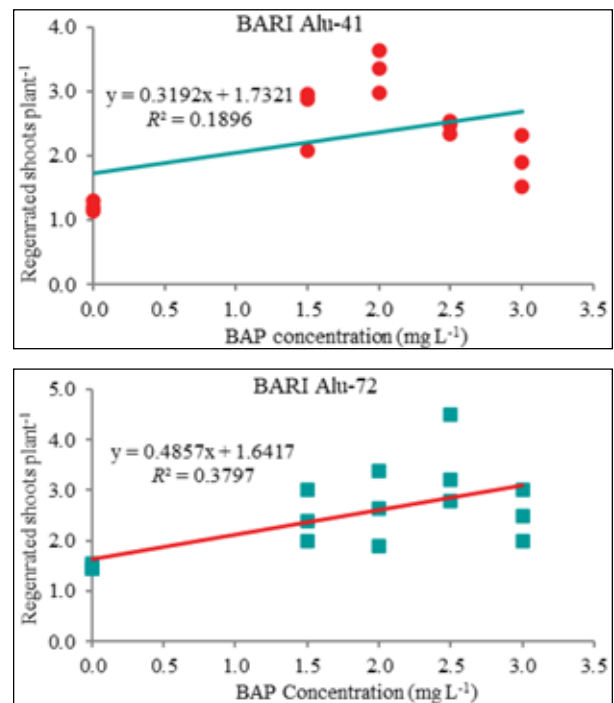


Fig. 2. Comparative regression analysis of BAP concentration and shoot multiplication efficiency in potato varieties.

Table 3. *Ex vitro* hardening of regenerated potato plantlets in different substrates

Variety	Hardening media	Survival rate (%)
BARI Alu-41	Cocopeat + Vermicompost	94.2 ± 0.85 ^a
	Soil + Sand + Compost (1:1:1)	87.5 ± 1.10 ^b
	Sand + Soil + Cow dung (1:1:1)	79.1 ± 1.24 ^c
	Garden Soil	71.0 ± 1.32 ^d
BARI Alu-72	Cocopeat + Vermicompost	92.8 ± 0.92 ^a
	Soil + Sand + Compost (1:1:1)	85.0 ± 1.18 ^b
	Sand + Soil + Cow dung (1:1:1)	78.3 ± 1.27 ^c
	Garden Soil	69.6 ± 1.40 ^d

sand + compost (1:1:1). Survival decreased further in sand + soil + cow dung (79.1%) and was the lowest (71.0%) in garden soil.

Similarly, in BARI Alu-72, cocopeat + vermicompost also supported the highest survival (92.8%), while soil + sand + compost (85.0%) and sand + soil + cow dung (78.3%) performed moderately. The lowest survival (69.6%) was observed in garden soil. Between the two varieties, BARI Alu-41 exhibited slightly higher survival percentages in all substrates compared to BARI Alu-72. However, the trend of survival across substrates was consistent in both varieties, with cocopeat + vermicompost performing the best and garden soil the least effective.

DISCUSSION

In vitro regeneration of potato plantlets has become an important strategy for

producing disease-free and high-quality planting materials, especially given the susceptibility of potatoes to viral and bacterial pathogens. The present study evaluated the interaction effect of variety and BAP concentration on *in vitro* shoot multiplication efficiency in two potato varieties, BARI Alu-41 and BARI Alu-72, using shoot tip explants (Fig. 3). The results (Table 2) revealed that shoot proliferation parameters, including shoot number, node number, leaf number, root traits, and plant length, were significantly influenced by both genotype and BAP concentration, indicating a genotype $\times$ hormone interaction effect.

Influence of BAP on shoot and node multiplication

Cytokinins, particularly BAP, are well known for their role in inducing axillary

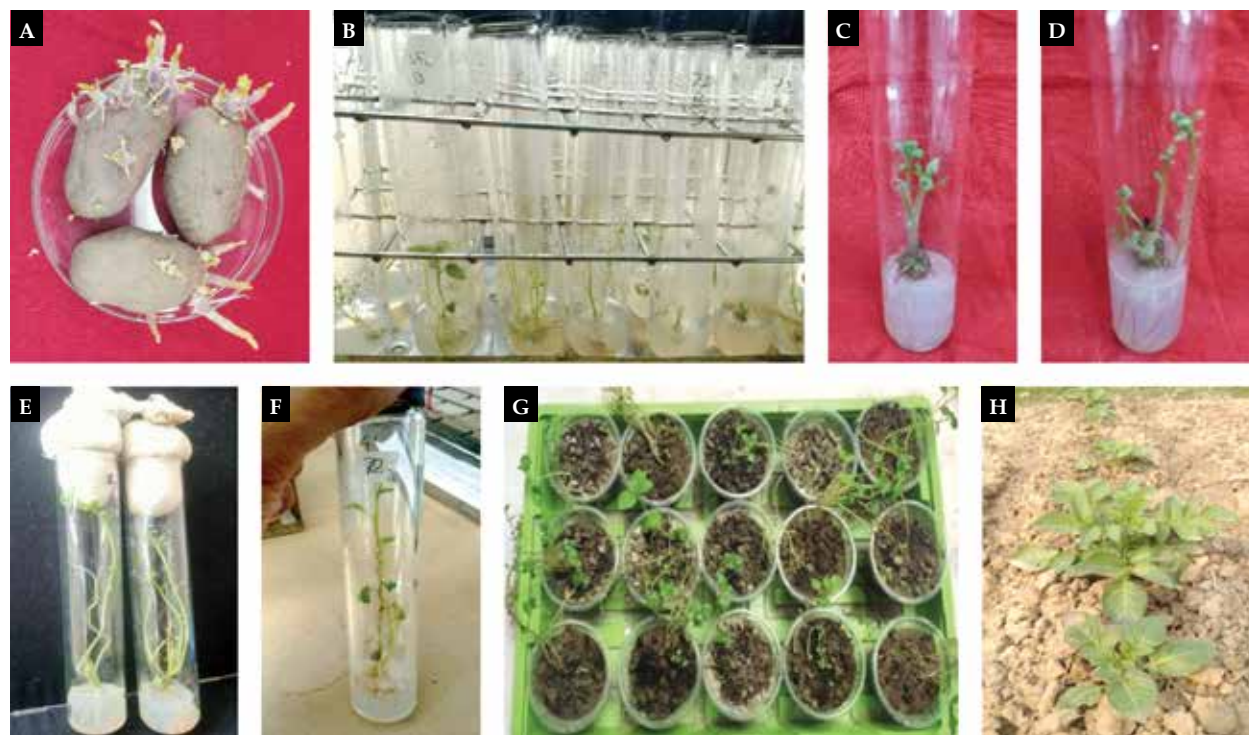


Fig. 3. Sequential steps of clonal micropropagation of potato: A. Potato sprouts used as a source of explant, B. *In vitro* incubation of culture, C-D. *In vitro* shoot multiplication and root growth of BARI Alu-41, E-F. *In vitro* shoot multiplication and root growth of BARI Alu-72, G. *Ex vitro* hardening of plantlets, H. Established micropropagated potato plants in the field.

shoot proliferation through cell division and apical dominance release (Lyndon, 1990; Müller and Leyser, 2011). In this study, both varieties showed increased shoot and node multiplication with increasing BAP concentration up to an optimum range, beyond which performance either plateaued or declined. For BARI Alu-41, the highest shoot number (3.32) and node number (10.03) were recorded at 2.0 mg L⁻¹ BAP, whereas higher concentrations (2.5-3.0 mg L⁻¹) reduced efficiency. In contrast, BARI Alu-72 responded better to 2.5 mg L⁻¹ BAP with the highest shoot number (3.50), suggesting that genotypic differences strongly influence cytokinin sensitivity. These results align with previous reports where optimal shoot multiplication was observed within the range of 1.5-3.0 mg L⁻¹ BAP in potato varieties (Motallebi-Azar *et al.*, 2011). Similar varietal variation in BAP requirement was reported by Hajare *et al.* (2021), where variety Gudiene responded best at 1.5 mg L⁻¹ BAP + 3.0 mg L⁻¹ NAA, whereas variety Belete performed better at 1.0 mg L⁻¹ BAP + 0.2 mg L⁻¹ NAA. Such findings emphasize that no unique BAP concentration ensures maximum shoot induction across varieties.

Effect on leaf number and shoot length

Leaf development was also significantly influenced by BAP concentration and variety interaction. BARI Alu-72 consistently produced more leaves, with the maximum leaves plantlet⁻¹ (12.42) observed at 1.5 mg L⁻¹ BAP, whereas BARI Alu-41 lagged behind with fewer leaves under all concentrations. This suggests a stronger morphogenic capacity of BARI Alu-72 under cytokinin influence. Cytokinins are reported to stimulate foliar development and enhance photosynthetic tissue formation in potato shoot tip cultures (Dilshad *et al.*, 2021), which could partly explain the superior response

of BARI Alu-72. Shoot length exhibited a similar trend, with the highest elongation (93.12 mm) in BARI Alu-72 at 1.5 mg L⁻¹ BAP. Comparatively, BARI Alu-41 recorded only moderate elongation, even at optimal concentrations. Comparable findings were reported by Dhaka and Nailwal (2015), and Masekesa *et al.* (2016), who observed significant enhancement of shoot length with BAP in combination with GA₃. Our results corroborate that moderate BAP concentrations not only induce axillary shoot multiplication but also support elongation, although varietal background remains a decisive factor.

Root development under BAP influence

BAP affected root induction variably across varieties. BARI Alu-72 produced the highest number of roots (21.66 plant⁻¹) at 1.5 mg L⁻¹ BAP, while BARI Alu-41 attained the maximum (17.78 plant⁻¹) at 3.0 mg L⁻¹ BAP. However, root length was less responsive to BAP in BARI Alu-41 compared to BARI Alu-72. This partially contradicts earlier findings suggesting that BAP tends to inhibit root formation in potato meristem culture (Aprilia *et al.*, 2022). It is possible that varietal genetic makeup modulates the balance between cytokinin-induced shoot proliferation and root formation. In this context, supplementary auxins *viz.*, NAA or IBA are generally recommended to achieve balanced rooting (Rout *et al.*, 2001), which was also observed in several earlier studies (Hajare *et al.*, 2021).

Varietal differences in regeneration potential

The comparative performance of BARI Alu-41 and BARI Alu-72 demonstrates that varietal differences play a significant role in tissue culture responsiveness. BARI Alu-72 consistently outperformed BARI Alu-41 in most traits, particularly in shoot length,

leaf number, and rooting ability, indicating a higher regeneration potential. Such genotypic variability in micropropagation efficiency has been reported earlier (Rohela *et al.*, 2018), suggesting that tissue culture success is inherently genotype-dependent.

***Ex vitro* hardening**

Ex vitro hardening success varied with substrate and genotype (Sharma *et al.*, 2023). Cocopeat + vermicompost gave the highest survival in both varieties due to its superior aeration, moisture retention, and nutrient availability. Intermediate survival in soil + sand + compost and sand + soil + cow dung indicates partial suitability, while the lowest survival in garden soil reflects poor porosity and nutrient balance. Between varieties, BARI Alu-41 showed slightly higher survival than BARI Alu-72, suggesting genotypic differences in adaptability.

The regression analysis further substantiates the ANOVA-based findings presented in Tables 1 and 2, where BAP concentration exerted a significant influence on shoot production efficiency in both varieties. For BARI Alu-41, the regression indicated only a weak positive relationship ($R^2 = 0.1896$), suggesting that shoot proliferation was less responsive to increasing BAP levels. This aligns with the ANOVA results, where BARI Alu-41 showed relatively lower shoot numbers compared to BARI Alu-72. In contrast, BARI Alu-72 displayed a stronger positive response to BAP concentration, as reflected in a higher regression coefficient and R^2 value (0.3797). This trend is consistent with the ANOVA-based interaction effects, which revealed that higher BAP concentrations, particularly 2.5 mg L^{-1} , markedly enhanced shoot multiplication in BARI Alu-72. Together, these results confirm that varietal differences strongly modulate the response to BAP

(Hossain *et al.*, 2019), with BARI Alu-72 showing greater efficiency and predictability in shoot induction compared to BARI Alu-41.

BAP alone can successfully induce shoot multiplication in potato (Motallebi-Azar *et al.*, 2011; Dilshad *et al.*, 2021); however, Salem and Hassanein (2017) and Buckseth (2023) suggested that MS medium devoid of growth regulators is sufficient for potato single-node cultivation. Our findings clearly demonstrated that exogenous cytokinin supplementation is essential for efficient regeneration in the tested potato varieties. This discrepancy may arise from differences in explant type, physiological state, or inherent varietal traits. The ANOVA results indicated significant varietal and BAP concentration effects, with BARI Alu-72 exhibiting superior shoot multiplication compared to BARI Alu-41. Regression analysis further supported this observation, revealing a stronger positive relationship between BAP concentration and shoot induction efficiency in BARI Alu-72 ($R^2 = 0.3797$) than in BARI Alu-41 ($R^2 = 0.1896$). These findings suggest that while both varieties respond to BAP, the degree of responsiveness is cultivar-specific. Moreover, the results corroborate earlier reports by Kazemiani *et al.* (2018), who concluded that the most favorable shoot induction occurs with BAP concentrations ranging between $1.5\text{--}3.0 \text{ mg L}^{-1}$. The present study strengthens this conclusion, emphasizing that the optimal concentration lies within this range but differs according to varietal background.

CONCLUSION

The present study demonstrated that *in vitro* multiplication efficiency of potato is significantly influenced by the interaction between genotype and BAP concentration. Both BARI Alu-41 and BARI Alu-72 exhibited differential responses to varying BAP levels, highlighting the necessity of genotype-

specific optimization. Among the tested combinations, MS medium supplemented with 2.0 mg L⁻¹ BAP supported superior shoot multiplication in BARI Alu-41, while 2.5 mg L⁻¹ BAP favored higher shoot proliferation in BARI Alu-72. Furthermore, BAP concentrations strongly influenced shoot number, node production, leaf development, and shoot length; whereas root traits were less responsive, suggesting that additional auxin supplementation may be required for optimal root induction. The genotype-specific variation observed in this study reinforces that no universal protocol exists for potato regeneration. Standardization of hormone regimes for individual varieties is therefore crucial for efficient micropropagation and for the large-scale production of disease-free, quality seed potatoes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest for the article.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals.

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