Research Article

Combined Impact of Ethanol Priming and Storage Conditions on the Dormancy Termination of Potato (*Solanum tuberosum* L.) Mini-Tubers

Ghani Gul[1]*, Fazli Wahab[1], Muhammad Umair Khan[2], Syed Awais Ali Shah[2], Ijaz Naeem Khan[2], Iqrar Hussain[1], Tamana Bakht[5], Rimsha Zianab[3], Sahid Zaman[4] and Ali Taj[6]

[1]Directorate of Agriculture Research (Merged Areas), Agriculture Research Institute (ARI), Tarnab, Peshawar, Pakistan; [2]Department of Biotechnology, University of Swabi, Swabi, Pakistan; [3]Department of Botany, Shaheeb Benazir Bhutto Women University Peshawar, Pakistan; [4]Department of Agricultural Extension Education and Communication, The University of Agriculture Peshawar, Pakistan; [5]Department of Environmental Science, Shaheed Benazir Butto University Sheringal, Dir Upper (KP), Pakistan; [6]Department of Soil and Environmental Sciences, The University of Agriculture Peshawar, Pakistan.

Abstract | Dormancy in seed potato (mini-tubers) significantly impacts seed production and planting schedules, necessitating effective strategies for its termination. This study was conducted in the Agriculture Research Institute Tarnab, Peshawar, Khyber Pakhtunkhwa, Pakistan to explore the combined impact of ethanol priming and storage conditions on dormancy termination in potato mini-tubers. Freshly harvested mini-tubers were dipped in ethanol for different time durations (1, 3 and 5 minutes) and kept under four different storage conditions (Dark, Farm yard manure (FYM), Diffused light and open light). Our results demonstrate a significant interplay in the acceleration of dormancy termination for all studied parameters. The mini-tubers primed with ethanol for 5 minutes and stored in FYM were resulted in higher respiration rate (3.2 mg/kg/hour), GA_3 (4.8 ng/g), CK (5.6 ng/g) and lower ABA (3.7 ng/g). While early sprouted within (43.7 days), sprouting percentage (82.9%), Sprout Length (6.0 cm) and Number of Sprouts (3.7) were also achieved in the mini-tubers primed with ethanol for 5 minutes and stored in pit with FYM. These findings offer novel priming approach for freshly harvested seed potato of dipping in ethanol for 5 minutes and store in a pit with FYM for dormancy termination. This transformative strategy paves the way for enhanced planting schedules, elevated crop productivity and a new era of sustainable potato cultivation.

Received | December 02, 2024; **Accepted** | May 26, 2025; **Published** | August 24, 2025
***Correspondence** | Ghani Gul, Directorate of Agriculture Research (Merged Areas), Agriculture Research Institute (ARI), Tarnab, Peshawar, Pakistan; **Email:** ghanihot26@gmail.com
Citation | Gul, G., F. Wahab, M.U. Khan, S.A.A. Shah, I.N. Khan, I. Hussain, T. Bakht, R. Zianab, S. Zaman and A. Taj. 2025. Combined impact of ethanol priming and storage conditions on the dormancy termination of potato (*Solanum tuberosum* L.) mini-tubers. *Sarhad Journal of Agriculture,* 41(3): 1266-1274.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.3.1266.1274
Keywords | Seed potato, Mini-tubers, Dormancy, Ethanol

Introduction

Potato (*Solanum tuberosum* L.) is an important crop that is cultivated all over the world by farmers in various growing seasons. It is among the four major crops which has a significant contribution to national domestic consumption and food needs (Majeed and Muhammad, 2018). Domestication of

the potato occurred 8,000–10,000 years ago, from a diploid wild species (2x = 2n = 24) that originated in the Southern Peruvian Andes (Struik and Wiersema, 1999). The edible part of potato plant is tubers, which are modified underground swelling stems that can be used for industrial, feed, food purposes and they can also be used as seed for subsequent crops. Following a series of physiological processes, such as stolonization, tuber induction and initiation, tuberization, and bulking, until the tubers finally mature, stolons and tubers are begun as the potato crop grows (Struik and Wiersema, 1999).

Potatoes are a highly promising food crop because of their high starch, high protein, high mineral content, high concentration of vital vitamins and relatively low-fat level (Andre *et al*., 2007). Tubers are rich in nutrients like potassium and phosphorus, but low in salt and calcium. There's also an average quantity of silicon, sulfur, iron, magnesium, zinc, manganese, and chlorine. Boron, iodine, bromine, copper, aluminum, molybdenum, cobalt, and nickel are present in trace amounts (Andre *et al*., 2007).

Duration of potato tuber dormancy and the beginning of sprouting have significant economic importance for seed and ware potatoes (Aksenova *et al*., 2013). It is thought that the two main aspects of tuber behavior to be studied in order to release a promising clone are dormancy and sprouting (Virtanen *et al*., 2013). It has been reported that a variety of intrinsic and extrinsic factors, such as light, temperature, photoperiod, phytohormones, and balanced nutrition, can regulate the tuberization process of potatoes (Pathak *et al*., 2021).

In plants, dormancy is a stage of temporarily reduced activity and an endogenously controlled but environmentally imposed suspension of growth and development. Dormancy is the state of inactivity of meristem and the absence of germination even in the most favorable conditions (Lang *et al*., 1987). Potato tubers enter a state of progressive dormancy as soon as cell division in the sobol on tip finishes and the tuber begins to develop the potato tubers continue to be dormant for two to three months after their harvesting. The potato tubers continue to be dormant for two to three months after their harvesting (Suttle, 2007). Freshly harvested tubers do not sprout even under optimum growing conditions; this is because they need a period of dormancy, which varies throughout cultivars. The start of dormancy and tuber initiation on the stolons occurs at the same time throughout dormancy, the depth of dormancy varies. It builds up gradually until the haulm removal, at which point it quickly reaches its peak. Longer storage causes the apical dominance decrease and several sprouts to emerge down the tuber. For practical purposes, the period of dormancy is the interval between harvest and the emergence of sprouts, which on 80% of tested tubers attain a height of at least 2 mm (Struik and Wiersema, 2023). Development of dormancy is a survival strategy because physiologic alteration leading to irregular times in stressful environment. Research on potato tuber dormancy is fundamentally important for seed and food tubers alike (Suttle *et al*., 2007).

The duration of dormancy is further influenced by a variety of storage factors, including temperature, humidity of the storage atmosphere, light, oxygen and carbon dioxide concentrations, and the potential presence of volatile potato compounds (ethylene) (Van and Hartman, 1987). Dormancy breaking treatments may be the solution to overcome this problem. Sprouting can be stimulated by chemicals, by damaging the tuber, by increasing the humidity of the storage atmosphere, by temperature variation, etc.

Dormancy breakup could be the opposite of dormancy development, showing that tuber induction and dormancy development can be comparable (Claassens *et al*., 2002). Gibberellins (GAs) have been demonstrated to disrupt seed dormancy in seeds, which has been the subject of extensive research (Groot and Karrsen, 1987). Moreover, it has been demonstrated that a wide range of non-hormonal organic and inorganic compounds, such as ethanol, can also influence dormancy in seeds in addition to Gas, red rice, for example Cohn *et al*. (1989) studied with various inhibitors, it has been suggested that the stimulatory effect of ethanol on dormancy breaking in seeds specifically acts through alcohol dehydrogenase (ADH) activity (Cohn *et al*., 1989).

It has been shown that ethanol can cause tubers to come out of dormancy in Jerusalem artichokes (Petel *et al*., 1993). It was demonstrated by preliminary tests that ethanol can induce potato tubers cultivated in vitro to emerge from dormancy. Alcohol metabolism has been proposed as a potential explanation for how ethanol functions in the dormant breaking

phenomena in seeds (Corbineau *et al*., 1991). It was recently found that *in vitro* cultured growing and maturing tubers rapidly break their dormancy when ethanol and sugar are combined. The concentration of sugar influenced the budding bud's destiny (Claassens *et al*., 2005).

This study deals with the use of dipping mechanism of tubers in a dormancys breaking chemical Ethanol in addition to different storage methods. There were four different storage conditions, namely; Dark, Diffused light, Farm-yard manure and open light. The effect of ethanol treatment on the sprouting of minitubers was studied.

Materials and Methods

This study was conducted in completely randomized design (CRD), evaluating two factors namely ethanol priming duration and storage conditions. The treatments were randomly assigned to experimental units (mini-tubers) with three replications.

Plant material

The plant material for the current experiment consists of medium size (20-25 g) disease free mini-tubers of potato cultivar Desiree, harvested from the *in vitro* developed plantlets at the greenhouse of plant tissue culture laboratory, Agriculture research institute (ARI) Tarnab, Peshawar. The mini-tubers were manually harvested, washed and air dried for 24 hours at room temperature.

Experimental condition

Three sets of twenty uniform size mini-tubers were separated and treated each set with 100 % ethanol for proposed durations (1, 3 and 5 minutes) represented by D1, D2 and D3 respectively. After treatment all of three sets were farther divided into four sets each containing five mini-tubers to store each set of five mini-tubers at all of the proposed storage conditions (Open light, diffused light, dark and pit with farm yard manure) denoted by S1, S2, S3 and S4 respectively. Subsequently, a set of five mini-tubers from each D1, D2 and D3 were assigned to each storage condition S1, S2, S3 and S4, separately.

Data collection

All the experimental units were closely observed weekly to monitor sprouting progress until all mini-tubers had sprouted. At the end of the 60-days storage period, final measurements for sprout length and the number of sprouts per mini-tuber were recorded. The dormancy period of all mini-tubers were defined as the number of days from treatment to sprouting.

Statistical analysis

The data was analyzed using Analysis of variance (ANOVA) and Treatment means were separated by least significant differences (LSD) using software statistic 8.1.

Studied parameters

Dormancy duration: The number of days was recorded as from treatment storage initiation to visible sprout emergence (≥ 2 mm) on each mini-tuber.

Sprouting percentage: The proportion of mini-tubers that sprouted within 60 days, calculated using the formula:

$$\text{Sprouting \%} = \frac{Number\ of\ sprouted\ minitubers}{Total\ number\ of\ minitubers} \times 100$$

Sprout length (mm): The lengths of each sprout on all mini-tubers were measured after 60 days using a ruler. Number of sprouts per mini-tuber: The average number of sprouts emerging from a single mini-tuber was recorded.

Respiration rate

The select five representative mini-tubers from each treatment were weigh using a digital balance and record the weight in kilograms and recorded initial CO_2 reading inside the airtight chamber, then kept for 1 hour. After an hour the final CO_2 concentration inside the chamber was measured using a CO_2 gas sensor.

The CO_2 emission rate was calculated using the formula for the respiration Rate (RR) (mg CO_2/kg/h).

$$RR = \frac{Final\ CO2 - Initial\ CO2}{Weight\ of\ tubers \times Time\ (hours)}$$

Hormonal analysis

Sample preparation: A sample of 2 g mini-tuber tissue was grinded it in liquid nitrogen from each treatment and the hormones were extracted using 10 mL of methanol: water (80:20 v/v) with 1% formic acid. The extracts were centrifuged at 10,000 rpm for 10 minutes and collected the supernatant and pass

through SPE cartridges for purification.

HPLC analysis

The mobile phase was prepared using acetonitrile and water with 0.1% formic acid and injected 20 µL of the purified extract into the HPLC system. Wavelengths were set for detestation: ABA (265 nm), GA (210 nm), CK (280 nm) and the hormones were quantified by comparing retention times and peak areas with those of standards.

Results and Discussion

Days to sprouting

The interaction of ethanol priming durations and storage conditions have significantly affected the days to sprouting of mini-tubers (Figure 1).

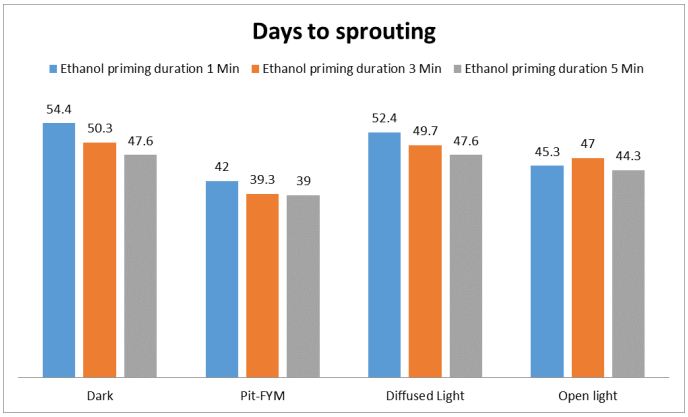

Figure 1: *The combined effect of ethanol priming durations and storage conditions on days to sprouting of potato minitubers.*

The results revealed a strong influence of the interaction of both ethanol dipping duration and storage conditions in reducing the number of days to sprouting. The dormancy period of mini-tubers dipped in ethanol for 5 minutes and stored in having FYM was significantly reduced to (39 days) after treatment, while the mini-tubers treated with for one minute with ethanol and stored in dark took (54.4 day) (Figure 1).

Previous studies reveal that ethanol is likely to disrupt abscisic acid (ABA) pathways, enhanced gibberellin synthesis and stimulate metabolic activity that is critical for dormancy break. The sprouting percentage at 4% ethanol treatment for 30 minutes was observed as 80% of tubers for two potato cultivars (Wróbel *et al.*, 2017). Our results are also in line with Claassens (2002), stated that ethanol has been explored for its dormancy breaking because of its role in reducing the dormancy of seed potato. It has also been observed that the physiological condition of potato tubers during post-harvest storage and ethanol applications affects the seed potato sprouting and dormancy-breaking (Delaplace *et al.*, 2009). Other studies also advocated the role of ethanol and plant growth regulators PGRs in dormancy termination (Wróbel *et al.*, 2017).

The FYM pit provided a supportive microenvironment to dormancy termination with warmth, moderate humidity and aeration. The storage conditions also influence the nature of sprouting in tubers. The farm yard manure and pit storage as compared to open light or DLS are proved to be most suitable in providing best sprout vigor and number (Mustefa *et al.*, 2017). The combine effect of ethanol and storage condition on dormancy termination have also revealed as dormancy breaking agent physiological activity accelerator (Ewing *et al.*, 2004; Verhees *et al.*, 2002). This interaction highlights the synergistic effect of chemical and environmental treatments in reducing dormancy. Such strategies offer practical solutions for optimizing seed tuber management and ensuring timely planting, particularly in regions with intensive cropping systems.

Sprouting percentage

The interactive effect of ethanol priming durations and storage conditions has significantly influenced the sprouting % of potato mini-tubers (Figure 2). The best sprouting percentage (87.7 %) was achieved from the mini-tubers dipped in ethanol for five minutes and stored in a pit with FYM. While (57.4 %) of mini-tuber were sprouted when treated with ethanol for one minute and stored in dark condition (Figure 2).

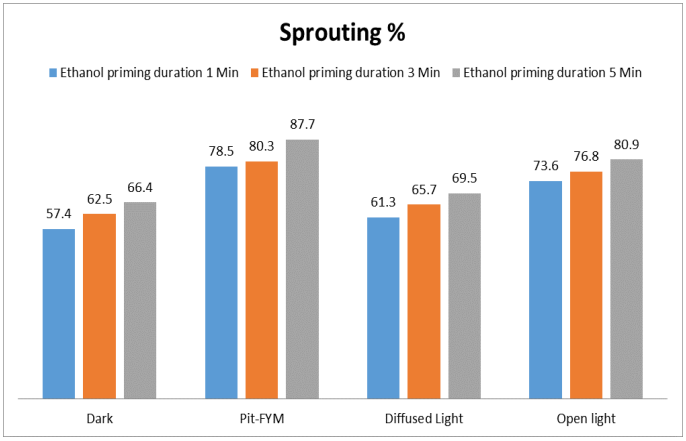

Figure 2: *The combined effect of ethanol priming durations and storage conditions on sprouting % of potato minitubers.*

The significant improvement in sprouting percentage due to ethanol treatment reflects its ability to disrupt

dormancy-related hormonal balance. Ethanol is known to reduce abscisic acid (ABA) levels, enhance gibberellin biosynthesis and activate enzymes that trigger metabolic processes in dormant seed potatoes. Previous studies have also encouraged our results as 80 to 90 % of the seed potato of different cultivars was sprouted when treated with ethanol compare to the control with only 13 % sprouting (Wróbel *et al.*, 2017). Another study has also stated that after 30 days of treatment, the tubers treated with ethanol were sprouted to 100% and the control reached up to 64%. In this way the tubers treated with ethanol showed approximately 64% sprouting soon after 5 days of treatment and 100% sprouting was obtained after 30 days (Claassens *et al.*, 2005). The storage conditions are also reported to have a visible impact on sprouting percentage of seed potatoes as previous work, under farm yard manure and pit storage, the highest percentage of sprouting was 100% and 99.17%, respectively, for the Babu variety, and 100% under both FYM and pit for the Bate type (Mustefa *et al.*, 2017). It is apparent from the previous research that ethanol priming with adequate post-harvest storage conditions stimulates metabolic activity and facilitates dormancy termination in potato tubers (Bologa *et al.*, 2003).

These results suggest that adopting a five-minute ethanol dipping treatment followed by FYM storage could be a practical approach to maximize sprouting percentage, especially for seed tuber production in intensive cropping systems.

Sprout length

The combined impact of ethanol priming durations and storage conditions has considerably influenced the sprout length of potato mini-tubers (Figure 3). The maximum sprout length (7.3 cm) was achieved from the mini-tubers primed with ethanol for five minutes and stored in a pit with FYM. While (3.4 cm) length gained by the sprouts on the mini-tubers primed with ethanol for one minute and stored on open (Figure 3).

The present study emphasizing the positive effect of ethanol priming on dormancy termination and promoting bud elongation. It is evident that ethanol simultaneously increasing gibberellin activity, which is crucial for cell elongation and bud growth. Ethanol has been explored for its dormancy breaking capacity in potato tubers with a specific focus on its mode of action via alcohol dehydrogenase (ADH). This suggests that ethanol may play a role in influencing the dormancy status of potato tubers, potentially affecting sprout growth and sprout length (Claassens, 2002). Research has also advocated ethanol as dormancy breaking agent because it accelerates metabolic and hormonal changes, promoting sprout elongation (Delaplace *et al.*, 2009).

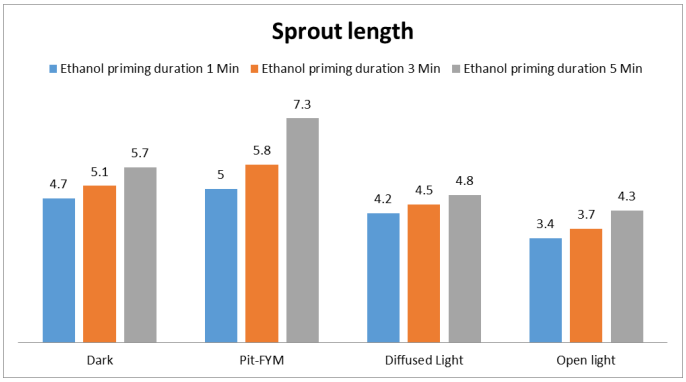

Figure 3: *The combined effect of ethanol priming durations and storage conditions on sprout length of potato minitubers.*

On the other hand postharvest storage conditions considerably seed potato dormancy, as the farm yard manure and pit storage in comparison with open light or DLS are proved to be most suitable in providing best sprout vigor and number (Mustefa *et al.*, 2017). It is also evident that the organic matter in FYM develops a microenvironment, ensuring optimal conditions for bud growth, termination of dormancy and subsequent sprouting in potato tubers while studied in relation to ethanol and growth regulators (Wróbel *et al.*, 2017). Pit storage also moderates temperature fluctuations and maintains high humidity levels that are essential factors for sprout initiation improved aeration and nutrient release from FYM further enhance sprout growth.

These results underscore the low-cost, sustainable method that is particularly beneficial for small-scale farmers, providing an eco-friendly solution to improve sprouting performance and seed tuber quality. The longer sprouts obtained through this combination are advantageous for uniform crop establishment and improved productivity in potato cultivation.

Number of sprouts

The collective effect of ethanol priming durations and storage conditions has noticeably influenced the number of sprouts^{-1} of potato mini-tubers (Figure 4). The maximum sprout count (3.4) was noted in the mini-tubers primed with ethanol for five minutes and

stored on open light conditions. While (2.1) sprouts were observed on the mini-tubers treated with ethanol for one minute and stored in dark (Figure 4).

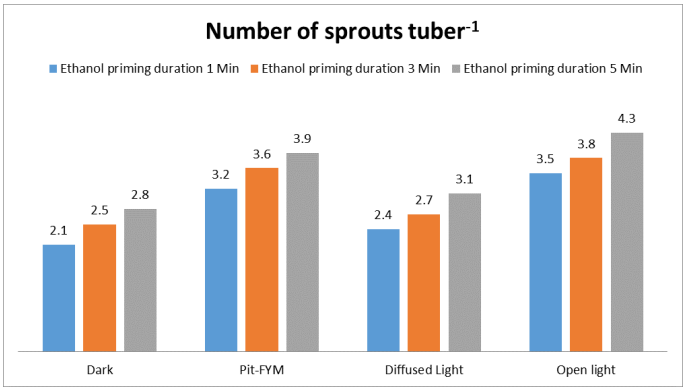

Figure 4: *The combined effect of ethanol priming durations and storage conditions on number of sprouts tuber^{-1} of potato minitubers.*

Recent studies have advocated the pivotal role of both ethanol treatment and post treatment storage conditions on number of sprouts per mini-tuber as ethanol has the ability to reduce abscisic acid (ABA) levels and promote gibberellin biosynthesis, thereby breaking dormancy and stimulating bud activation. Mustefa *et al.* (2017) reported that the number of sprouts per tuber was found to be significantly impacted by the storage under pit/farm yard manure, the largest number of sprouts per tuber was observed, 6.57 and 6.32, respectively. FYM has reported to create an ideal microclimate with adequate warmth, stable humidity and satisfactory aeration, which are crucial for activating metabolic and hormonal pathways that drive sprouting. The decomposing organic matter in FYM may also release ethylene and other gases that stimulate sprout initiation (Taylor *et al.*, 2019). The dormancy termination by ethanol treatment is also linked with carbohydrates metabolism and sugars break down by different pathways like acid invertase (AI), neutral invertase (NI), sucrose synthase (SS), sucrose phosphate synthase (SPS) (Dai *et al.*, 2016).

The overall results show that ethanol dipping chemically primes the mini-tubers, while optimal storage conditions enhance environmental cues for sprouting. These findings suggest that adopting both treatments in seed tuber management could increase the number of sprouts per tuber with improved planting efficiency and productivity.

Respiration rate (mg/kg/hour)

The respiration rate of the mini-tubers was significantly affected by the combination of ethanol priming duration and storage conditions. The highest respiration rate (3.2 mg/kg/h) was recorded in the mini-tubers dipped in ethanol for five minutes and stored in a pit with FYM. While the lowest respiration rate (1.3 mg/kg/h) was recorded in the mini-tubers dipped in ethanol for one minute and stored in the dark (Figure 5).

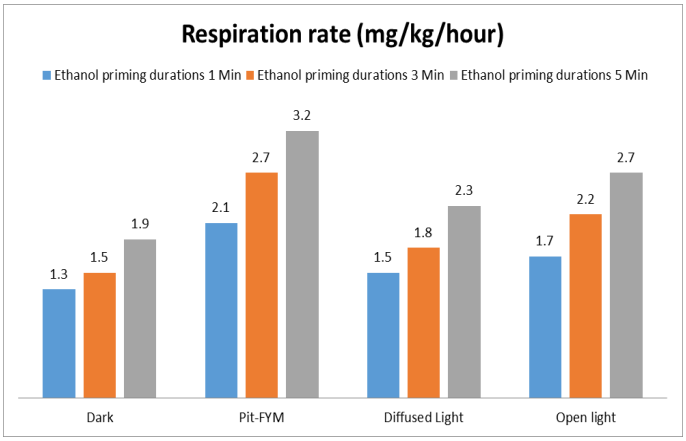

Figure 5: *The combined effect of ethanol priming durations and storage conditions on Respiration rate of potato minitubers.*

The significant interactive effect of ethanol priming duration and storage conditions on the respiration rate of potato mini-tubers shows the potential influence of postharvest handling on the physiological processes of seed potatoes. Liu *et al.* (2022) reported the ethanol priming to induce physiological changes by altering enzymatic activity and modulating oxidative stress. The rise in respiration rate is because of the boosted metabolic activity due to extended ethanol exposure. Ethanol priming might induce stress responses and activated antioxidant pathways that resulted in increased respiratory activity. On the other hand pit with FYM, provide favorable storage conditions by maintaining higher humidity and moderated temperature to increased respiratory activity (Zhang *et al.*, 2023). So, the dormancy of seed potato may release by the combined effect of ethanol priming and storage condition, where ethanol-induced stress is amplified by the microenvironment of the pit with FYM that influenced tuber physiology and induced sprouting (Kumar *et al.*, 2023).

Abscisic acid ng/g (265 nm)

The Abscisic acid (ABA) levels of potato mini-tubers were significantly influenced by the interaction of ethanol priming duration and storage conditions. The lowest ABA (3.7 ng/g) were noted in the mini-tubers primed with ethanol for five minutes and stored in a pit with FYM. While the highest ABA (5.8 ng/g) were recorded in the mini-tubers treated with ethanol

for one minute and stored in the dark (Figure 6).

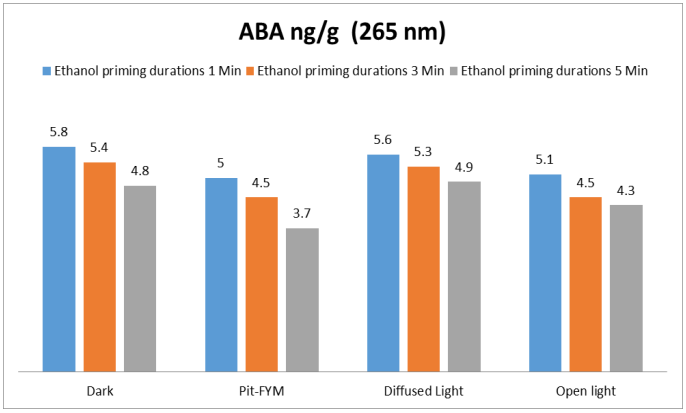

Figure 6: *The combined effect of ethanol priming durations and storage conditions on ABA of potato minitubers.*

The interactive effect of ethanol priming duration and storage conditions shows the insights of dormancy release mechanisms by lowering ABA levels in potato mini-tubers. The prolonged ethanol exposure is reported to induce stress responses, promoting ABA catabolism and facilitating dormancy release (Liu *et al.*, 2022). Moreover, the dynamic, nutrient-rich conditions in FYM-enriched pit storage may also improve metabolic activity and reduce ABA levels supporting dormancy termination (Zhang *et al.*, 2023). While no or lower ethanol priming stress and stable storage favor ABA retention, associated with maintained dormancy (Chen *et al.*, 2021). Our finding paves the way to enhance the physiological readiness and accelerating dormancy termination of seed tubers resulting in early sprouting and subsequent planting.

Gibberellic acid content (GA3) ng/g (210 nm)

The combined effect of ethanol priming durations and storage conditions significantly influenced the gibberellic acid (GA3) content in potato mini-tubers. The highest GA3 content (4.8 ng/g) was recorded in the mini-tubers primed with ethanol for five minutes and stored in a pit with FYM. While the lowest GA3 content (2.1 ng/g) was found in the mini-tubers treated with ethanol for one minute and stored in the dark (Figure 7).

The prolonged ethanol priming is evident to induce stress signals that results in GA3 biosynthesis that is crucial for dormancy termination as it stimulates cell elongation, enzyme activity and metabolic changes that facilitate sprouting and promote sprouting of seed (Kumar *et al.*, 2023). In addition, the pit with FYM storage maintained higher humidity and moderated temperatures, which are conducive to activate metabolic activity and hormonal pathways associated with dormancy termination (Zhang *et al.*, 2023).

Cytokinin content (CK) ng/g (280 nm)

The interaction of ethanol priming duration and storage conditions significantly influenced Cytokinin content (CK) in potato mini-tubers. The highest CK content (5.6 ng/g) was noted in the mini-tubers primed with ethanol for five minutes and stored in a pit with FYM. While the lowest CK content (2.8 ng/g) was recorded in the mini-tubers treated with ethanol for one minute and stored in the dark (Figure 8).

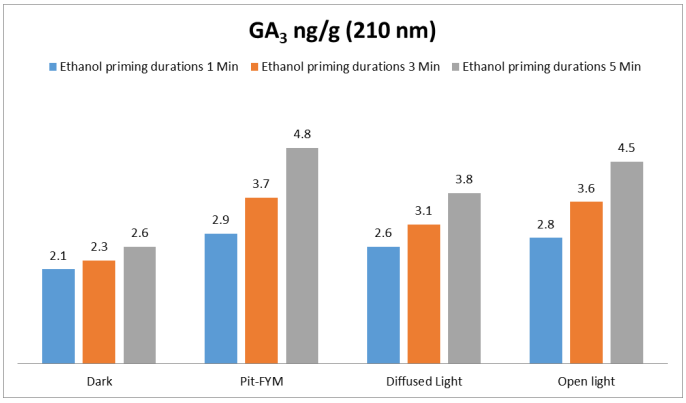

Figure 7: *The combined effect of ethanol priming durations and storage conditions on GA_3 of potato minitubers.*

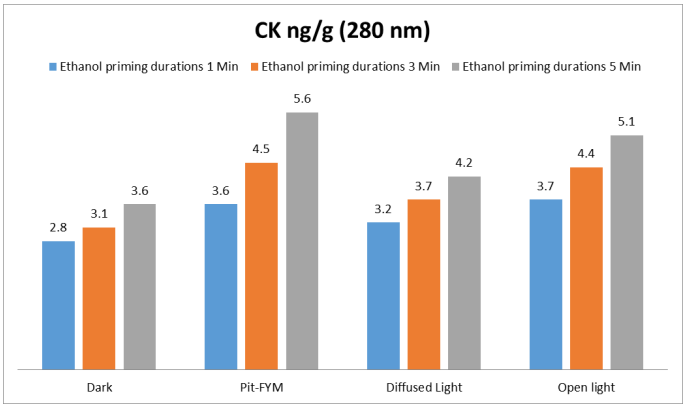

Figure 8: *The combined effect of ethanol priming durations and storage conditions on CK of potato mini-tubers.*

Ethanol priming and pit with FYM synergistically stimulate cytokinin biosynthesis, that encouraging cell division, sprouuting and meristematic activity (Liu *et al.*, 2022). The pit with FYM provides a humid and aerated microenvironment supportive to hormonal activity, while ethanol priming induced mild stress, triggering metabolic and hormonal pathways that favor dormancy release (Zhang *et al.*, 2023). The rise in cytokinin content through such treatments leads to improved sprouting vigor, better shoot development, and higher productivity in subsequent planting cycles.

Conclusions and Recommendations

It was shown by results that ethanol dipping times and storage methods had significant effect on the dormancy breaking of potato minitubers. The treatment which showed best results for all parameters was the treatment having five minutes dipping times in ethanol and stored in pit with farm yard manure (FYM). To minimize the gap between potato growing seasons, ethanol treatment is recommended for seed potatoes followed by storage in farm yard manure.

Acknowledgements

The authors are thankful to the Directorate of Agriculture Research (Merged Areas) and to the staff of Plant Tissue Culture Laboratory (ARI) Tarnab, Peshawar for their invaluable support throughout this research study.

Novelty Statement

This research pioneers the exploration of the synergistic effects of ethanol priming and storage conditions on dormancy termination in seed potato (mini-tubers). These findings not only enhance potato propagation efficiency but also offer transformative insights for advancing sustainable crop management practices.

Author's Contribution

Ghani Gul: Principal author conducted this research and wrote this paper.
Muhammad Umair Khan: Helped in writing and submission.
Ijaz Naeem Khan and Syed Awais Ali Shah: Helped in research and designing of the results.
Fazli Wahab and Iqrar Hussain: Helped in research methodology and analysis.
Tamana Bakht and Rimsha Zianab: actively involved in proof reading and composing of the manuscript.
Sahid Zaman and Ali Taj: Helped formatting and writing.

Conflict of interest
The authors have declared no conflict of interest.

References

Aksenova, N.P., L.I. Sergeeva, T.N. Konstantinova, S.A. Golyanovskaya, O.O. Kolachevskaya and G.A. Romanov. 2013. Regulation of potato tuber dormancy and sprouting. Russian J. Plant Physiol., 60: 301-312. https://doi.org/10.1134/S1021443713030023

Andre, C.M., M. Ghislain, P. Bertin, M. Oufir, M.D.R. Herrera, L. Hoffmann and D. Evers. 2007. Andean potato cultivars (*Solanum tuberosum* L.) as a source of antioxidant and mineral micronutrients. J. Agric. Food Chem., 55(2): 366-378. https://doi.org/10.1021/jf062740i

Bologa, K.L., A.R. Fernie, A. Leisse, M.E. Loureiro and P. Geigenberger. 2003. A bypass of sucrose synthase leads to low internal oxygen and impaired metabolic performance in growing potato tubers. Plant Physiol., 132(4): 2058-2072. https://doi.org/10.1104/pp.103.022236

Chen, J., S. Wu and T. Feng. 2021. Effects of dark storage on the metabolic activity of tuber crops. Sci. Horticult., 290(4): 110424.

Claassens, M.M., 2002. Carbohydrate metabolism during potato tuber dormancy and sprouting. Wageningen University and Research.

Claassens, M.M. and D. Vreugdenhil. 2000. Is dormancy breaking of potato tubers the reverse of tuber initiation? Potato Res., 43: 347-369. https://doi.org/10.1007/BF02360540

Claassens, M.M., J. Verhees, L.H. van der Plas, A.R. van der Krol and D. Vreugdenhil. 2005. Ethanol breaks dormancy of the potato tuber apical bud. J. Exp. Bot., 56(419): 2515-2525. https://doi.org/10.1093/jxb/eri245

Cohn, M.A., K.L. Jones, L.A. Chiles and D.F. Church. 1989. Seed dormancy in red rice: VII. Structure-activity studies of germination stimulants. Plant Physiol., 89(3): 879-882. https://doi.org/10.1104/pp.89.3.879

Corbineau, F., B. Gouble, S. Lecat and D. Come. 1991. Stimulation of germination of dormant oat (*Avena sativa* L.) seeds by ethanol and other alcohols. Seed Sci. Res., 1(1): 21-28. https://doi.org/10.1017/S0960258500000593

Dai, H., M. Fu, X. Yang and Q. Chen. 2016. Ethylene inhibited sprouting of potato tubers by influencing the carbohydrate metabolism pathway. J. Food Sci. Technol., 53: 3166-3174. https://doi.org/10.1007/s13197-016-2290-0

Delaplace, P., C. Biemelt, P. Cuypers, M. Lüthen, and J.F. Hausman. 2009. Ethylene and

gibberellin control in dormancy and sprouting of potato tubers: A transcriptomics approach. J. Exp. Bot., 60(6):1619–1631. https://doi.org/10.1093/jxb/erp021

Es, A. and K.J. Hartmans. 1987. Dormancy, sprouting and sprout inhibition. In: A. Rastovski, A. van Es *et al.* (Eds), Storage of Potatoes. Pudoc, Wageningen, the Netherlands, pp. 114-140.

Ewing, E.E., I. Simko, E.A. Omer and P.J. Davies. 2004. Polygene mapping as a tool to study the physiology of potato tuberization and dormancy. Am. J. Potato Res., 81: 281-289. https://doi.org/10.1007/BF02871770

Groot, S.P.C. and C.M. Karssen. 1987. Gibberellins regulate seed germination in tomato by endosperm weakening: A study with gibberellin-deficient mutants. Planta. 171:525-531. https://doi.org/10.1007/BF00392302

Kumar, R., A. Singh and P. Mishra. 2023. Enhancing dormancy and sprouting control in potatoes: Interactions of chemical treatments and storage methods. Food Storage Preserv., 16(2): 257-269.

Lang, G.A., J.D. Early, G.C. Martin and R.L. Darnell. 1987. Endo-, para-, and ecodormancy: Physiological terminology and classification for dormancy research. HortScience, 22(3): 371-377. https://doi.org/10.21273/HORTSCI.22.3.371

Liu, H., Y. Wang, and Z. Zhao. 2022. Role of ethanol priming in enhancing stress tolerance in stored tubers. J. Plant Physiol., 175(3): 1127-1135.

Majeed, A. and Z. Muhammad. 2018. Potato production in Pakistan: Challenges and prospective management strategies. A review. Pak. J. Bot., 50(5): 2077-2084.

Mani, F., T. Bettaieb, N. Doudech and C. Hannachi. 2014. Physiological mechanisms for potato dormancy release and sprouting: A review. Afr. Crop Sci. J., 22(2): 155-174.

Mustefa, G., W. Mohammed, N. Dechassa and D. Gelmesa. 2017. Effects of different dormancy-breaking and storage methods on seed tuber sprouting and subsequent yield of two potato (*Solanum tuberosum* L.) varieties. Open Agric., 2(1): 220-229. https://doi.org/10.1515/opag-2017-0023

Pathak, A. and C.P. Upadhyaya. 2021. A brief insight on the role of various phytohormones in potato (*Solanum tuberosum* L.) tuber development. Salicylic Acid-A versatile plant growth regulator. pp. 249-263. https://doi.org/10.1007/978-3-030-79229-9_13

Petel, G., P. Candelier and M. Gendraud. 1993. Effect of ethanol on filiate tubers of Jerusalem artichoke: A new tool to study tuber dormancy. Plant Physiol. Biochem. (Paris). 31(1): 67-71.

Struik, P.C. and S.G. Wiersema. 2023. Seed potato technology. Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-759-2

Suttle, J.C., 2000. The role of endogenous hormones in potato tuber dormancy. In: (eds. J. Kigel and G. Galili), Dormancy in plants: From whole plant behaviour to cellular control. Springer, pp. 211-226. https://doi.org/10.1079/9780851994475.0211

Suttle, J.C., 2007. Dormancy and sprouting. In: (eds. D. Vreugdenhil *et al.*), Potato Biology and Biotechnology. Elsevier, pp. 287-309. https://doi.org/10.1016/B978-044451018-1/50056-7

Taylor, P., H. Green and J. Brown. 2019. Effects of organic storage environments on sprouting and growth of potato seed tubers. Agric. Sci., 14(2): 98-105.

Van Es, A., and K.J. Hartmans. 1987. Dormancy, sprouting and sprout inhibition. In: Rastovski, A., and Van Es, A. (Eds.), Storage of Potatoes. Pudoc, Wageningen, The Netherlands, pp. 114–140.

Verhees, J., A.R. van der Krol, D. Vreugdenhil and L.H. van der Plas. 2002. Characterization of gene expression during potato tuber development in individuals and populations using the luciferase reporter system. Plant Mol. Biol., 50: 653-665. https://doi.org/10.1023/A:1019922329081

Virtanen, E., A. Visse, and L. Valkonen. 2013. Influence of storage temperature on tuber sprouting and yield formation in seed potato. Agric. Food Sci., 22(3): 236–243.

Wróbel, S., J. Kęsy and K. Treder. 2017. Effect of growth regulators and ethanol on termination of dormancy in potato tubers. Am. J. Potato Res., 94: 544-555. https://doi.org/10.1007/s12230-017-9592-2

Zhang, L., Q. Li and X. Sun. 2023. Influence of storage microenvironment on respiration and dormancy in potatoes. Postharvest Biol. Technol., 189(1): 111048.