Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Interaction of Gibberellic Acid Concentration and Storage Environment on Dormancy Release of Three Potato Varieties in Malawi

Vincent Mgoli Mwale

vmgoli@luanar.ac.mw

Lilongwe University of Agriculture and Natural Resources (LUANAR) https://orcid.org/0009-0004-0631-602X

Rosemary Mzembe Munkhondia

Lilongwe University of Agriculture and Natural Resources (LUANAR)

Abel Sefasi

Lilongwe University of Agriculture and Natural Resources (LUANAR)

Jacinta Andrew Nyaika

Lilongwe University of Agriculture and Natural Resources (LUANAR)

Rowland Maganizo Kamanga

Lilongwe University of Agriculture and Natural Resources (LUANAR)

Deborah Thayo

Lilongwe University of Agriculture and Natural Resources (LUANAR)

Research Article

Keywords: Solanum tuberosum, diffused light store, gibberellic acid, sprouting; postharvest physiology, Malawi, dormancy, seed-tuber quality

Posted Date: May 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9568735/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Interaction of Gibberellic Acid Concentration and Storage Environment on Dormancy Release of Three Potato Varieties in Malawi

Vincent Mgoli Mwale*, Rosemary Mzembe Munkhondia, Abel Sefasi, Jacinta Andrew Nyaika, Rowland Maganizo Kamanga, Deborah Thayo

Horticulture Department, Lilongwe University of Agriculture and Natural Resources (LUANAR), P.O. Box 219, Lilongwe, Malawi

***Corresponding author Email:** Dr Vincent Mgoli Mwale, Email: vmgoli@luanar.ac.mw

Abstract

Potato (*Solanum tuberosum* L.) is a significant food and seed crop in Malawi; however, premature sprouting and postharvest deterioration compromise seed-tuber quality in smallholder storage systems. There is insufficient evidence that gibberellic acid (GA_3) interacts with storage conditions and genotype to affect dormancy and sprouting in tropical highland conditions. A split–split plot experiment with four replications was conducted to evaluate three storage methods (diffused light store, darkroom, and sack storage), three potato varieties (Chuma, Thandizo, and Zikomo), and five GA_3 concentrations (0, 10, 20, 30, and 40 ppm). Storage method, GA_3 dose, and variety significantly affected dormancy period, sprout number, sprout length, weight loss, and disease incidence ($p \leq 0.01$). Moderate GA_3 concentrations (20–30 ppm) decreased dormancy duration by 14–30 days. Diffused light storage minimized weight loss (~20%) compared to darkroom (~25%) and sack storage (~26%). A significant three-way interaction ($p = 0.01$) indicated varietal differences in GA_3 response across storage locations. GA_3 did not consistently reduce the incidence of late bright. Overall, GA_3 × storage × genotype interactions strongly influenced sprouting, with moderate GA_3 under diffused light storage offering the best balance between dormancy release and tuber quality.

Keywords: *Solanum tuberosum*; diffused light store, gibberellic acid; sprouting; postharvest physiology; Malawi; dormancy; seed-tuber quality

1.0 Introduction

Potato (*Solanum tuberosum* L.) is an increasingly important food and cash crop in Malawi, particularly in highland districts such as Dedza, Ntcheu, and Ntchisi, where cool temperatures favour production. Beyond its role in household food security, the potato crop contributes substantially to income generation and seed-system development (Devaux et al., 2014). However, postharvest losses during storage remain a major constraint to sustainable production, especially for seed tubers. Premature sprouting, excessive weight loss, and disease incidence frequently reduce planting quality and market value (Magdalena & Dariusz, 2018).

In Malawi, most smallholder farmers rely on low-cost storage systems such as diffused-light stores (DLS), dark structures, and sack storage because they have limited access to cold-chain facilities. The storage environment strongly influences tuber dormancy, sprouting behaviour, and physiological weight loss by affecting temperature, humidity, light exposure, and aeration (Alamar et al., 2017). Diffused light storage has been reported to improve seed-tuber quality by moderating sprout growth and reducing heat accumulation (Gachango et al., 2008). However, comparative evidence on how these storage systems interact with hormonal treatments under tropical highland conditions remains limited. Dormancy regulation is central to maintaining seed-tuber quality. In warm environments, tubers often break dormancy earlier and sprout more vigorously than in temperate regions, accelerating reserve depletion and physiological aging (Magdalena & Dariusz, 2018). Gibberellic acid (GA_3) is widely used to break dormancy and stimulate sprout initiation by promoting cell elongation and activating metabolic processes (Alexopoulos et al., 2008; Di et al., 2024). Several studies have shown that GA_3 concentrations of 10-40 ppm reduce dormancy duration and enhance sprouting in potato tubers (Mbiyu et al., 2012; Naz et al., 2018). However, most dose–response studies have been conducted under controlled or temperate conditions, with limited assessment under farmer-managed storage environments typical of sub-Saharan Africa.

In addition to environmental effects, dormancy duration and sprouting response are strongly genotype-dependent. Varieties differ in endogenous hormone balance, dormancy depth, and sensitivity to exogenous GA_3 (Zhu et al., 2023). In Malawi, cultivars such as Chuma, Thandizo, and Zikomo are widely grown but exhibit differing dormancy characteristics under storage. Despite their importance in local seed systems, little is known about how these varieties respond to GA_3 across common storage methods. Postharvest disease further complicates storage management. Storage microclimate can influence disease development by altering humidity, aeration, and tissue susceptibility (Peivastegan et al., 2019; Zhou et al., 2007). Although GA_3 promotes physiological activity, its interaction with the storage environment may indirectly

influence disease incidence. Empirical evidence on this interaction under smallholder storage systems in Malawi remains scarce.

Collectively, these gaps highlight the need to evaluate the combined effects of GA_3 concentration, storage environment, and genotype on dormancy release, sprouting behaviour, physiological weight loss, and disease occurrence under locally relevant conditions. We hypothesized that (i) moderate GA_3 concentrations (20–30 ppm) would reduce dormancy duration more effectively than lower or higher doses; (ii) storage environment would significantly modulate GA_3 efficacy; and (iii) varietal responses to GA_3 would differ due to inherent dormancy characteristics. Therefore, this study aimed to assess the interactive effects of GA_3 concentration, storage method, and potato variety on dormancy period, sprouting behaviour, weight loss, and disease incidence in three commonly cultivated varieties under highland storage conditions in Malawi.

2.0 Materials and Methods

2.1. Study site

The experiment was conducted at Bembeke Extension Planning Area (EPA) in Dedza District, Malawi, from April to July 2024. The site is located in a mid-altitude agroecological zone with cool temperatures, ideal for potato cultivation (Abamecha, 2025). It is situated at an altitude range of 1200 to 2200 m above sea level, with a mean annual temperature of 17.4 °C and a mean annual rainfall of 1110 mm (Munthali et al., 2021).

2.2. Experimental design

A split–split plot design with four replications was used. The main-plot factor consisted of storage conditions: diffused light store (DLS), sack storage, and darkroom storage. Potato variety (*Chuma*, *Thandizo*, *Zikomo*) was a subplot factor, and gibberellic acid (GA_3) concentration (0, 10, 20, 30, and 40 ppm) was a sub-subplot factor. The GA_3 treatment range was selected based on previous findings indicating that concentrations between 10 and 30 mg L^{-1} significantly break dormancy and promote systemic sprouting (Naz et al., 2018; Alexopoulos et al., 2008; Di et al., 2024; Dogramaci et al., 2024). There were 45 treatment combinations (3 storage methods × 3 varieties × 5 GA_3 concentrations). Therefore, a total of 180 treatments comprised the whole study. Each treatment had twenty-five egg-sized tubers; hence, a total number of 4500 tubers were used throughout the experiment.

2.3. Planting material

Farmer groups from CIP provided fresh matured seed tubers of *Chuma (CIP 396031.107)*, *Thandizo (CIP 397073.7)*, and *Zikomo (CIP 396038.107)*. At harvest, the tubers were carefully selected for uniformity in size and shape, as well as for damage- and disease-free status, and were cured in the shade for 2 weeks under ambient conditions (temperatures between 15 and 20 ˚C) before treatment (Thoma, 2022). The curing helped with wound healing and reduced rotting and disease infestation, thereby extending the potatoes' shelf life.

2.4. Preparation of GA_3 solutions

Preparation of GA_3 (Sigma-Aldrich, USA) was performed according to the manufacturer's protocol. A gram of GA_3 dissolved in 1,000 L of distilled water produces a 1 ppm solution. The concentration of GA_3 required was calculated using the following formula:

- $C\ (ppm) = M(mg)/V(L)$

Where C=concentration of GA_3 solution in ppm (mg/L)

M=mass of GA_3 weighed (mg)

V=volume of distilled water used (L)

GA_3 solutions were prepared by dissolving the required mass of GA_3 (mg) in a given volume of distilled water (L), according to the formula. For instance, to prepare a 20-ppm solution, 20 mg of GA_3 was dissolved in 1 L of distilled water.

An analytical scale (±0.1 mg) was used for weighing the samples. To prevent degradation, all solutions were freshly prepared before use. GA_3 acts as a key dormancy-breaking agent by enhancing cell elongation and modulating gibberellin-ABA balance in tuber tissues (Dogramaci *et al.,* 2024; Zheng *et al.*, 2024).

2.5. Application of GA_3 and storage conditions

A fortnight after harvest, 25 seed tubers per treatment were immersed in the GA_3 solution for 10 minutes, air-dried for 15 minutes, and then stored in the three conditions. (1) Diffused Light Store (DLS) involved the processing that included tubers being spread on bamboo shelves under indirect natural light to allow ventilation, reported to suppress excessive sprout elongation and weight loss while maintaining vigour (Gachango *et al.*, 2008; Abamecha, 2025). (2) Darkroom storage method involved the spreading of tubers on a mud floor inside a grass-thatched structure, and (3) Sack storage where tubers were placed in labelled

jute sacks and kept within the darkroom. All treatments were labelled and monitored throughout the 95-day storage period (April–July 2024).

2.6. Data collection

During a 95-day storage experiment, potato tubers were sampled biweekly. For each treatment, we recorded the initial number of tubers and their mass (W_0). At each sampling point we measured weight loss, calculated as $((W_0-Wf)/W_0\times100)$, days to sprouting (from storage start to first visible sprout), sprout count per tuber, sprouting percentage ((sprouted tubers/ total tubers) ×100), sprout thickness (mm) at the base using the twine method (Shibairo et al., 2006) and sprout length (mm) from base to tip (Shibairo et al., 2006). Thin, elongated sprouts were documented because they detach more readily and reduce post-planting germination. Late blight incidence was quantified by visual inspection and expressed as ((infected tubers/total tubers)×100). All measurements were taken twice per treatment with calibrated instruments and followed established protocols for seed-tuber quality assessment (Naz et al., 2018; Thoma, 2022; Visse-Mansiaux et al., 2024).

2.7. Statistical analysis

Data were analysed using GenStat 22nd Edition. Normality of data and homogeneity of variances were checked prior to ANOVA. Storage methods and GA_3 concentrations were treated as fixed effects, while variety was treated as a random effect since only three were used, which were considered a representative sample of the broader genetic diversity in Malawi. This approach allowed generalisation of findings on GA_3 × storage interactions beyond the specific varieties tested, while focusing fixed-effect analysis on GA_3 concentration and storage environment.

Post hoc pairwise comparisons were conducted using Fisher's Least Significant Difference (LSD) test at the 0.05 level. This statistical framework aligns with recommendations for postharvest physiological experiments, ensuring robust inference across treatment combinations. The statistical procedures align with recommendations for postharvest physiological experiments (Dogramaci et al., 2024; Di et al., 2024).

3.0 Results and Discussion

3.1 Effect of GA_3 on potato tuber weight loss under different storage methods

Tuber weight loss after 95 days of storage was significantly influenced by storage method, GA_3 concentration, variety, and their interactions ($p \leq 0.01$). A significant three-way interaction (Storage × GA_3 × Variety; $p = 0.01$) indicated that the response to GA_3 differed among varieties depending on storage environment. Across varieties, diffused light storage (DLS) recorded the lowest mean weight loss (≈20%), followed by darkroom storage (≈25%) and sack storage (≈26%). The least significant difference ($LSD_{0.05}$ = 5.46 percentage points) indicated that differences among storage methods and GA_3 treatments were statistically meaningful.

Moderate GA_3 concentrations (20–30 ppm) were generally associated with slightly lower weight loss compared to untreated controls, particularly under DLS conditions. However, the response was not strictly linear, and the highest concentration (40 ppm) did not consistently further reduce losses. These findings suggest that GA_3 effects on weight loss were dependent on both storage environment and genotype rather than universally suppressive. Physiologically, tuber weight loss during storage is primarily driven by respiration and transpiration. GA_3 is known to stimulate metabolic activity and promote sprout growth, processes that can increase respiratory demand and carbohydrate utilisation (Aksenova et al., 2013). Under well-ventilated and moderately illuminated conditions, such as DLS, controlled sprout development may facilitate more balanced reserve mobilisation, potentially limiting excessive water loss. In contrast, less ventilated systems, such as sack storage, may create microclimatic conditions that enhance moisture accumulation and variable respiration rates, contributing to greater and less predictable weight loss.

Overall, the results indicate that weight loss during storage was more strongly influenced by storage environment than by GA_3 concentration alone. While moderate GA_3 doses were associated with reduced losses under certain conditions, the effect was conditional and should be interpreted in light of environmental regulation of respiration and transpiration.

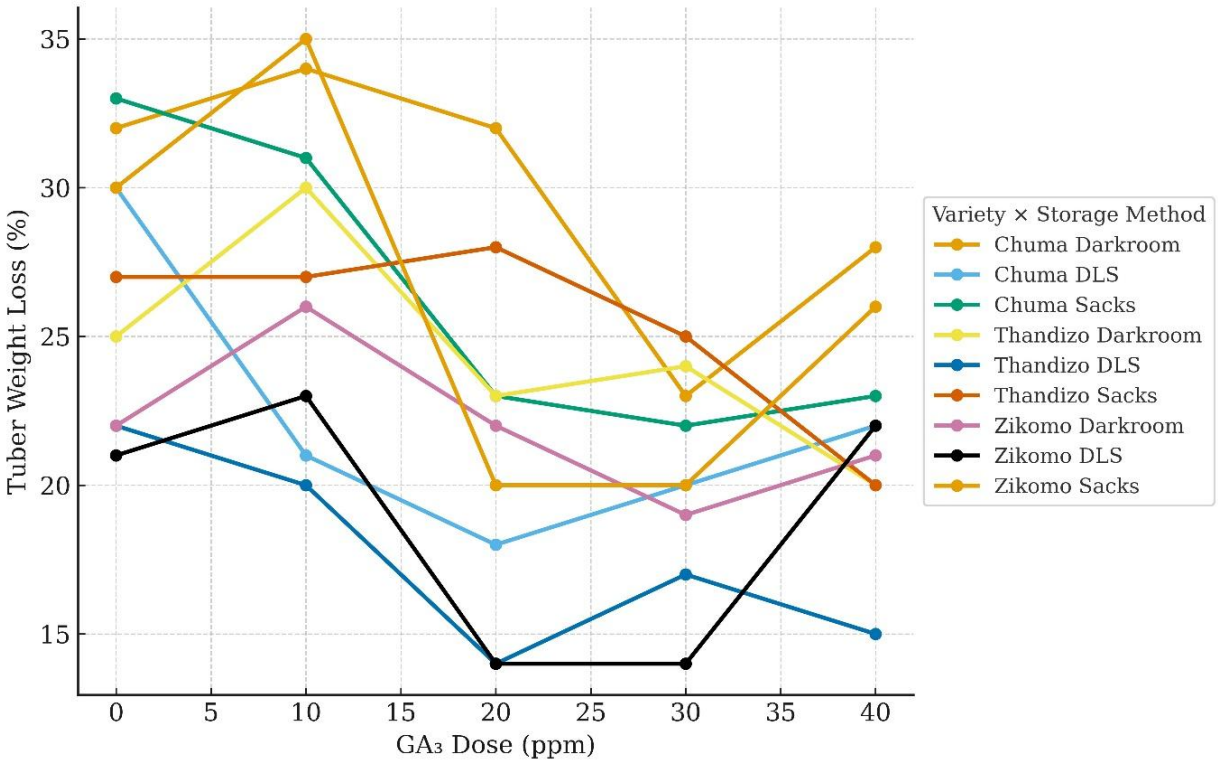


Figure 1: Effect of different doses of GA_3 on the weight loss of potato tuber under varying storage methods.

3.2 Period to tuber sprouting after GA_3 treatment

The period to tuber sprouting varied significantly ($p < 0.01$) among storage methods, GA_3 doses, and potato varieties (Figure 2). Across all varieties, tubers stored under Darkroom conditions recorded the longest dormancy period, averaging 75 days. At the same time, those in diffused light storage (DLS) and sacks sprouted earlier, averaging 33 and 43 days, respectively. Increasing GA_3 concentration progressively shortened the sprouting period across all varieties and storage methods, with the greatest reduction observed between 0 and 20 ppm. Further increases to 30 and 40 ppm did not significantly shorten the sprouting period, indicating a threshold effect. Among the varieties, *Chuma* exhibited the most extended dormancy (58 days, mean), followed by *Thandizo* (48 days) and *Zikomo* (46 days). In Darkroom storage, untreated (0 ppm) tubers of *Chuma* and *Thandizo* took about 91 days to sprout, whereas the same varieties stored in DLS or sacks sprouted within 35–49 days. The significant GA_3 × storage method × variety interaction ($p = 0.01$) suggests that both genetic and environmental storage factors strongly modulate the dormancy-breaking effect.

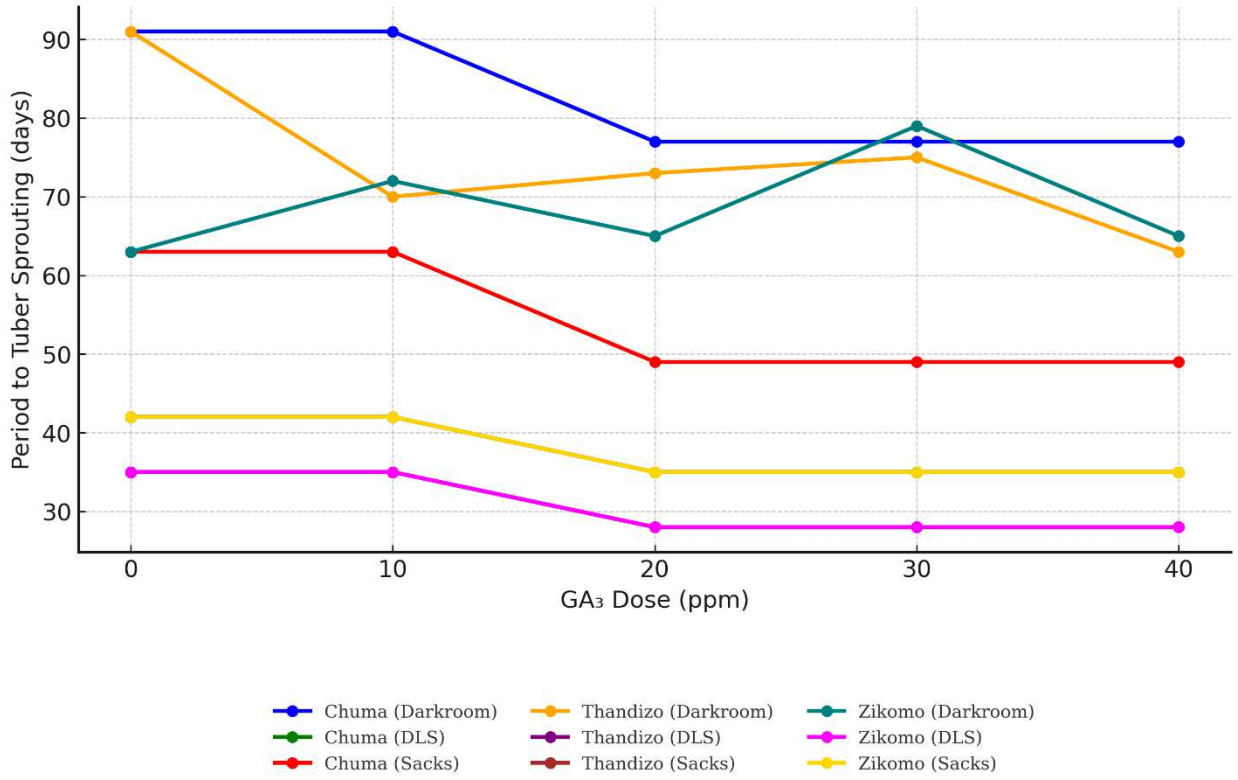


Figure 2. Period to Tuber Sprouting after GA_3 Treatment

The results demonstrate that GA_3 effectively shortened the dormancy period of potato tubers across all varieties and storage methods. This finding aligns with earlier studies that report that exogenous GA_3 application promotes early sprouting by stimulating cell elongation and activating enzymes that degrade stored starch, thereby mobilising energy for sprout emergence (Qayyum et al., 2025). Qayyum et al., (2025) noted that immersing freshly harvested potato tubers in gibberellins markedly curtailed their rest period, a pattern clearly evident in the current study, where GA_3-treated tubers sprouted 14–30 days earlier than untreated controls.

The observed dose-dependent reduction in sprouting period is consistent with reports by Mbiyu et al. (2012), who found that increasing GA_3 concentrations up to an optimum level (20–50 ppm) significantly reduced dormancy duration. However, higher doses did not yield further improvement. Similarly, in the present study, increasing GA_3 beyond 20–30 ppm produced minimal additional reduction in sprouting time, indicating that moderate doses are sufficient to trigger dormancy breakage without risk of over-stimulation or excessive sprout growth.

The significant influence of the storage method on sprouting time corroborates findings by Lohani et al., (2025) and Pandey et al. (2018), who observed that environmental conditions, such as temperature, light

intensity, and humidity, strongly regulate dormancy duration. The Darkroom environment likely maintained lower temperatures and limited light exposure, conditions known to prolong dormancy. At the same time, DLS and sack storage provided lighter and aeration, accelerating physiological activity and sprout initiation.

Varietal differences in response to GA_3 and storage conditions further emphasise the genetic basis of dormancy behaviour. *Chuma*'s more extended baseline dormancy compared to *Zikomo* and *Thandizo* suggests varietal variation in endogenous hormone balance, particularly the ratio of abscisic acid (ABA) to gibberellins. Studies by Zhu et al., (2023) indicate that cultivars with higher endogenous ABA exhibit prolonged dormancy, while those with higher GA levels or greater GA sensitivity sprout earlier when treated with exogenous GA_3.

Collectively, these findings affirm that GA_3 application, variety, and storage environment interact strongly to determine dormancy duration in potato. GA_3 doses of 20–30 ppm consistently induced earlier sprouting without adverse effects, suggesting an optimal treatment range for breaking dormancy under Malawian storage conditions.

3.3 Late blight disease occurrence (%) on tubers in three storage methods after GA_3 treatment

The results in Figure 3 show the effects of gibberellic acid (GA_3) treatments on the incidence of late blight in potato tubers stored under various conditions for 95 days. Disease incidence varied significantly among storage methods, varieties, and GA_3 doses ($p < 0.05$). Tubers stored under diffused light store (DLS) conditions exhibited the highest disease occurrence (approximately 39–42%), followed by those in the darkroom (18–22%), while sack-stored tubers had the lowest incidence (13–18%). Among the varieties, *Zikomo* showed the highest susceptibility, *Thandizo* displayed intermediate levels, and *Chuma* demonstrated comparatively lower disease occurrence. Although GA_3 doses of 10–30 ppm stimulated physiological activity, they did not uniformly suppress disease, and in some cases coincided with elevated late blight incidence, particularly in *Zikomo* under DLS conditions.

These findings align with evidence that GA_3 modulates plant defence signalling and can antagonise Jasmonate-mediated resistance mechanisms, thereby predisposing plant tissues to pathogen attack (Verbeek et al., 2019). Furthermore, storage microenvironments significantly impact disease development by influencing humidity, aeration, and spore survival (Di *et al.,* 2024). The relatively high late blight levels in DLS suggest that GA_3-induced physiological changes—such as softened tissues or increased metabolic activity—may have interacted with favourable microclimatic conditions to enhance pathogen colonisation. Previous studies have similarly reported that GA_3 treatments can increase physiological disorders and

wound formation on tubers, creating infection courts for pathogens (Ok, 2024). Overall, while GA_3 may promote sprouting and dormancy release, its use in poorly ventilated or humid environments should be carefully managed to minimise the risk of postharvest disease. The observed relationships between GA_3 application and disease incidence suggest important implications for potato storage physiology and disease management.

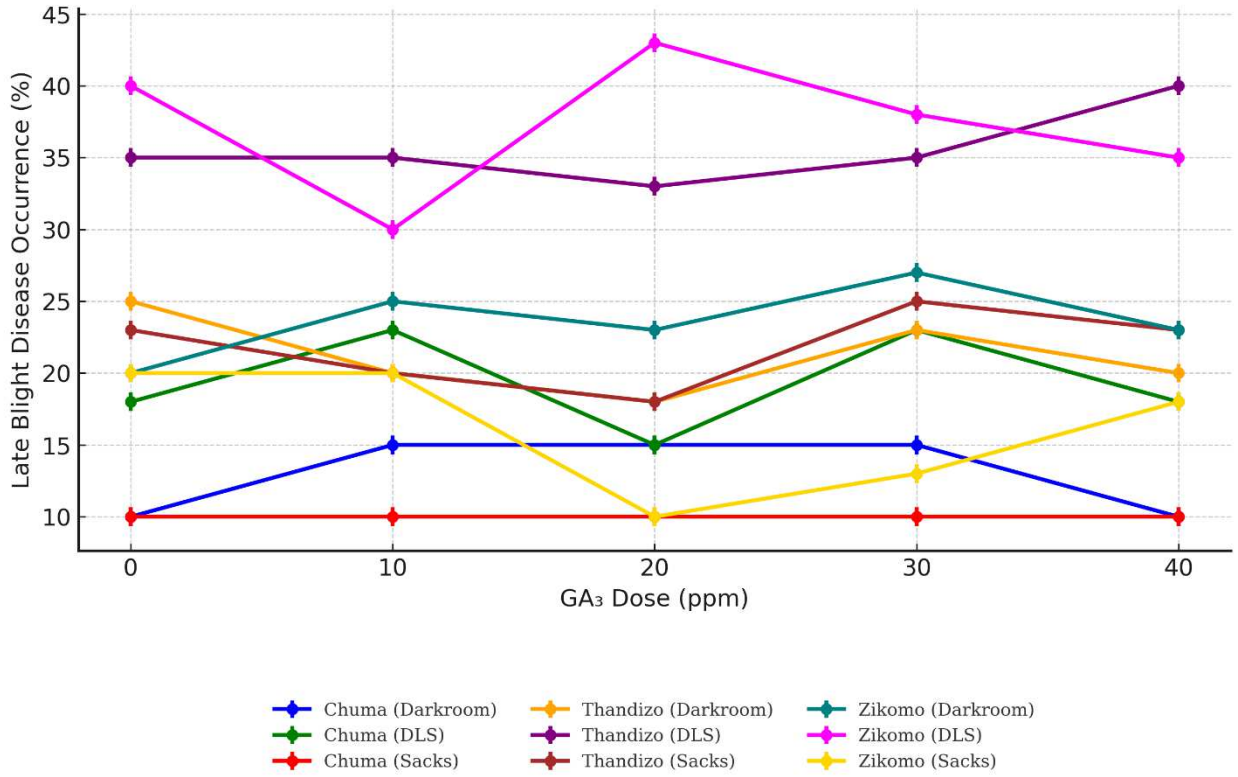


Figure 3. Late blight disease occurrence (%) by the tubers in three storage methods after GA3 treatment

The findings from Figure 3 emphasise the complex interactions among GA_3 application, storage environment, and varietal susceptibility to late blight. Scientifically, this highlights the dual role of GA_3 as both a dormancy-breaking agent and a potential modulator of pathogen susceptibility. In particular, the increased late blight incidence observed under diffused light conditions may result from GA_3-induced metabolic activation, which accelerates physiological ageing and creates favourable conditions for pathogen invasion (Di et al., 2024; Ok, 2024). These outcomes support the view that plant hormones influence not only growth and sprouting but also defence signalling pathways that govern disease resistance (Verbeek et al., 2019). The findings suggest that while GA_3 effectively promotes physiological activity and sprouting, it can inadvertently increase susceptibility to disease under certain environmental conditions.

These insights contribute to a growing understanding of GA_3's multifaceted role in postharvest physiology and plant defense (Di et al., 2024; Verbeek et al., 2019).

3.4 Effect of GA_3 on the number of sprouts per tuber

The number of sprouts per tuber differed significantly ($p < 0.01$) among GA_3 concentrations, storage methods, varieties, and their three-way interactions (Table 1). Sack storage produced the highest mean number of sprouts per tuber (≈ 4 sprouts), while darkroom and diffused-light store (DLS) each averaged ≈ three sprouts per tuber (Figure 4). Greater sprouting in sacks could stem from higher humidity and reduced air exchange, which maintain a more favourable micro-environment for dormancy release. These findings contrast with those of Gildemacher et al. (2007), who observed that seed tubers sprouted under darkroom conditions generally produced single sprouts. Recent studies, however, emphasise that subtle variations in temperature, humidity, and oxygen within storage containers can alter endogenous hormone ratios, enhancing multiple-sprout initiation (Di et al., 2024; Dogramaci et al., 2024).

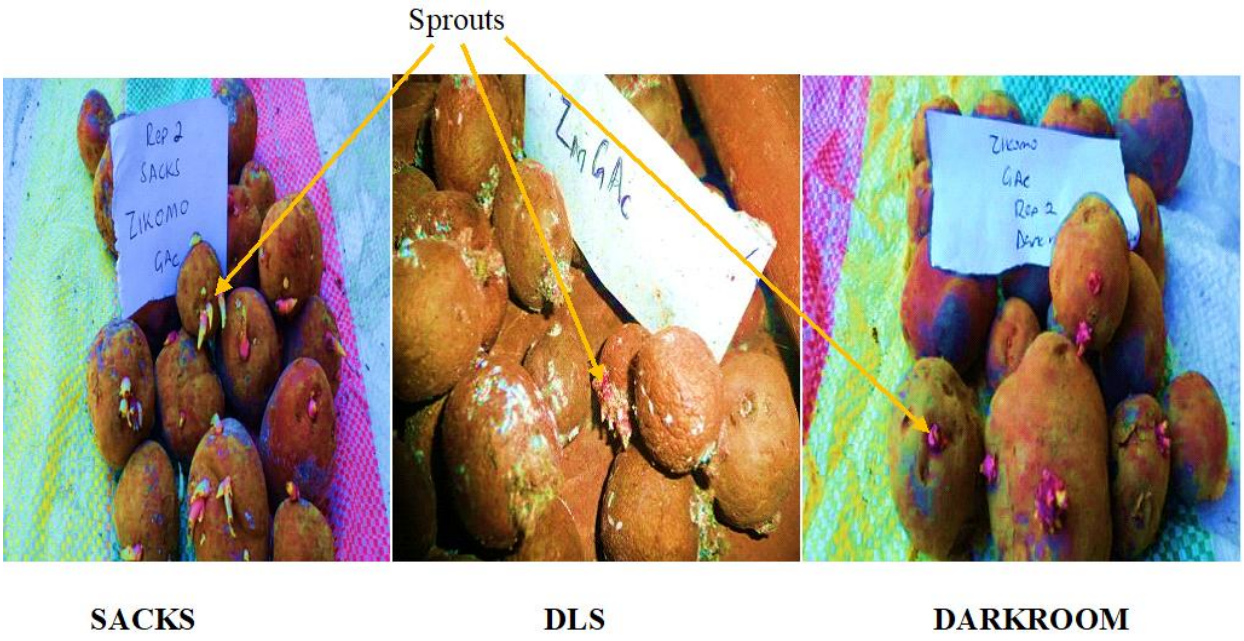


Figure 4. Number of sprouts per tuber in the *Zikomo* variety under three storage methods (sack, diffused-light store, and darkroom).

Table 1. Number of sprouts per tuber after GA_3 treatment in the three storage methods within 95 days of storage

	DARKROOM					**DLS**					**SACKS**					
	GA_3 Doses (ppm)					GA_3 Doses (ppm)					GA_3 Doses (ppm)					**Variety**
	0	**10**	**20**	**30**	**40**	**0**	**10**	**20**	**30**	**40**	**0**	**10**	**20**	**30**	**40**	**Means**
Chuma	3^{bc}	4^{cd}	3^{bc}	4^{cd}	4^{cd}	2^{ab}	2^{ab}	3^{bc}	4^{cd}	5^{de}	3^{bc}	4^{cd}	5^{de}	6^{e}	5^{de}	4
Thandizo	2^{ab}	2^{ab}	3^{bc}	3^{bc}	3^{bc}	1^{a}	2^{as}	3^{bc}	4^{cd}	2^{ab}	2^{ab}	2^{ab}	4^{cd}	4^{cd}	3^{bc}	3
Zikomo	2^{ab}	2^{ab}	3^{bc}	3^{bc}	4^{cd}	1^{a}	2^{ab}	3^{bc}	4^{cd}	4^{cd}	2^{ab}	2^{ab}	3^{bc}	4^{cd}	3^{bc}	3
GA_3 Means	2	3	3	3	4	1	2	3	4	4	2	3	4	5	4	
Storage method means			3					2.8					3.6			

$LSD_{1.0}$ – Means with different subscript letters within a column are significantly different

CV (%): = 23.0 **S.E =** 0.7

Treatment	**P-value**	**LSD $_{(P\ 0.05)}$**
GA_3 Dose	<0.001	0.3
Storage method	0.01	0.3
Variety	0.01	0.7
Method*Variety*GA_3 dose	0.01	1.0

3.5 Effect of GA_3 concentration on sprouting

Sprouting increased markedly with GA_3 concentration ($p < 0.001$) (Table 1 and Figure 5). Treated tubers produced more sprouts than untreated controls, and the number of sprouts rose progressively up to 40 ppm GA_3. This finding aligns with Shibairo et al. (2006), who reported that increasing GA_3 promotes bud activation and multiple-sprout formation, and with recent studies demonstrating that exogenous GA_3 accelerates cell elongation and overrides apical dominance (Naz et al., 2018; Zheng et al., 2024). Comparable GA_3-responsive increases in sprouting have been observed in potato and other storage organs, such as sweet potato and yam (Luitel et al., 2024; Abamecha et al., 2025), suggesting a conserved physiological mechanism involving the upregulation of GA_3-Responsive genes that control meristem activity.



Figure 5. Effect of GA_3 concentration on the number of sprouts per tuber in the *Zikomo* variety stored in sacks.

3.6 Effect of variety on potato sprouting

Varietal differences were also significant ($p = 0.01$). *Chuma* produced the greatest number of sprouts per tuber (4 sprouts), while *Thandizo* and *Zikomo* each averaged 3 sprouts. The variation among cultivars corroborates previous reports that GA_3 sensitivity and dormancy duration differ genetically due to

differences in endogenous hormone metabolism and skin permeability (Visse-Mansiaux et al., 2024; Dogramaci et al., 2024).

Overall, GA_3 application significantly increased the number of sprouts per tuber, particularly at 30–40 ppm, with the effect most pronounced in sack storage and in the *Chuma* variety. These findings reinforce earlier conclusions by Shibairo et al. (2006) that GA_3 enhances sprouting by breaking apical dominance. Recent molecular analyses have shown that GA_3 upregulates α-amylase and expansin genes, which facilitate bud growth and starch remobilisation (Zheng et al., 2024; Di et al., 2024). From a practical perspective, the observed increase in sprout numbers could be advantageous for the rapid multiplication of seed tubers; however, excessive sprouting may also deplete tuber reserves if storage is prolonged (Thoma, 2022). Follow-up field trials are therefore required to determine whether the greater sprout numbers recorded translate into higher yield or vigour under smallholder conditions.

3.7 Effect of storage method, GA_3 dose, and variety on sprout length

The effects of GA_3 dose, storage method, and variety on potato tuber sprout length after 95 days of storage are summarised in Table 2. A significant main effect was observed for all three factors: storage method ($p < 0.001$), GA_3 dose ($p = 0.01$), and variety ($p = 0.01$), as well as for the Variety × GA_3 interaction ($p = 0.01$). Tubers stored under diffused-light storage (DLS) conditions produced the longest sprouts (mean = 3.2 mm), followed by those in the Sacks (2.5 mm) and those in darkroom storage (2.1 mm). Across various storage environments, GA_3-treated tubers exhibited enhanced sprouting compared to untreated controls. Among varieties, *Chuma* had the longest mean sprout length (3.4 mm), followed by *Thandizo* (2.4 mm) and *Zikomo* (2.2 mm). These results indicate that environmental and hormonal regulation jointly control the dormancy and sprouting behaviour of stored potato tubers.

3.8 Influence of storage environment on sprout length

The superiority of DLS in promoting sprouting aligns with recent reports highlighting that the storage microclimate–encompassing light intensity, humidity, aeration, and temperature stability–plays a crucial role in modulating dormancy release (Di et al., 2024). Diffused-light storage enables partial exposure to light while minimising heat accumulation, thereby promoting metabolic reactivation in dormant buds without inducing etiolation. Conversely, complete darkness maintains higher ABA levels and prolongs dormancy (Dogramaci et al., 2024). This finding supports earlier work by Mou et al., (2024), who found that DLS systems yielded longer, healthier sprouts than bulk or pit storage. The strong effect of storage method ($p < 0.001$) in our data implies that optimising environmental conditions can be more effective for sprouting management than chemical stimulation alone.

3.9 GA_3 dose–response pattern to sprouting

GA_3-treated tubers consistently produced longer sprouts than untreated controls, confirming that exogenous GA_3 accelerates dormancy release and bud elongation. However, the relationship was non-linear, with sprout length increasing up to 30 ppm and declining slightly at 40 ppm. Similar dose-dependent responses were reported by Qayyum et al. (2025), who demonstrated that moderate GA_3 concentrations enhanced sprouting in seed tubers, whereas excessive doses provided no additional benefit. Zhu et al., (2023) observed comparable outcomes, noting that higher GA_3 levels can cause excessive elongation and postharvest weight loss. The plateau observed in our study may reflect saturation of GA_3 receptors or negative feedback within the gibberellin signalling pathway (Dogramaci et al., 2024). Thus, ~30 ppm GA_3 appears optimal under these conditions, balancing dormancy reduction with controlled sprout development.

3.10 Varietal responses and GA_3 × variety interaction

The ranking of varieties (*Chuma* > *Thandizo* > *Zikomo*) highlights the genetic basis of dormancy and sprouts behaviour. The significant Variety × GA_3 interaction ($p = 0.01$) suggests that GA_3 efficacy depends on genotype-specific hormone sensitivity and dormancy depth. *Chuma*'s superior response could result from lower endogenous ABA levels or greater sensitivity to GA_3 receptors. These observations correspond with Di et al., (2024). who reported that cultivar-dependent expression of hormonal signaling genes contributes to variation in dormancy duration and sprouting rate. Therefore, cultivar-specific optimization of GA_3 treatment protocols is necessary for consistent performance in commercial seed-tuber production.

3.11 Physiological and molecular mechanisms in the promotion of sprouting

At the physiological level, GA_3 promotes sprouting by antagonising ABA, lowering the ABA: GA ratio, and activating cell elongation pathways in the apical meristem (Zhu et al., 2023). Recent transcriptomic studies confirm that GA_3 upregulates genes associated with starch degradation, reactive oxygen species detoxification, and cell-cycle progression during dormancy release (Dogramaci et al., 2024). Environmental cues such as diffused light may further enhance these effects by increasing GA biosynthesis and carbohydrate mobilisation in tuber buds (Di et al., 2024). Hence, the observed synergy between DLS and GA_3 treatments likely reflects a combined hormonal and photo-physiological control mechanism governing dormancy termination.

Table 2. Sprout length (mm) of tubers after GA_3 treatment in three storage methods within 95 days of storage

	SACKS					**DARKROOM**					**DLS**					**Variety Means**
	GA_3 Doses (ppm)					GA_3 Doses (ppm)					GA_3 Doses (ppm)					
	0	**10**	**20**	**30**	**40**	**0**	**10**	**20**	**30**	**40**	**0**	**10**	**20**	**30**	**40**	
Chuma	2.8^{a}	3.8^{d}	2.8^{a}	4.0^{d}	3.5^{e}	2.3^{cg}	2.5^{c}	3.0^{ab}	3.0^{ab}	3.0^{ab}	2.5^{c}	3.8^{d}	4.0^{d}	4.0^{d}	4.0^{d}	3.4
Thandizo	1.5^{f}	2.3^{cg}	2.3^{cg}	2.3^{cg}	2.3^{cg}	2.0^{g}	2.3^{cg}	2.3^{cg}	2.3^{cg}	1.5^{f}	3.0^{ab}	3.0^{ab}	3.0^{ab}	3.3^{b}	3.0^{ab}	2.4
Zikomo	2.0^{g}	2.0^{g}	2.0^{g}	2.0^{g}	2.3^{cg}	0.5^{h}	1.8^{k}	1.8^{k}	1.8^{k}	1.8^{k}	3.0^{ab}	2.8^{a}	2.8^{a}	3.0^{ab}	3.0^{ab}	2.2
GA_3 Means	2.1	2.7	2.4	2.8	2.7	1.6	2.2	2.4	2.4	2.1	2.8	3.2	3.3	3.4	3.3	
Storage method means			2.5					2.1					3.2			

$LSD_{0.4998}$ – Means with different subscript letters within a column are significantly different.

CV (%): = 21.9 **S.E** = 0.5730

Treatment	**P-value**	**LSD (p 0.05)**
Storage method	< 0.001	0.207
GA_3 Dose	0.01	0.317
Variety	0.01	0.499
Method *Variety* GA_3 Dose	0.01	0.318

4.0 Conclusion

This study demonstrates that storage environment, GA_3 concentration, and variety interact to influence dormancy release, sprouting behaviour, and weight loss in potato tubers under highland storage conditions in Malawi. Moderate GA_3 concentrations (20–30 ppm) reduced dormancy duration and promoted sprouting across varieties, while diffused light storage (DLS) was associated with lower mean weight loss compared with darkroom and sack storage systems. However, the magnitude and direction of GA_3 effects depended on genotype and storage environment.

The findings suggest that, under smallholder storage conditions similar to those evaluated in this study, moderate GA_3 doses combined with well-ventilated, diffused-light storage may support more controlled sprouting and reduced physiological losses. Nevertheless, these conclusions should be interpreted cautiously, as storage microclimatic conditions (temperature and humidity) were not continuously monitored, and the field performance of treated tubers was not assessed. Given these limitations, further research should validate these treatments under controlled environmental monitoring and evaluate subsequent field emergence and yield. Such evidence is necessary before broad recommendations can be made for farmer-level seed-tuber management in Malawi.

Conflict of interest

The authors declare that there are no conflicts of interest in this submission.

Use of Generative AI

The authors declare the effective use of generative AI tools, namely Grammarly and ChatGPT 5.2, in enhancing the clarity, length, and readability of this manuscript.

Acknowledgements

The authors declare that there are no any conflicts of interest in this submission.

Funding

This research was funded by Internal Research Grant from the Directorate of Research and Outreach at the Lilongwe University of Agriculture and Natural Resources (LUANAR), Malawi.

Author Contributions:

Conceptualization, Vincent Mgoli Mwale and Rosemary Mzembe Munkhondia; **methodology**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia, Rowland Maganizo Kamanga,Abel Sefasi, Jacinta

Andrew Nyaika; **Software**, Rowland Maganizo Kamanga; **validation**, Vincent Mgoli Mwale,; Rosemary Mzembe Munkhondia,; **formal analysis**, Rowland Maganizo Kamanga, Vincent Mgoli Mwale; **investigation**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia, Rowland Maganizo Kamanga,;**data curation**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia, Abel Sefasi, Jacinta Andew Nyaika; **writing-original draft preparation**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia,; **writing-review and editing,** Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia, Rowland Maganizo Kamanga, Jacinta Andrew Nyaika; **visualization,** Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia,; **supervision**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia, Rowland Maganizo Kamanga,; **project administration**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia,; **funding acquisition**, Vincent Mgoli Mwale, Rosemary Mzembe Munkhondia. All authors have read and agreed to the published version of the manuscript.

5.0 References

Abamecha, N., Techane, T., & Adem, M. (2025). Storage solutions for roots and tubers in Ethiopia through traditional and improved methods. *Discover Food*, *5*(1). https://doi.org/10.1007/s44187-025-00587-0

Aksenova, N. P., Sergeeva, L. I., Konstantinova, T. N., Golyanovskaya, S. A., Kolachevskaya, O. O., & Romanov, G. A. (2013). Regulation of potato tuber dormancy and sprouting. *Russian Journal of Plant Physiology*, *60*(3), 301–312. https://doi.org/10.1134/S1021443713030023

Alamar, M. C., Tosetti, R., Landahl, S., Bermejo, A., & Terry, L. A. (2017). Assuring potato tuber quality during storage: A future perspective. *Frontiers in Plant Science*, *8*(November 2017), 1–6. https://doi.org/10.3389/fpls.2017.02034

Alexopoulos, A., Aivalakis, G., Akoumianakis, K., & Passam, H. (2008). Effect of gibberellic acid on the duration of dormancy of potato tubers produced by plants derived from true potato seed. *Postharvest Biology and Technology*, *49*, 424–430. https://doi.org/10.1016/j.postharvbio.2008.02.009

Devaux, A., Kromann, P., & Ortiz, O. (2014). Potatoes for Sustainable Global Food Security. *Potato Research*, *57*(3–4), 185–199. https://doi.org/10.1007/s11540-014-9265-1

Di, X., Wang, Q., Zhang, F., Feng, H., Wang, X., & Cai, C. (2024). Advances in the Modulation of Potato Tuber Dormancy and Sprouting. *International Journal of Molecular Sciences*, *25*(10). https://doi.org/10.3390/ijms25105078

Dogramaci, M., Dobry, E. P., Fortini, E. A., Sarkar, D., Eshel, D., Campbell, M. A., & Considine, M. (2024). Physiological and molecular mechanisms associated with potato tuber dormancy. Journal of Experimental Botany, 75(19), 6093–6109. https://doi.org/10.1093/jxb/erae182

Gachango, E., Shibairo, S. I., Kabira, J. N., Chemining, G. N., & Demo, P. (2008). Effects of light intensity on quality of potato seed tubers. *Journal of Agricultural Research*, *3*(10), 732–739.

Lohani, U. C., Goraya, R. K., Ramalingam, S., Senthilkumar, T., & Singh, C. B. (2025). Potato post-dormancy sprouting: a problem during storage and its control by essential oils as alternatives to artifact chemicals – a review. *Journal of the Science of Food and Agriculture*, *105*(15), 8330–8345. https://doi.org/10.1002/jsfa.14419

Magdalena, G., & Dariusz, M. (2018). Losses during Storage of Potato Varieties in Relation to Weather Conditions during the Vegetation Period and Temperatures during Long-Term Storage. *American*

Journal of Potato Research, *95*(2), 130–138. https://doi.org/10.1007/s12230-017-9617-x

Mou, W., Wang, K., Hu, J., Tang, M., He, W., Jia, W., Xu, Z., & Luo, R. (2024). Effects of Natural Diffused Light Storage on Highland Seed Potatoes and Subsequent Field Performance in Lowland. *Potato Research*, *67*(1), 1–13. https://doi.org/10.1007/s11540-023-09620-0

Munthali, C., Kinoshita R., Aiuchi D., Palta J., & Tani M. (2021) Soil Fertility Status for Potato Production in Central Highlands of Malawi. Academic Journals Vol 17, pp.1472 – 1479. https://doi.org/10.5897/AJAR2021.15768.

Naz, R. M. M., Li, M., Ramzan, S., Li, G., Liu, J., Cai, X., & Xie, C. (2018). QTL mapping for microtuber dormancy and GA3 content in a diploid potato population. *Biology Open*, *7*(1). https://doi.org/10.1242/bio.027375

Peivastegan, B., Hadizadeh, I., Nykyri, J., Nielsen, K. L., Somervuo, P., Sipari, N., Tran, C., & Pirhonen, M. (2019). Effect of wet storage conditions on potato tuber transcriptome, phytohormones and growth. *BMC Plant Biology*, *19*(1), 1–18. https://doi.org/10.1186/s12870-019-1875-y

Qayyum, M. M., Shahzad, U., Jahan, M. S., El-Beltagi, H. S., Ghuffar, S., Qasim, M., Mehmood, N., Anwaar, S., Qureshi, H., Anwar, T., Rebouh, N. Y., Shah, M. A., & Muminov, M. M. (2025). Optimizing gibberellic acid concentration and exposure time for effective dormancy breaking and sprouting enhancement in potato. *Scientific Reports*, *15*(1), 1–10. https://doi.org/10.1038/s41598-025-13219-5

Shibairo, S. I., Demo, P., Kabira, J. N., Gildemacher, P., Gachango, E., Menza, M., Nyankanga, R. O., Chemining'wa, G. N., & Narla, R. D. (2006). Effects of gibberellic acid (GA_3) on sprouting and quality of potato seed tubers in diffused light and pit storage conditions. Journal of Biological Sciences, 6(4), 723–733. https://doi.org/10.3923/jbs.2006.723.733

Thoma, J. N. (2022). Sprout suppressants in potato storage: Conventional options and promising essential oils—A review. Sustainability, 14(11), 6382. https://doi.org/10.3390/su14116382.

Verbeek, R. E. M., Van Buyten, E., Alam, M. Z., De Vleesschauwer, D., Van Bockhaven, J., Asano, T., Kikuchi, S., Haeck, A., Demeestere, K., Gheysen, G., Höfte, M., & Kyndt, T. (2019). Jasmonate-Induced Defense Mechanisms in the Belowground Antagonistic Interaction Between Pythium arrhenomanes and Meloidogyne graminicola in Rice. *Frontiers in Plant Science*, *10*(November), 1–15. https://doi.org/10.3389/fpls.2019.01515

Visse-Mansiaux, M., Shumbe, L., Brostaux, Y., Ballmer, T., Smit, I., et al. (2024). Identification of potato varieties suitable for cold storage and reconditioning: A safer alternative to anti-sprouting chemicals. Food Research International, 184, 114249. https://doi.org/10.1016/j.foodres.2024.114249.

Zheng, X., Li, M., Zhang, X., Chen, J., Ge, X., Li, S., Tian, J., & Tian, S. (2024). Unraveling the mechanism of potato tuber sprouting using transcriptome and metabolome analyses. Frontiers in Plant Science, 14, 1300067. https://doi.org/10.3389/fpls.2023.1300067

Zhou, R., Su, S., Yan, L., & Li, Y. (2007). Effect of transport vibration levels on mechanical damage and physiological responses of Huanghua pears (Pyrus pyrifolia Nakai, cv. Huanghua). *Postharvest Biology and Technology*, *46*(1), 20–28. https://doi.org/https://doi.org/10.1016/j.postharvbio.2007.04.006

Zhu, T., Pei, H., Li, Z., Zhang, M., Chen, C., & Li, S. (2023). The Postharvest Application of Carvone, Abscisic Acid, Gibberellin, and Variable Temperature for Regulating the Dormancy Release and Sprouting Commencement of Mini-Tuber Potato Seeds Produced under Aeroponics. *Plants*, *12*(23). https://doi.org/10.3390/plants12233952