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Evaluation of *Thymus laevigatus* Aqueous Extract on Sprouting and Weight Loss of Stored Potato

Younis Ahmed Humaid*, Mansoor Abdul Halim Al-Thobhani, Adel Sultan Alqadasi

Department of Horticulture and its Techniques, Faculty of Agriculture, Food, and Environment, Sana'a University, Sana'a, Yemen

*Corresponding author's email: Y.humaid@su.edu.ye

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ABSTRACT

Potato is one of the most economically important horticultural crops in Yemen. However, due to the high costs of cold storage and sprout-inhibiting chemicals, potatoes are typically consumed fresh and cannot be stored for extended periods. As a result, their prices fluctuate based on the production season. Recently, natural plant-based alternatives to industrial chemicals for potato storage have gained attention due to their effectiveness, ease of application, and safety for human health and the environment. This study aimed to evaluate the effect of thyme aqueous extract at four concentrations (0, 250, 500, and 750 ppm) over a 12-week storage period on potato tuber sprouting and weight loss. The experiment was conducted under room conditions using a factorial randomized complete block design (RCBD) with three replications. Results indicated that the 250 ppm concentration achieved the highest sprouting inhibition (33.33%) and the lowest weight loss (5.76%). While there was no significant difference among thyme concentrations in terms of sprout inhibition, a significant difference was observed in tuber weight loss. The recorded weight losses were 7.98%, 6.68%, 5.98%, and 5.76% for the 0, 750, 500, and 250 ppm concentrations, respectively. These findings suggest that thyme aqueous extract can effectively extend the shelf life of stored potato tubers.

Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important crop worldwide, following rice, maize, and wheat. It is also the most significant underground crop, ahead of cassava, yams, sweet potatoes, and taro (Dolničar, 2021). In Yemen, potatoes are a key vegetable crop contributing to food security. Their cultivation plays a crucial role in improving farmers' livelihoods in production areas (Khalil et al., 2021). Yemen ranks ninth among Arab countries in terms of potato cultivation area (Hunaish, 2023). According to the latest FAOSTAT data (https://www.fao.org/faostat/en/#data/QCL), Yemen produced 336,738.90 tons of potatoes in 2022 from an area of 17,604 ha. Following harvest, an influx of potatoes into the market often leads to a supply surplus. In developing and economically disadvantaged countries, high-yield years frequently result in an oversupply. Due to inadequate storage, marketing, and processing facilities, farmers are often forced to sell their crops at extremely low prices (Paul, 2016). Potato tuber dormancy depends on genotype, environmental conditions, and tuber age (Haider et al., 2021). Cold storage can help prolong dormancy by reducing metabolic activity, respiration rates, and tuber aging. Optimal storage temperatures range between 8–10 °C, often combined with sprout suppressants such as isopropyl N-(3-chlorophenyl) carbamate (Datir et al., 2020). However, temperatures below 3 °C or above 30 °C can stress the tubers, leading to premature sprouting (Wurr and Allen, 1976). Deterioration of stored potatoes begins with sprouting, weight loss, shrinkage, and tissue softening, ultimately leading to decay. This reduces their quality, rendering them unmarketable (Tartoura et al., 2015). To extend tuber dormancy, cold storage is commonly used alongside chemical sprout inhibitors such as chlorpropham (CIPC). However, these methods are costly and often inaccessible to small-scale farmers (Western Potato Council, 2003).

The use of inorganic chemicals to protect edible food crops is widely discouraged due to their health risks, high costs, and limited availability (Onyishi, 2005). Chemical sprouting inhibitors also pose environmental and human health concerns. For these reasons, many countries have shifted toward environmentally friendly natural alternatives (Kleinkopf, 2003). Increasing attention has been given to natural products for controlling decay and extending the storage life of perishable foods (Tripathi, 2008). Medicinal and aromatic plant extracts offer an effective, locally available solution for preventing sprouting and diseases in stored potatoes. The ideal natural compounds should be affordable, safe, easy to use, and should not alter the flavor or quality of potatoes (Tartoura et al., 2015).

Thymus species have been valued since ancient times for their health benefits, largely attributed to their essential oils and other bioactive compounds (Salehi et al., 2019). Studies have demonstrated the allelopathic potential of *Thymus vulgaris* in influencing germination parameters of various crops and weeds. For instance, increasing concentrations of thyme aqueous extracts and essential oils significantly affected the germination of wheat (*Triticum aestivum*) and its associated weed *Chenopodium album*, as well as rice (*Oryza sativa*) and its associated weed *Echinochloa crus-galli* (Elghobashy et al., 2024). Low concentrations (10–20%) enhanced wheat germination energy, percentage, seedling shoot length, and shoot-to-root ratio, while higher concentrations inhibited germination. Additionally, seed germination of *Amaranthus retroflexus* and *Poa annua* was completely inhibited using 50 g of fresh *Thymus proximus* material in a 1.5 L airtight container. The essential oil exhibited potent phytotoxic activity at 2 mg mL^{-1} and 5 mg mL^{-1}, leading to 100% germination failure in *Amaranthus retroflexus* and *Poa annua*, respectively (Zhou et al., 2021).

Various techniques, including fumigation, dipping, and spraying, have been used to apply *T. vulgaris* essential oil on potato tubers stored at both cold (10 °C) and ambient (35/15 °C) temperatures. These applications showed positive effects, particularly in preserving dry matter, when compared to chlorpropham (CIPC) treatment and control samples (El-Awady et al., 2011). *Thymus laevigatus* Vahl is one of Yemen's most well-known endemic medicinal and aromatic plants, commonly found in the high mountains of the northern region (Humaid and Al-Thobhani, 2023). This study aimed to evaluate the effect of different concentrations of *T. laevigatus* aqueous extract on sprouting and weight loss in potato tubers stored at ambient temperatures.

Material and methods

The experiment was conducted in the Department of Horticulture and its Techniques, Faculty of Agriculture, Food, and Environment, Sana'a University, Yemen. The experiment spanned from June to September 2023.

Plant materials

Fresh potato tubers (*cv. 'Diamant'*) of uniform size and shape were obtained from Green Land Company for Seeds Production Using Tissues Limited, Yareem, Yemen. Fresh twigs (leaves and branches) of *Thymus laevigatus* were collected from the wild in the Utmah District, Sama area, following a method described by Humaid and Al-Thobhani (2023). The twigs were air-dried for several days in the shade at room temperature (25 ± 2 °C). Once dried, they were ground into fine powder using an electric grinder, then sieved to ensure uniformity. The resulting powder was stored in plastic bags and kept at 4 °C in a refrigerator until use in the experiments.

Preparation of aqueous extract and concentrations

The method was adapted from Kim (2011) with minor modifications. Thus, 20 g of thyme powder was mixed with 200 mL of boiled water, with continued shaking for 24 h. The obtained mixture was filtered using Whatman No. 1. Extract was concentrated at 40 °C in an oven. From the concentrated extract, 250, 500, and 750 mg were diluted separately by 1000 mL of water.

Experimental design

This research was carried out as a factorial experiment in a randomized complete block design (RCBD). Thyme aqueous extract (0, 250, 500, and 750 ppm) and storage period (12 weeks) were independent variables. Similar size and shape tubers (6 tubers $replication^{-1}$) were distributed in equal weights (300 g $replication^{-1}$). Three replications were soaked in distilled water

(0 ppm), and the same number of replications were soaked in other treatments for an hour. After applying the thyme aqueous extracts, the tubers were air-dried and stored in paper bags at room conditions (22.94 ± 2.6 °C and 32.29 ± 6.53% RH) until data recording.

Data collection

Data were collected according to Tartoura et al. (2015):

Weight loss (WL): Potato tubers were weighed before storage and at one-week intervals during the storage period. The difference between the initial and final weight of the tubers was considered as total weight loss during the storage interval and expressed as percentages.

$$\% \text{ WL} = \frac{\text{Initial weight} - \text{weight after storage at different times}}{\text{Initial weight}} \times 100$$

Sprouting was calculated weekly using the following formula:

$$\% \text{ Sprouting} = \frac{\text{No. of sprouted tubers}}{\text{No. of total tubers}} \times 100$$

Data transformation

Data percentage of sprouting were within the range of 0 to 100%, so the arcsine transformation was used according to Gomez and Gomez (1984).

Statistical analysis

Analysis of variance (ANOVA) was performed using SAS software (version 9) to detect the significance of differences among the treatments, and the means were compared using Duncan's multiple range test at 5% probability level.

Results

The analysis of variance (Table 1) revealed significant differences (P≤0.05) in weight loss due to varying extract concentrations. Additionally, the storage period significantly influenced both sprouting and weight loss. A significant interaction between extract concentrations and storage periods was observed for both sprouting and weight loss.

Table 1. Analysis of variance regarding the effects of different concentrations of thyme aqueous extract (0, 250, 500, and 750 ppm) during the storage period (12 weeks) on sprouting and weight loss of potato tubers.

S.O. V	D.f	Mean of Squares		
		Sprouting (%)	Sprouting (%) (Transformed)	Weight loss (%)
AEC	3	131.17^{ns}	98.03^{ns}	35.76*
SP	11	20877.53*	16334.38*	124.26*
AEC × SP	33	136.78*	104.22*	0.49*
Blocks	2	486.11	352.59	7.02
Error	94	336.39	280.83	1.31
CV (%)	-	51.79	52.46	17.31

SP: storage period, AEC: aqueous extract concentrations, *: significant at 5% level, ^{ns}: non-significant.

Effect of different concentrations on sprouting and weight loss of potato tubers

The results for sprouting (Fig. 1a) showed no significant differences among the concentrations of thyme aqueous extract. However, the 250 ppm concentration resulted in the lowest sprouting percentage (33.33%). For weight loss (Fig. 1b), significant differences were observed among the thyme aqueous extract concentrations. The 250 and 500 ppm concentrations recorded the lowest weight losses at 5.76% and 5.98%, respectively, compared to the 750 ppm concentration (6.68%) and the control (7.98%).

Effect of storage period on sprouting and weight loss of potato tubers

The results related to the storage period, specifically sprouting and weight loss (Fig. 2), showed significant differences. During the first five weeks of storage, no sprouting was observed. In the 6th week, sprouting was initiated only in tubers treated with distilled water (0 ppm). From the 7th week onward, the sprouting rate gradually increased until the 12th week. Regarding weight loss, a gradual decrease was observed during the first seven weeks. No significant weight loss occurred between the 7th and 8th weeks or between the 10th and 11th weeks. However, weight loss continued to increase gradually until the 12th week.

Effect of interaction between concentrations of aqueous extract and storage period on sprouting and weight loss of potato tubers

The interaction between extract concentrations and storage period (Figs. 3 and 4) showed significant differences. Concentrations of 250, 500, and 750 ppm inhibited sprouting for an additional week compared to the control (Fig. 3). Throughout the experiment, the 250 ppm concentration resulted in the lowest weekly weight loss, followed by the 500 ppm concentration, in comparison to the control (Fig. 4).

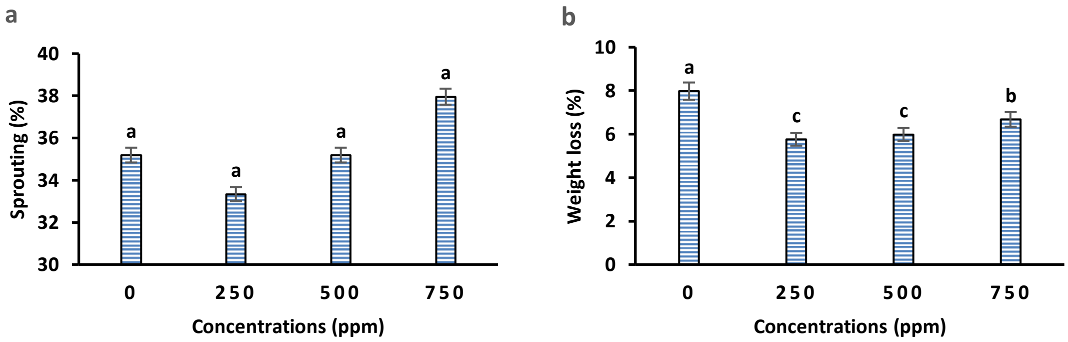

Fig. 1. Effect of different concentrations (0, 250, 500, and 750 ppm) of thyme on sprouting (a) and weight loss (b) of potato tubers. Mean values with similar letters had no significant difference (P≤0.05).

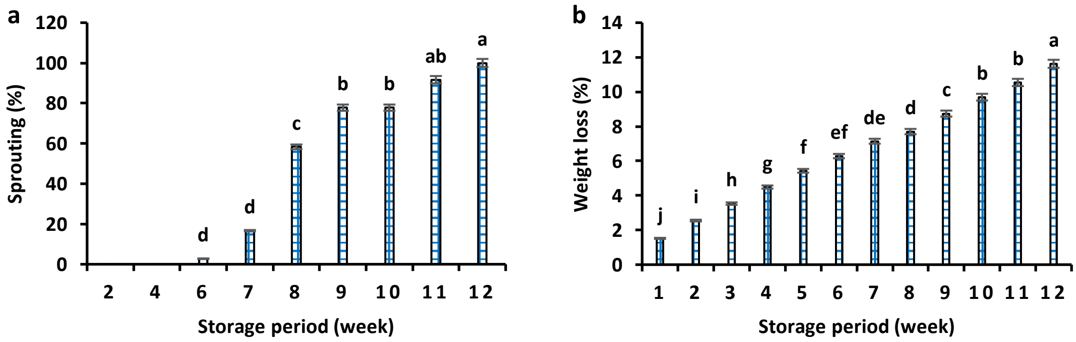

Fig. 2. Effect of storage period (week) on sprouting (a) and weight loss (b) of potato tubers. Mean values with similar letters had no significant difference (P≤0.05).

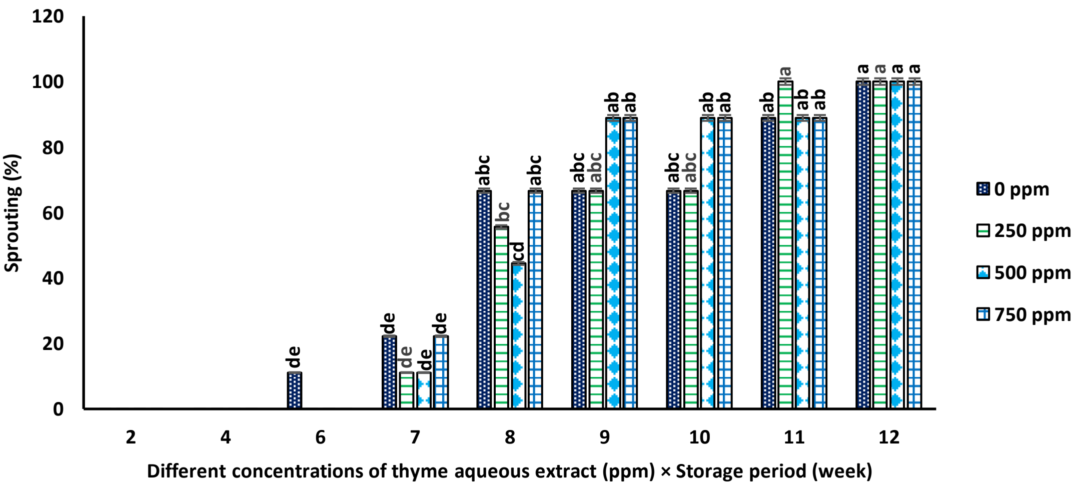

Fig. 3. Effect of different concentrations (0, 250, 500, and 750 ppm) of thyme during the storage period (12 weeks) on sprouting of potato tubers. Mean values with similar letters had no significant difference (P≤0.05).

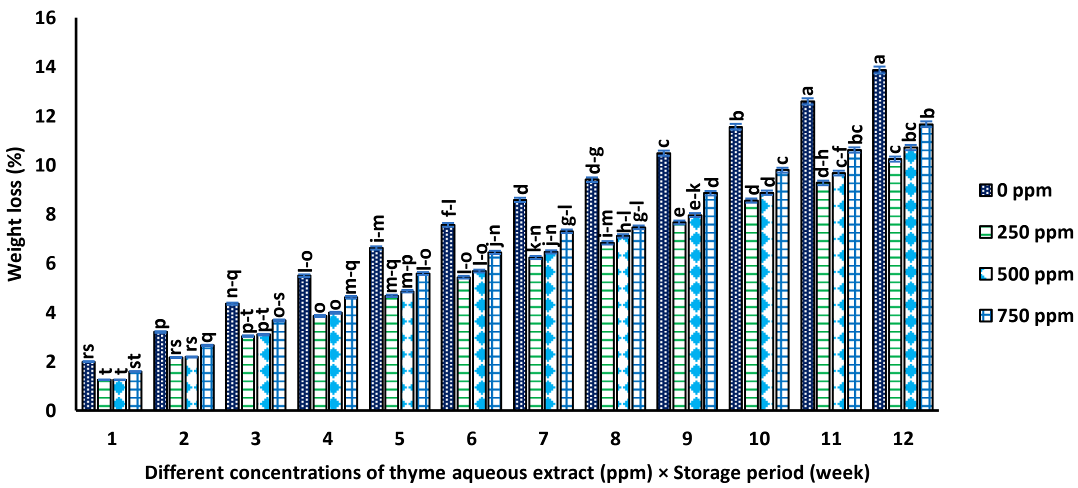

Fig. 4. Effect of different concentrations (0, 250, 500, and 750 ppm) of thyme during the storage period (12 weeks) on weight loss of potato tubers. Mean values with similar letters had no significant difference ($P \leq 0.05$).

Extent of sprouting effect on weight loss of potato tubers

In Figure 5, the data points are dispersed across the plot, showing a general trend that indicates a significant positive correlation between sprouting and weight loss at the 0.01 level ($r = 0.82$). However, the significant spread of data points, particularly in the lower range of weight loss, suggests that other factors may be influencing weight loss in addition to sprouting.

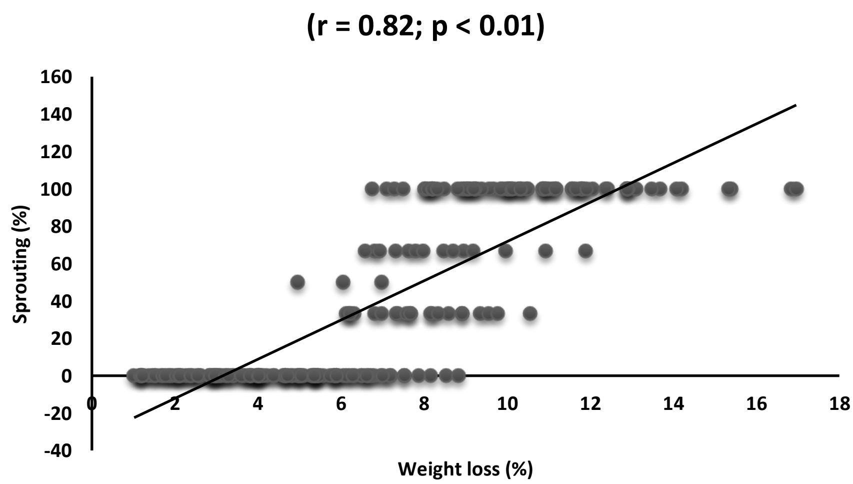

Fig. 5. Relationship between sprouting and weight loss of stored potato tubers.

Discussion

During ambient storage in retail settings and homes, potato tubers are exposed to various environmental factors that impact their quality. Light exposure can cause tuber greening (Manamela et al., 2024), while fluctuations in temperature and relative humidity can shorten tuber dormancy, leading to earlier sprouting (Di et al., 2024). Several studies have demonstrated methods to maintain potato quality during ambient storage, utilizing cost-effective and biologically friendly materials such as edible wax (Manamela et al., 2024), ethylene emitted by climacteric fruits (Bopape et al., 2024), and essential oils (El-Awady et al., 2011; Eshel et al., 2008; Teper-Bamnolker et al., 2010). Bopape et al. (2024) highlighted the use of essential oils as biological, cost-effective sprout suppressants in potato tubers. However, these oils are highly volatile and require continuous application to remain effective.

Plant-based extracts are emerging as natural preservatives that are safer for maintaining postharvest quality and preventing sprouting in stored potatoes (Shahbaz et al., 2022; Tartoura et al., 2015). In the present study, tubers treated with different concentrations of thyme aqueous extract suppressed sprouting for an additional week compared to the control (Fig. 3). A large coefficient of variation (51.79%), even after arcsine transformation (52.46%) (Table 1), may be attributed to the sprouting data being zero for the first five weeks and reaching 100% by the 11th week. Similar findings regarding the use of plant extracts as anti-sprouting agents have been reported (Amoah et al., 2011; Bibah, 2014; Tartoura, 2015). The results obtained (Figs. 1a and 3) suggest that thyme aqueous extract contains compounds that delay sprouting. Sekine et al. (2020) also reported strong inhibitory activity of *Thymus vulgaris* against radicle and hypocotyl growth in lettuce.

Additionally, potato tubers treated with various concentrations of thyme aqueous extract might form a barrier around the tubers, reducing moisture loss and, consequently, tuber weight loss compared to the control (Figs. 1b and 4). Other plant extracts, such as neem, onion, ginger (Bibah, 2014), lemon balm, sage, and nees (Tartoura, 2015), also resulted in the lowest weight loss with significant differences compared to the control. The percentage of weight loss remained relatively stable during the storage period under appropriate ambient conditions, particularly between the 7th and 11th weeks (Fig. 2), a period during which rainfall was recorded. This increase in ambient relative humidity likely helped maintain the internal moisture of the tubers. Di et al. (2024) noted that during storage, water evaporates from the surface of potato tubers into the surrounding air, with the loss rate proportional to the difference in vapor pressure between the intercellular space and ambient humidity. Therefore, high humidity is crucial in minimizing weight loss.

Figure 1 clearly shows that the most effective concentration of thyme aqueous extract for inhibiting sprouting and reducing weight loss was 250 ppm, with no additional benefits observed at higher concentrations. According to Morales (2002), thyme species such as *T. schimperi*, *T. origanoides*, and *T. serrulatus* grow in mountain regions of arid areas, and *T. laevigatus* belongs to the same group. Haile et al. (2021) determined the chemical composition of *T. serrulatus* aqueous extract using LC-MS, finding that phenolic compounds, particularly caffeic and salvianolic acids, were more dominant than rosmarinic acid and flavones. Bhattacharya et al. (2021) studied the effects of simple aliphatic and aromatic acids on potato sprouting inhibition and found that aromatic organic acids, including ferulic acid, caffeic acid, and gallic acid, inhibited sprouting for 1 to 2 weeks. This supports the idea that the inhibitory effect of thyme aqueous extract concentrations may be due to its caffeic acid content. The active concentration of 250 ppm in this study aligns with findings by Bhattacharya et al. (2021), who reported that concentrations of malic acid and L-tartaric acid higher than 200 ppm were less effective in inhibiting potato tuber sprouting.

Sprouting triggers physiological changes in the tubers, including water loss through new growth and the breakdown of starch, leading to a reduction in fresh weight (Alamar, 2017). The correlation shown in Figure 5 indicates a linear relationship between sprouting and weight loss, consistent with previous findings by Ezekiel et al. (2007). Factors other than sprouting, such as changes in relative humidity and its interaction with temperature, may also influence weight loss. This is particularly relevant given the difference between the tubers' production area (Yareem) and the experiment's location (Sana'a), as the tubers are freshly harvested. Weight loss is more pronounced during the early stages of storage due to higher tuber respiration rates, elevated temperatures for wound healing, and increased transpiration (Singh et al., 2020). In later stages of storage, weight loss can be influenced by continuous respiration, pressure flattening, and transpiration from initiated sprouts, especially since the storage is at ambient temperature (Wang, 2020).

Conclusions

Thyme aqueous extract can extend the storage period of potato tubers under ambient conditions by an additional week compared to untreated tubers. Among the concentrations tested, 250-500 ppm was the most effective. Potato tubers, with their thin skins, are more susceptible to moisture loss compared to those treated with thyme extract, which forms a protective barrier around the tubers, restricting gas exchange. Thyme components are locally available, non-toxic, and do not leave residual chemicals on the tubers. Additionally, they are easy to apply and effective at room temperature. As a result, their use on a commercial scale would be cost-effective, safe, and practical. Further research is needed to determine the chemical composition of thyme aqueous extract and assess its impact on other quality parameters of potato tubers.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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