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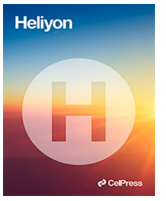

Research article

Apple fruit as a biological suppressant for potato tuber sprouting during ambient storage

Lesibana Bopape [a], Thabiso Satekge [a,*], Paulus Mafeo [a], Manape Lekganyane [b]

[a] Department of Plant Production, Soil Science and Agricultural Engineering, School of Agricultural and Environmental Sciences, University of Limpopo, Turfloop, South Africa
[b] Department of Biochemistry, Microbiology and Biotechnology, School of Molecular and Life Sciences, University of Limpopo, Turfloop, South Africa

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ABSTRACT

In many countries, potato (*Solanum tuberosum*) is a crucial carbohydrate-rich crop and staple food. However, sprouting during storage can adversely affect the quality of the harvested tubers. To maintain the postharvest quality, this study assessed the potential of apple fruit as one of the biological suppressants for potato tuber sprouting at ambient storage. Potato tubers were obtained from four commercial farms. Thereafter, they were stored in a brown paper alone (control) or with apple fruit at ±23 °C for 30-day period. Potato tubers were evaluated for their weight loss, sprouting percentage, decay and soluble sugars during storage duration. Tubers stored with apple fruit had significantly ($P < 0.05$) reduced physiological weight loss after 30-day storage compared to the control. The results indicated that sprouting was significantly lower on tubers stored with fruit compared to the control. Sucrose, glucose and fructose increased in tubers stored with apple fruit compared to the control, especially in tubers obtained from Jamba and Leeubult. Tubers stored with apple fruit decayed significantly compared to the control in tubers from Jamba and Leeubult. Furthermore, dry matter and starch content were significantly lower tubers stored with apples compared to the control. In conclusion, apple fruit could serve as an effective sprout suppressant for potatoes at ambient storage. Therefore, apple fruit can be adopted as an alternative sprout suppressant to synthetic ethylene gas and various chemicals such as Chloropropham.

1. Introduction

Potato tubers serve as a vital food source for human diet [1,2]. They are highly valued for their nutritional benefits and positive impact on the human health [3]. Nevertheless, their postharvest quality is adversely affected due to physiological defects including sprouting [3]. Sprouting is a natural physiological process after dormancy whereby a potato tuber starts to develop shoots at the tuber buds base [4]. Sprouting of tubers negatively affects the potato industry, especially processing industries [5]. Sprouted tubers have reduced external and internal qualities, with the saleable weight mostly affected and tuber appearance, reducing their acceptability by consumers [5]. In addition, tuber sprouting reduces processing qualities, remobilization of starch and proteins, loss of water and tuber shrinkage thus reducing shelf-life and their marketability [6]. Furthermore, sprouted tubers have reduced nutritional quality, with the production of toxic compounds [7]. Therefore, for optimum utilisation of tubers, it is important during storage to have a complete

* Corresponding author.
E-mail address: thabiso.satekge@ul.ac.za (T. Satekge).

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inhibition of sprouting.

It has been demonstrated by several studies that postharvest methods such as cold storage between 2-5 °C [8,9], chlorpropham (CIPC) [8], ethylene gas [10] and maleic hydrazide [11] inhibit sprouting and maintain quality during storage [6,12,13]. However, most of these methods are cost-ineffective and eco-unfriendly [3,9,14]. For instance, cold storage and synthetic ethylene gas result in the accumulation of fructose and glucose, which lead to the darkening of potatoes during frying [8]. Thus, potato tubers with higher soluble sugars are rejected by the processing industry [14]. Moreover, CIPC and ethylene gas require long-term application, often with high concentrations [15] which is cost-ineffective and environmentally unacceptable [9,16]. Therefore, it is important to search for a cost-effective and a biological user-friendly sprout-suppressants method. The application of essential oils such as peppermint, coriander and eucalyptus oil are reported as biological and cost-effective sprout suppressant in potato [3,17]. However, essential oils are highly volatile [3], requiring continuous application to be effective sprout suppressants.

Ethylene can be generated biologically by crops. Plants emit ethylene endogenously as a signalling hormone to modulate growth and development [18]. The hormone plays a crucial role in response to various biotic and abiotic stresses in plants and is also considered a ripening hormone in fruit crops [18]. Climacteric fruit are an important biological ethylene agent since they emit ethylene abundantly during ripening [19]. The external ethylene application has been demonstrated to effectively supress sprouting in potatoes [20], sweet potatoes [7] and onions [21]. Therefore, we hypothesized that a biological ethylene emitted by climacteric fruit during ripening can also have the same effect. The ethylene gas emitted by climacteric fruit can diffuse into potato tubers during storage; thereby modulating sprouting and dormancy. A recent study demonstrated that storing apple fruit with orange (non-climacteric fruit) improved colour development [22], and the results were attributed to ethylene emitted by the fruit as it plays a role in modulating chlorophyll metabolism [22]. However, there is a dearth of information regarding the impact of storing potato tubers with climacteric fruits on dormancy and sprouting. Hence, the study was aimed at investigating the effect of climacteric fruit, apple, on the sprouting behaviour of potato tubers stored at ambient temperatures.

2. Materials and methods

2.1. Study materials

The tubers (*cv. Mondial*) were collected from four commercial farms *viz* Solly, Elmar, Leeubult and Jamba located in Bochum, Bandelierkop, Indermark and Dendron during December harvest period. Apple fruit (Granny Smith) were obtained from the Polokwane fresh produce in the Limpopo Province, South Africa. The total soluble solids (TSS) and firmness of the apples were 11.07 and 7.48, respectively, before storage with potato tubers.

2.2. Experimental treatments, procedures and design

A 2 by 3 completely randomized design was employed for the in a study. The experiment had apple fruit factor (alone or with apple fruit) and storage duration factor (0, 15 and 30 days). The experiment had seven replicates. A total of 896 potato tubers were used in the study. Each location comprised of 224 potato tubers, with 112 tubers per treatment. Sixteen potato tubers were stored in a brown paper bag with four apple fruits or alone as control under ambient temperature (±23 °C) to stimulate typical market conditions. Thereafter, the tubers were then stored in separate storage units (different cupboards) to ensure distinct storage conditions for each treatment group. After 14-days the apples were removed from storage due to rotting (data not shown). During storage, for each replicate, 10 randomly selected tubers were evaluated for non-destructive assay (changes in physiological weight loss, sprouting incidence, decay development), whilst 6 tubers were subjected to destructive assay (dry matter, quantification of sucrose, fructose and glucose) at a 15-day interval for 30 days.

2.3. Data collection

2.3.1. Physiological weight loss

A scale (Model: HBC1002, Adam Equipment, South Africa) was used to determine potatoes weights. Thereafter, equation (1) [23], was used to determine the percentage tuber weight loss:

$$\text{physiological weightloss}\ (\%) = \frac{\textit{initial weight loss} - \textit{final mass loss after storage}}{\textit{initial mass}} \times 100 \quad (1)$$

2.3.2. Sprouting percentage

Tubers exhibiting sprouts of at least 3 mm in length were categorized as sprouted [24,25]. Equation (2) [26] was used to calculate the percentage sprouting of potato tubers.

$$\textit{sprouting}\ (\%) = \frac{\textit{Number of sprouted tubers}}{\textit{Total number of tubers}} \times 100 \quad (2)$$

2.3.3. Dry matter content

The peeled tubers were sliced into approximately 50 g. Thereafter; they were oven-dried at 65 °C for 3 days, where a constant mass

was achieved. Equation (3) was used to determine the dry matter content [24,25]:

$$\text{Dry matter } (\%) = \frac{\textit{Final weight}}{\textit{initial weight}} \times 100 \quad (3)$$

2.3.4. Soluble sugars

The soluble sugars were determined following the methodology described by Ngobese et al. [27]. Briefly 10 mL of 70 % ethanol was added to 0.5 g of fresh potato flesh. The samples were submerged in an 80 °C water bath for 1 h 30 min with occasional agitation using a vortex. Thereafter, samples were stored at 4 °C overnight. Supernatant was evaporated at 60 °C using oven (Model: 279, Ecotherm, Labotec, South Africa). The evaporated samples were re-suspended in 2 mL of high performance liquid chromatography (HPLC) H_2O and then put in glass vials for HPLC analysis after being filtered by 0.45 μm syringe nylon filters. A HPLC binary pump with a refractive index detector was used to measure the concentrations of sucrose, fructose and glucose. The samples were injected (1 %) in a RezexTM RHM-monosaccharide H+ (8 %) column of 7.8 mm diameter × 300 mm in length. Fluoride distilled water was used as mobile phase and analysis was performed at a flow rate of 0.6 μL/min and column temperature of 80 °C. The individual samples were calculated using a standard curve of each sugar: fructose (0.5–3 mg/mL; Y = 111409x – 10693; R2 = 0.99), Sucrose (0.5–3 mg/mL; Y = 37432x + 3313.4; R^2 = 0.99) and glucose (0.5–3 mg/mL; Y = 79323x + 1143.3; R^2 = 0.99) standard concentration curves and expressed in mg/mL fresh mass basis.

2.3.5. Starch content

The starch content determined as described by Refs. [24,28] using equation (4):

$$Y = 0.942 \text{ x } 5.099 \quad (4)$$

Y = % starch content; X = % dry matter content

2.3.6. Tuber decay percentage

Potato tubers showing brown copper lesions or white sporulation on the tuber surface during storage were considered as decayed, and thereafter decay percentage was calculated according to equation (5) [29].

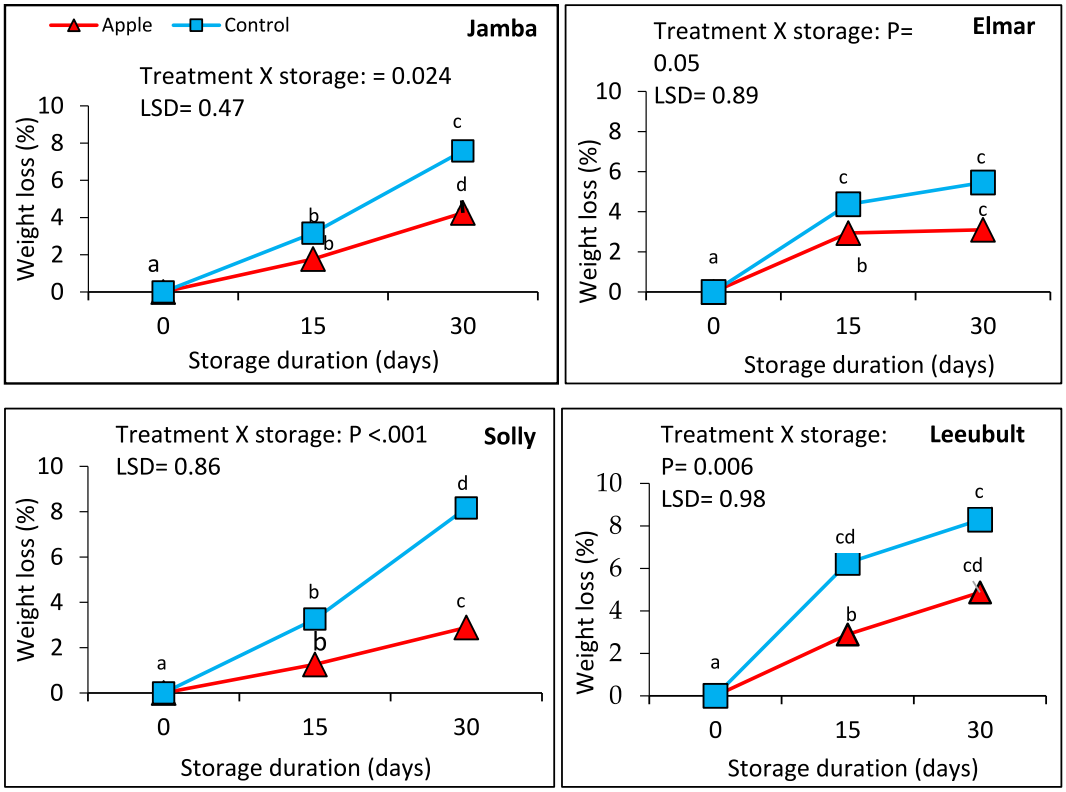

Fig. 1. Physiological weight loss of Mondial cultivar potato tubers, harvested from Elmar, Jamba, and Solly farms and stored with apple fruits at 23 °C for 30-day shelf-life. The vertical bar means indicated standard error (n = 7) with statistically significant differences (P ≤ 0.05) among treatments during the storage indicated by different letters.

2.3.7. Apple fruit ripening parameters

To assess the ripening of apple fruit and ethylene emission as the sprout suppressant [11], the fruit colour was evaluated based on hue angle at a 7-day interval for 2 weeks during storage. Briefly, a* ((CIE red (+)/green (−) and b* (CIE yellow (+)/blue (−)) were measured using a Chroma meter. Thereafter, hue angle (h^*) was calculated using equation (6).

$$Decay\ (\%) = \frac{Number\ of\ decayed\ tubers}{Total\ number\ of\ tubers} \times 100 \quad (5)$$

$$h^* = tan^{-1}(a^* / b^*) \quad (6)$$

2.4. Statistical analysis

The data were subjected to the analysis of variance (ANOVA) using GenStat version 21st, VSN International, UK. The differences between means were determined using a least significant difference (LSD) at 5 % level of significance through GenStat software.

3. Results and discussion

3.1. Storing potato tubers with apple fruit reduced sprouting and weight loss

Potatoes stored with apple fruit significantly($P < 0.05$) lost lower weight compared to the control (Fig. 1). Control potatoes significantly ($P < 0.05$) lost 2.5 % weight at 15-day storage compared to tubers stored with apples (2 %) from Jamba. Tubers stored alone from Solly showed significantly higher weight loss (4.02 %) as compared to tubers stored with apples (1.269 %). The same trend was observed in tubers obtained from Leeubult. However, there was an increased weight loss in tubers stored with apple fruit (4.85 %) compared to the control (2.43 %) from Elmar tubers stored with apple fruit. Sprouting increases physiological weight loss in tubers [29, 30]. This was also observed in the present study, whereby physiological weight loss increased with sprouting percentage (Figs. 1 and 2). In the current study, sprout growth was low in potatoes stored with apples. Hence apple fruit was chosen as a potential biological suppressant due to its availability and ethylene-emitting properties, which have been hypothesized to influence sprout inhibition in potato tubers. However, it is acknowledged that incorporating apples into storage practices may entail additional costs, including

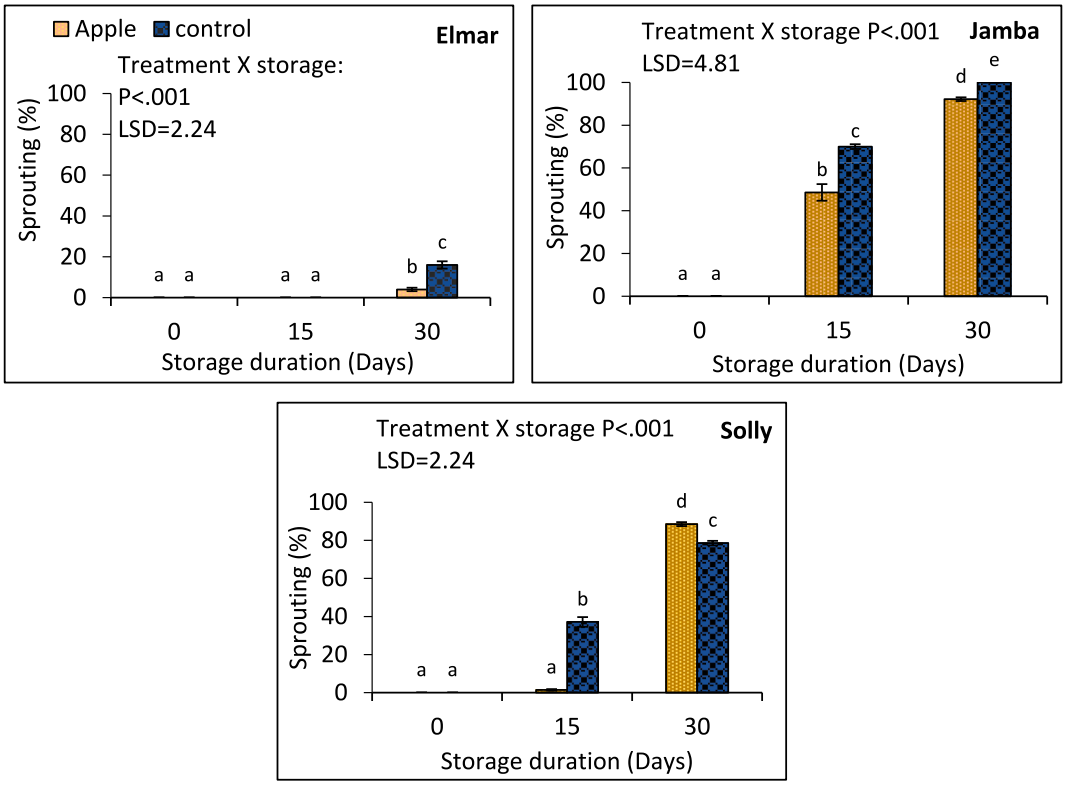

Fig. 2. Sprouting percentage of Mondial cultivar potato tubers, harvested from Elmar, Jamba, and Solly farms and stored with apple fruit 23 °C for 30-day shelf-life. The vertical bar means indicates standard error (n = 7) with statistically significant differences ($P \leq 0.05$) among treatments during the storage indicated by different letters.

procurement expenses and logistical considerations.

Sprouting percentage differed significantly ($P < 0.05$) on potatoes stored with apples compared to the control potatoes (stored alone) (Fig. 2). Tubers obtained from Leeubult did not differ on sprouting ($P > 0.05$), hence mean separation was not performed, and the results are not illustrated. Sprouting was delayed in potatoes stored with apples in all the production sites, with tubers obtained from Elmar showing the lowest sprouting percentage of 18 % and the control with 20 %. Sprouting in potatoes stored with apples was significantly lower (45 %) compared with the control potatoes (70 %) during shelf-life on tubers obtained from Jamba. The same trend was observed for tubers obtained from Solly farm. However, at 30-day, tubers stored with apple fruit had significantly higher sprouting percentage (90 %) compared to the control (80 %). These results indicated that storing apple fruit with potato tuber delays sprouting as observed in the three production sites, except Leeubult (Fig. 2). Climacteric fruits like apples emit ethylene during ripening at storage (Fig. 8) [22], however in this study ethylene emission was not measured. Since hue angle in apple fruits decrease with an increase in ethylene production in climacteric fruits (Fig. 8), peel colour (hue angle) was therefore measured to predict the ethylene production during ripening and storage of the apple fruits. Therefore, ethylene might have diffused into tubers (as hue angle decreased) (Fig. 8) which as a result delayed sprouting. Prange et al. [32] showed that short term application of ethylene (72 h at concentration of 0.02–20 μL) induced dormancy, while continuous ethylene application (2 μL for 6 months) inhibited sprouting completely. In the present study, the complete inhibition of sprouting was not observed, probably because apples were removed 14 days after storage as they started rotting (data not shown). Furthermore, the observed inconsistencies in the results across tubers from different production sites, particularly regarding sprouting behaviour, maybe attributed to differences in environmental conditions, cultural practices, or genetic factors among the potato cultivars sourced from different locations. For example, cultural practices, such as timing and methods of harvesting, affect tuber physiological state, with late harvesting increasing susceptibility to sprouting [30]. Factors such as soil composition, climate variability, and storage practices at each production site could contribute to these inconsistencies.

3.2. Incidence of tuber decay during storage

The tubers started showing signs of decay at 15-day storage in both control and tubers stored with apple fruit. This decay incidence was only observed in tubers obtained from Jamba and Leeubult (Table 1). The tubers from the two production sites had significantly ($P < 0.05$) higher decay incidence (47.85 % and 17.29 %) during storage with apple fruit compared to the control (21.67 and 7.59 %) (Table 1). The findings indicated that storing potatoes tubers with apples induces decay incidence and deterioration. It is unclear how this occurred. However, it was observed in the present study at 15-day storage that apple fruit were showing signs of decay (data not shown). Therefore, the apple decay might have affected the tubers.

Arancibia et al. [32] showed that ethephon (ethylene), increased the incidence of root tip rot in sweet potato. It is possible that during storage, climacteric fruits like apples emit substrates that are used by microorganisms for proliferation. Additionally, decay incidence coincided with signs of decay in the apple fruit stored alongside potato tubers. One possible explanation for the observed decay could be microbial interactions between the potato tubers and apple fruit during storage. Ethylene emitted by ripening apples may influence microbial proliferation, potentially facilitating decay incidence on both commodities [32]. Moreover, decay of apple fruit may release substrates that promote microbial growth, affecting the surrounding environment and contributing to decay incidence on the potato tubers. Nevertheless, given that tubers from other locations were unaffected, our findings imply that this deterioration is specific to the production sites. Therefore, the Jamba and Leeubult Farms cultural methods might have influenced the susceptibility of the tubers to microbial attacks [10].

3.3. Dry matter content of tubers stored with apple fruits during storage

The dry matter was significantly ($P < 0.05$) lower in tubers stored with apples throughout the 30-day shelf-life compared to the control (Fig. 3). The low dry matter was observed in tubers harvested from Jamba and Solly farms. Significantly higher dry matter was obtained in tubers from Leeubult and Elmar (Fig. 3). Potato tubers showing high dry matter content are considered more appropriate for processing industry [33]. The increased dry matter in tubers stored with apple fruit was due to delayed sprout development [34]. The ethylene emitted by apple fruit might have diffused into the tubers during storage, resulting in a delayed sprout growth. This may

Table 1
Decay incidence of potato tubers with stored with apple fruit during 30-day ambient storage.

Location		Storage duration			P-value	$LSD_{0.05}$
		0	15	30		
Jamba	**Control**	**0 ± 0^{a}**	**0 ± 0^{a}**	**21.67 ± 2.54^{b}**	**<.001**	**3.03**
	Apple	**0 ± 0^{a}**	**0 ± 0^{a}**	**47.85 ± 1.32^{c}**		
Leeubult	**Control**	**0± 0^{a}**	**1.44 ± 0.42^{ab}**	**07.59 ± 1.05^{c}**	**<.001**	**1.29**
	Apple	**0± 0^{a}**	**1.43 ± 0.42^{ab}**	**17.29 ± 1.05^{a}**		
Elmar	**Control**	ns	ns	ns		
	Apple	ns	ns	ns		
Solly	**Control**	ns	ns	ns		
	Apple	ns	ns	ns		

*Different letters indicate the statistical significance difference among treatments during storage duration ($P \leq 0.05$). Each value is a mean of replicates ($n = 7$) ± standard error. *NS*, not significant according to ANOVA

be supported by the fact that the dry matter was high in tubers stored with apple fruit as compared to the control (Fig. 3). High dry matter content was linked with increased storability in onion [21].

3.4. Starch content of tubers stored with apple fruits during storage

Potato tubers stored with apples had significantly ($P < 0.05$) lower starch content compared to the tubers stored alone (Fig. 4). This low starch content was only observed in tubers obtained from Jamba farm. In tubers from Solly, Leeubult and Elmar, there was no significant difference ($P > 0.05$) between tubers stored alone and with apple fruit (Fig. 4). Starch constitutes 65–80 % of the total dry weight of the potato tuber. However, sprouting leads to remobilization of starch and proteins [22]. Sprouting in potato tubers enhances the hydrolysis of starch into reducing sugars [6]. In the present study, starch content decreased with an increase in sprouting in tubers stored alone as compared to tubers stored with apple fruit (Fig. 4). This therefore confirms that ethylene emitted by (Fig. 8) apple fruit inhibited sprouting which as a result reduced the breakdown of starch content in Jamba. The reduced starch content in tubers from Jamba is due to the hydrolysis of starch-by starch degrading enzymes [35]. As a result, ethylene from apples inhibited sprouting as compared to tubers kept alone, resulting in a lower starch content as a result of starch remobilization. However, the lack of uniformity across different production sites suggests that other factors may also influence starch content and sprouting in Leeubult, Elmar and Solly. Thammawong, Arakawa [36] and Cools et al. [37], reported that ethylene gas application on sweet potatoes and onion reduced starch content, and increased respiration rate, indicating that during sprouting carbohydrate metabolism increases. It can, therefore, be inferred that ethylene emitted by the apple fruit retard starch degradation thus, reducing sprouting in potato tubers.

3.5. Soluble sugars of the tubers during storage

Potato tubers from the four production sites did not have significant difference ($P > 0.05$) in glucose and fructose when stored alone and with apple fruit (Figs. 5 and 6). The sucrose content in experimental and control tubers from Solly, Elmar and Leeubult production sites did not have significant difference ($P > 0.05$) (Fig. 7). This was in contrary to the experimental and control sample tubers from Jamba farm where the sucrose content was significantly higher ($P > 0.05$) in the experimental tubers. Overall, though not statically significant compared to the control, sugars were lower in tubers stored with apple fruit, suggesting that the use of this biological sprout suppressant does not induce sweetening, a phenomenon where fructose and glucose are high in tubers. Therefore, the technique presented in the present study is a promising approach for potato processing industry that want to reduce darkening of potato fries.

Synthetic ethylene gas increased soluble sugars in potato tubers, which is undesirable [20]. Tosetti et al. [38] also discovered that synthetic ethylene gas inhibited sprouting but increased reducing sugars. Higher soluble sugars in potato tubers lead to colour darkening of fried potatoes, and acrylamide production which can be carcinogenic [20,31]. Therefore, the utilisation of synthetic

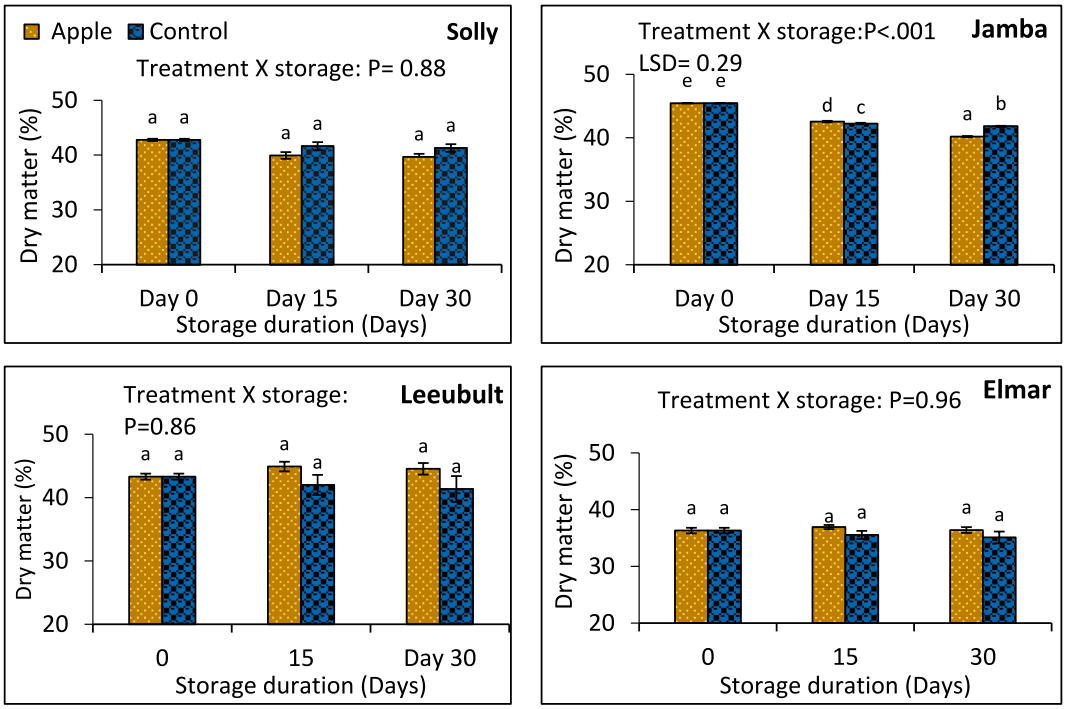

Fig. 3. Dry matter percentage of potatoes stored alone or with apples harvested from Solly, Jamba, Leeubult and Elmar farms stored with apple fruit at 23 °C for 30-day shelf-life. The vertical bar indicates a mean of seven replicates ± standard error. Different letters indicate significant different at $P \leq 0.05$ among treatments according to LSD.

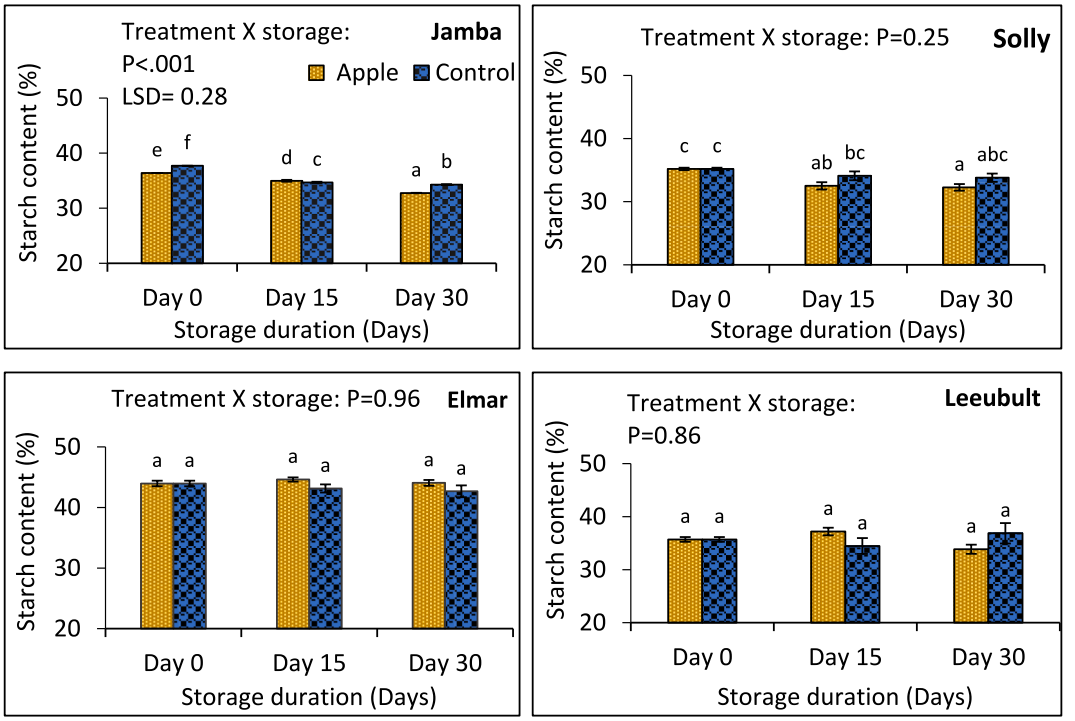

Fig. 4. Starch content (%) of potatoes stored alone or with apples harvested from Solly, Jamba, Leeubult and Elmar farms stored with apple fruit at 23 °C for 30-day shelf-life. The vertical bar indicates a mean of seven replicates ± standard error. Different letters indicate significant different at P ≤ 0.05 among treatments according to LSD.

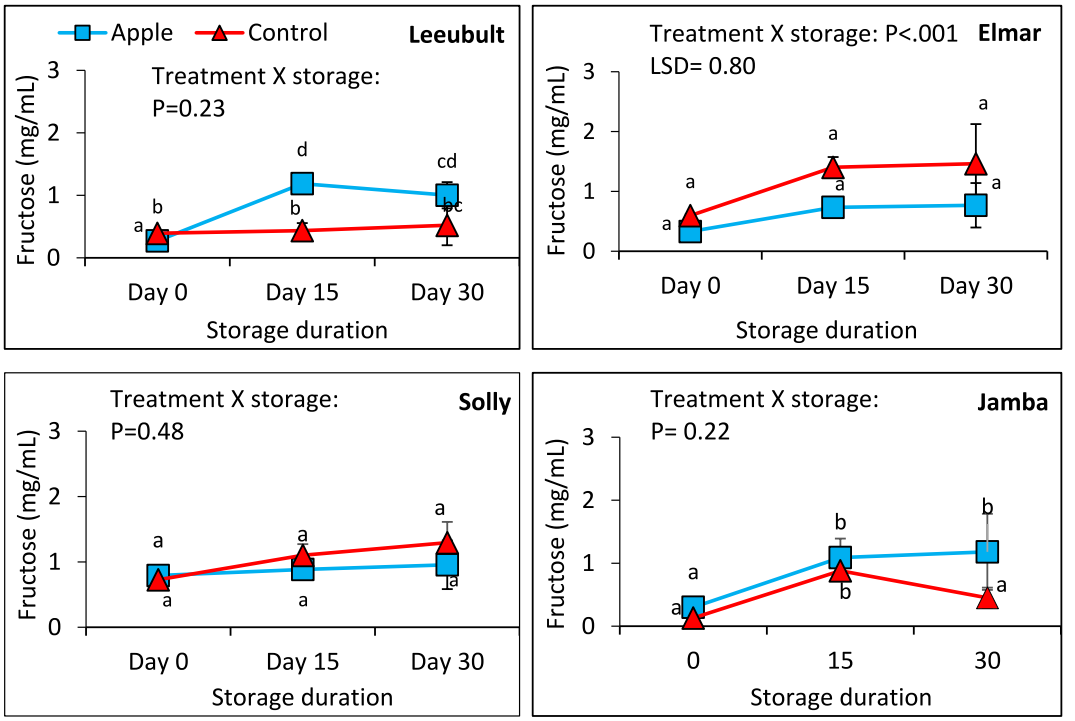

Fig. 5. Fructose content of potatoes stored alone or with apples harvested from Solly, Jamba, Leeubult and Elmar farms stored with apple fruit at 23 °C for 30-day shelf-life. The vertical bar indicates a mean of seven replicates ± standard error. Different letters indicate significant different at P ≤ 0.05 among treatments according to LSD.

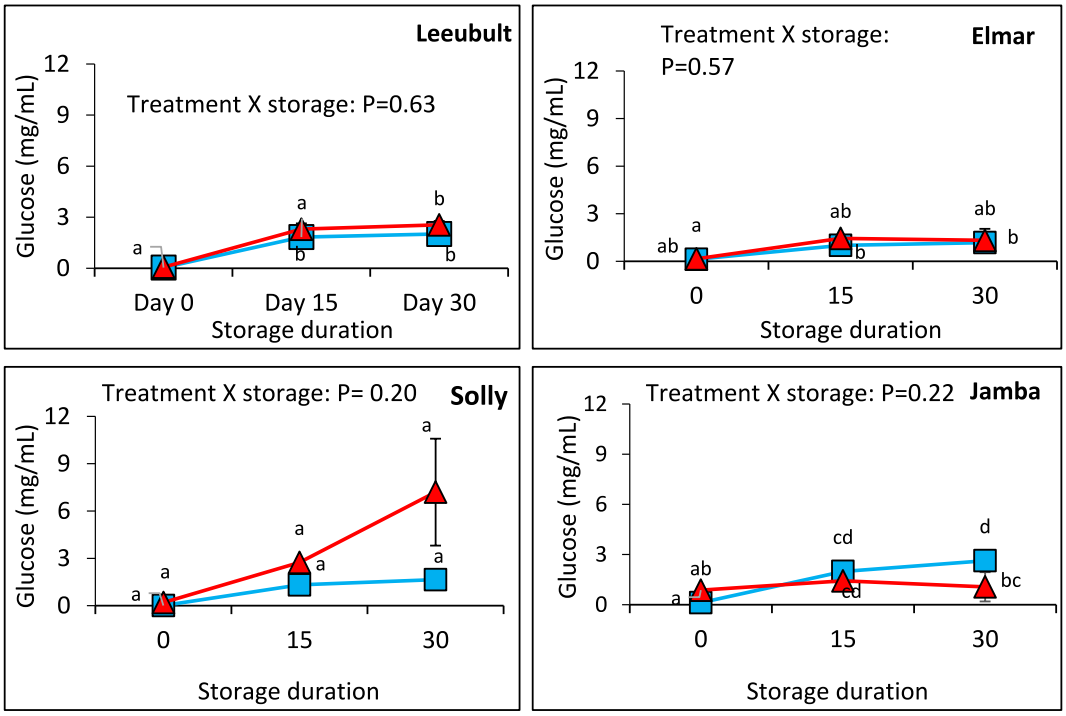

Fig. 6. Glucose content of potatoes stored alone or with apples harvested from Solly, Jamba, Leeubult and Elmar farms stored with apple fruit at 23 °C for 30-day shelf-life. The vertical bar indicates a mean of seven replicates ± standard error. Different letters indicate significant different at P ≤ 0.05 among treatments according to LSD.

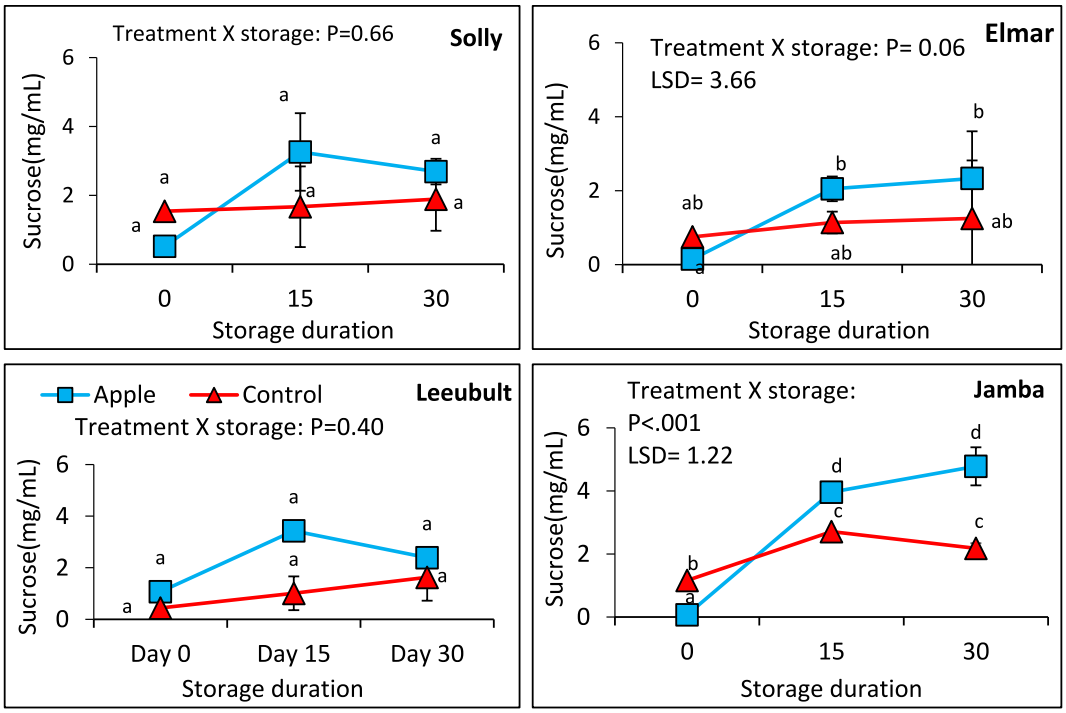

Fig. 7. Sucrose content of potatoes stored alone or with apples harvested from Solly, Jamba, Leeubult and Elmar farms stored with apple fruit at 23 °C for 30-day shelf-life. The vertical bar indicates a mean of seven replicates ± standard error. Different letters indicate significant different at P ≤ 0.05 among treatments according to LSD.

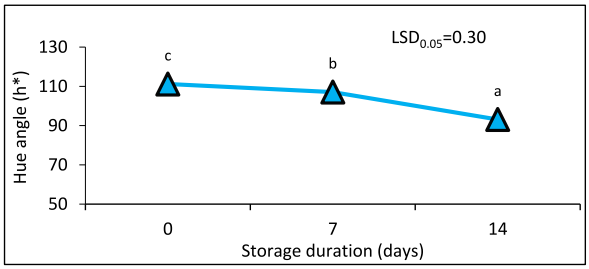

Fig. 8. The relationship between apple fruit peel colour change (as represented by hue angle) and ethylene production during ambient storage. Letters indicate that peel colour change was changing significantly $P \leq 0.05$. over 14-day according to LSD test.

ethylene gas as a sprout suppressant is limited due to its ability to induce reducing sugars. In the present study, apple fruit as a biological ethylene agent maintained lower soluble sugars in tubers during storage, with reduced sprouting. This is significant for processing industry as they need potatoes with low sugar content to avoid browning of fries.

4. Conclusion

The objective of this study was to assess use of apple fruit as a biological agent to inhibit sprouting in potato tubers. Our findings indicate that storing potatoes with apples resulted in a reduced sprout growth than control potatoes. Additionally, we observed that sugar content in potato tubers varied depending on the production site, and the ethylene emitted by apple fruit prevented the remobilization of starch content. However, our results on decay were not consistent across all tubers from different locations, indicating variability in the effectiveness of this method. Although our study demonstrates the potential of using apples, ethylene emitting fruit as a sprout suppressant for short-term (30 days) at ambient temperatures, the non-significant results for sugars might be due to the storage of samples at lower temperatures. Therefore, further research is needed to investigate the effects of long-term storage under cooler conditions and to address inconsistencies observed across different production sites. Future studies should explore the optimization of storage conditions, cultivar-specific responses, and the integration of biological sprout suppressants with existing storage practices to enhance the post-harvest quality and shelf-life of potato tubers.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Lesibana Bopape: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Thabiso Satekge:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Paulus Mafeo:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Manape Lekganyane:** Writing – review & editing, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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