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Effects of Foliar and Tuber Sprout Suppressants on Storage of Ware Potatoes under Tropical Conditions

R. O. Nyankanga[1] · W. W. Murigi[1] · S. I. Shibairo[2] · O. M. Olanya[3] · R. P. Larkin[4]

Abstract

Potato (*Solanum tuberosum* L.) is an important source of dietary carbohydrate and cash income generation for farmers in the tropical highlands of Kenya. The feasibility for cold storage at the farm level is limited due to the high costs of maintaining such a facility and there is limited data on the long-term post-harvest storage and quality of tubers of tropical-adapted cultivars. Application of sprout suppressants to control premature sprouting of ware potato is an attractive proposition. The objectives of this study were to evaluate the efficacy of pre-harvest foliar applications of paclobutrazol (PBZ) and ethephon for sprout suppression on ware potato tubers in storage. Post-harvest spray applications of Isopropyl N-(3-chlorophenyl carbamate) chloropropham (CIPC) and 1,4-dimethylnaphthalene (DMN) on tubers as fog was also evaluated. Potato cultivars had varying levels of tuber dormancy. The tubers were stored at ambient temperature (23 C) and evaluated weekly for 24 weeks for percent of tubers sprouting, length of longest sprouts, tuber weight loss and assessed for dormancy for 24 weeks. Paclobutrazol prolonged tuber dormancy by 21–31 days and reduced tuber weight loss. Ethephon treatment had no effect on dormancy and tuber weight loss. Potato tubers treated with CIPC had greater sprout control than the other treatments in storage. Tuber response to DMN treatment varied among the three potato cultivars evaluated. The findings from this study imply that PBZ is effective in prolonging potato tuber dormancy for short-term basis at 23 C, while CIPC applied on tubers was effective for long term storage. Optimization of post-harvest potato storage can improve food security in the highland tropics.

Resumen

La papa (*Solanum tuberosum* L.) es una fuente importante de carbohidratos en la dieta y de generación de ingresos para agricultores en los altiplanos tropicales de Kenia. La factibilidad para almacenamiento en frío a nivel de campo es limitada debido a los altos costos del mantenimiento de tales instalaciones y hay datos limitados en el almacenamiento postcosecha a largo plazo y la calidad de los tubérculos de variedades adaptadas al trópico. La aplicación de inhibidores de la brotación para controlar la brotación prematura de papa de consumo es una propuesta atractiva. Los objetivos de este estudio fueron evaluar la eficacia de aplicaciones foliares pre-cosecha de paclobutrazol (PBZ) y de etefon para inhibir brotación en tubérculos de consumo en almacenamiento. También se evaluaron aplicaciones por aspersión en postcosecha de Isopropil N-(3-clorofenil carbamato), chloroprofam (CIPC), y 1, 4-dimetilnaftaleno (DMN), en tubérculos en nebulización. Las variedades de papa tuvieron diversos niveles de dormancia del tubérculo. Estos fueron almacenados a temperatura ambiente (23 C) y evaluados semanalmente por 24

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✉ O. M. Olanya
modesto.olanya@ars.usda.gov

[1] Department of Plant Science and Crop Protection, University of Nairobi, P.O. Box 30197-00100, Nairobi, Kenya

[2] Kibabii University, P.O. Box 1699-50200, Bungoma, Kenya

[3] Eastern Regional Research Center, Food Safety and Intervention Technologies Research Unit, USDA-ARS, Wyndmoor, PA 19038, USA

[4] New England Plant, Soil, and Water Laboratory, USDA-ARS, Orono, ME 04469, USA

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semanas para porcentaje de tubérculos brotados, longitud de los brotes más largos, pérdida de peso del tubérculo y analizados para dormancia por 24 semanas. Paclobutrazol prolongó la dormancia por 21–31 días y redujo la pérdida de peso del tubérculo. El tratamiento con etefon no tuvo efecto en el período de dormancia ni en la pérdida de peso. Los tubérculos tratados con CIPC tuvieron un mayor control de brotación que los otros tratamientos en el almacén. La respuesta de los tubérculos al tratamiento con DMN varió entre las tres variedades evaluadas. Lo que se encontró de este estudio implica que PBZ es efectivo en la prolongación de dormancia en tubérculos de papa con base a corto plazo a 23 C, mientras que CIPC aplicado en tubérculos fue efectivo para almacenamiento a largo plazo. La optimización del almacenamiento postcosecha puede mejorar la seguridad alimentaria en los altiplanos tropicales.

Keywords Sprout inhibitors · *Solanum tuberosum* · Post-harvest · Weight loss · Tropical highlands

Introduction

In Kenya, potato (*Solanum tuberosum* L.) is an important food crop, secondary only to maize (*Zea mays* L.), and contributes 32% of the overall dietary energy consumption (Lung'aho et al. 2006; Olanya et al. 2012; Nyankanga et al. 2014). However, annual post-harvest losses are 10–13% (Kinyua et al. 2005; Nyankanga et al. 2004; Janssens et al. 2013; Kaguongo et al. 2014). Sprout development on tubers is one of the major causes of quality loss in stored ware potato and it leads to loss of marketable tubers (tuber quality), and saleble weight (Suttle 1998). In addition, tuber sprouting leads to physiological changes in tubers and reduces processing qualities (Suttle 2003). Therefore, for optimum utilization of tubers, it is important to have effective sprout inhibition during storage.

The feasibility for improved post-harvest storability of potato tubers of tropical-adapted cultivars is difficult due to the fluctuating tropical environments characterized by mean ambient temperatures of 20 to 33 C. Post-harvest tuber sprout control may be achieved by using low temperature storage or treatments with sprout suppressant agents (Khanbari and Thompson 1996). However, in the tropical environments of Kenya, cold storage technique (low temperature) is not feasible for the resource-constrained farmers, due to the high costs and maintenance associated with refrigeration.

Worldwide, chemical sprout suppressants and natural compounds have been used to control sprout development on potato tubers during storage. Isopropyl-N (3-chlorophenyl carbamate) chlorpropham (CIPC) has been the primary method used to control sprouting of tubers. Other chemical compounds that have been documented to suppress sprout development in tubers are: napthalenes, ethylene, essential oils, jasmonates and hydrogen peroxide based materials (Kleinkopf et al. 2003; Afek et al. 2000). Although these chemicals have been found to be effective in controlling sprouting on ware (table stock) potato, the potential of chemical residues on tubers have prompted the search for alternative sprout control agents (Suttle 2003). Several studies have identified pre-harvest foliar applications or soil drench with paclobutrazol (PBZ) to be efficacious in suppressing growth in various plant species (Starman and Williams 2000; Balamani and Poovaiah 1985). It has also been reported that both pre-harvest and post-harvest applications of the ethylene-releasing agent ethephon in potatoes resulted in significant prolongment of tuber dormancy (Cvikrova et al. 1994).

It has been hypothesized that pre-harvest treatment of tubers with suitable growth inhibitors can suppress sprout growth with minimal or no adverse effects on yield and quality of tubers when compared to the post-harvest application of CIPC and other chemical sprout inhibitors. Moreover, pre-harvest foliar application can be easier than post-harvest application of the chemicals. Due to limited knowledge on the storage potential of potato tubers of tropical-adapted cultivars, and the high demand and post-harvest utilization of potato, the objective of the present study was to determine the efficacy of PBZ and ethephon (ethylene foliar application) for sprout suppression of tubers of potato plants grown under field conditions compared to post-harvest applications of CIPC and DMN on tubers when stored under ambient conditions (23 C).

Materials and Methods

Experimental Set-Up

Certified potato seed tubers of medium size (50–70 mm diameter) of three commercially cultivated cultivars, Shangi (short dormancy), Asante (medium dormancy) and Kenya Mpya (medium to long dormancy) were obtained from Kenya Agricultural and Livestock Research Institute (KALRO) Tigoni. Whole non-treated potato seed tubers were grown at Kabete Field Station of the University of Nairobi, Kenya from April to July 2013 (Season 1) and from October to January 2014 (Season 2). The site is at an altitude of 1737 m above sea level and on latitude 1° 15' South and longitude 36° 44′ East. The area has a bimodal rainfall pattern which peaks in April and November. The annual rainfall is about 1000 mm. The maximum and minimum mean temperatures are 24.3 C and 13.7 C respectively. The dominant soils are Nitosols, which are characterized

by very deep, well-drained, dark reddish, friable clay type resistant to erosion (Jaetzold et al. 2006).

The tubers were planted in 4 m long by 4 rows wide plots with spacing of 0.3 × 0.75 m. Diammonium phosphate (DAP) was applied at planting time at a rate of 150 kg P ha^{-1} and urea was side dressed after full emergence at a rate of 100 kg N ha^{-1}. Standard agronomic practices recommended for potatoes including ridging, pest control and weeding were followed (Nyankanga et al. 2004). The experiment was arranged in a randomized complete block design with split plot arrangement whereby the sprout suppressants were the main plots while the cultivars were the subplots. The treatments had three replications.

Sprout Suppressant Treatments and Applications

Sprout suppressants of two different types were assessed; 1) foliar application on potato plants prior to harvest; and 2) tuber applications after harvest. For foliar application, there were 2 compounds assessed, paclobutazol, 1-(4-chlorophenyl) 4, 4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol (PBZ) (Austar Chemicals PTY Ltd., Australia) and ethephon, 2-Chloroethylphosphonic Acid (Sigma-Aldrich Co., Germany). At early tuber initiation (~30 days after plant emergence), plants were treated with PBZ applied at the rate of 250 mg L-1, or ethephon at a rate of 2500 mg L-1 as foliar sprays on potato. The application was done using a backpack sprayer containing 20 L of carrier water. Distilled water of equal volume was applied on the non-treated potato plants. The foliar treatments were repeated 2 weeks after full bloom (4–6 weeks after emergence). Plants were dehaulmed 2 weeks (75 days after planting) prior to harvest by vine-cutting (removal of vines). Tubers were hand-harvested and sorted into three categories: ware (table stock 50–90 mm diameter), seed (30–50 mm diameter), and rejects (<25 mm diameter). At harvest, tubers without any blemishes on the surface and any visible signs or symptoms of disease and without any signs of sprouting were selected and cured for 14 days under ambient conditions (air temperatures of 23 C, and humidity of 81%). Twenty tubers per cultivar were selected for each foliar treatment and replication. These were weighed, placed in khaki bags and stored at ambient temperature of 23 C, and subsequently assessed for sprouting and weight loss weekly for 24 weeks.

For tuber application of sprout suppressants, healthy, non-treated, medium-sized (50–70 mm diameter) ware tubers were selected from non-treated plots and cured for 14 days under ambient conditions prior to applying the sprout inhibitors at post-harvest. Two post-harvest suppressants were assessed, Isopropyl N-(3-chlorophenyl carbamate) chloropropham (CIPC), and 1,4- dimethylnaphthalene (DMN). Tubers were thinly spread on plastic trays and CIPC (granules containing 95% CIPC), at a rate of 22 mg a.i. Kg −1. (Sigma-Aldrich, USA), or DMN applied at the rate of 100 mg a.i. Kg −1 of fresh tuber weight as a liquid fog (Sigma-Aldrich, USA). The non-treated was sprayed with distilled water. After treatment, the tubers were wrapped in airtight plastic bags for 24 h. The treated potato tubers (20 tubers per cultivar per treatment) in each replicate were packed in khaki (cloth) bags. Potato tubers were stored for up to 24 weeks at ambient storage of 23 C. The experiment had three replications per treatment.

Data Collection

Assessment of dormancy and sprouting parameters were conducted following published procedures (Shibairo et al. 2006). Dormancy was considered to have ended when over 80% of the tubers in a sample had sprouts ≥3 mm long. Potato sprouting was quantified by evaluating samples of 20 tubers in three replicates weekly for up to 6 months of storage. Sprouting percentage was calculated as the number of sprouted tubers / total tubers in the sample multiplied by 100. The change in weight was expressed as a percentage of the initial weight. Dormancy period (number of days from tuber harvest to sprout development of 80% of tubers), length of longest sprout (mm), number of sprouts per tuber (all sprouts with at least 3 mm length were counted from every tuber and averaged), and thickness of the longest sprout (mm) from each tuber were quantified from replicated experiments.

Data Analysis

Data for treatments from each experiment were analyzed separately by using Proc GLM of the Statistical Analysis System, SAS Version 9.3 (SAS Institute Inc., Cary, NC, USA). The effects of treatments (sprout inhibitors and duration of storage on % sprouting of tubers, sprout numbers, sprout length, sprout thickness and weight loss) were computed for each experiment, separately. The significance of treatment means within an experiment was also computed by using Tukey's Honest Significant Difference (HSD) at $P < 0.05$.

Results

Dormancy of Potato Tubers

When compared to the non-treated, application of PBZ treatments significantly ($P < 0.05$) increased dormancy period of tubers of each cultivar based on the foliar application experiment, but the ethephon treatment was not significantly ($P > 0.05$) different from the non-treated (Table 1). Shangi tubers had the shortest dormancy period. Relative to the non-treated, foliar treatment with PBZ prolonged dormancy by 4.4 weeks for tubers of cultivar Shangi and 3 weeks for Kenya Mpya and

Table 1 Effect of sprout suppressant treatment on dormancy of 3 potato cultivars during storage at 23 C

	[a]Dormancy (Days)		
Foliar Application Expt.[b]	Asante[f]	Kenya Mpya	Shangi
Control	60bc	67b	24d
Ethephon	58c	69b	27d
Paclobutrazol (PBZ)	81a	89a	55c
Tuber Application Expt.[c]	Asante[g]	Kenya Mpya	Shangi
Control	60e	70d	28f
DMN[d]	70d	98c	28f
CIPC[e]	140ab	146a	133b

[a] Dormancy refers to number of days from harvest to sprout development (sprouts ≥3 mm long) in 80% of tubers

[b] Foliar and [c] tuber applications for dormancy evaluations were done in separate experiments

[d] DMN = 1,4-Dimethylnapthalene and [e] CIPC = Isopropyl N-(3-chlorophenyl carbamate) chloropropham

[f] Means in the rows and columns of the foliar application experiment with different letters indicate significant differences ($P < 0.05$) in treatment means based on Tukey's Honest Significant Difference (HSD)

[g] Means in the rows and columns of the tuber application experiment with different letters indicate significant differences ($P < 0.05$) in treatment means based on Tukey's Honest Significant Difference (HSD)

Asante tubers (Table 1). In the tuber application experiment, Shangi tubers had shorter dormancy relative to Kenya Mpya and Asante tubers (Table 1). For the CIPC tuber applied treatment, sprout development was not observed until 18 weeks after treatment. The DMN treatment on Asante tubers resulted in moderate tuber sprout inhibition (3 weeks longer than the non-treated), while tubers of cultivar Shangi had no significant difference when compared to the non-treated tubers (Table 1).

Average Number of Sprouts per Tuber

For foliar applied treatments, there was a significant ($P \leq 0.05$) interaction among treatment and cultivars. Ethephon and the non-treated tubers had the greatest number of sprouts per tuber compared to the other treatments. Tubers of potato cultivars Asante and Kenya Mpya treated with PBZ recorded the lowest sprout number (Fig. 1a, b). The tubers of cultivar Kenya Mpya sprouted towards the end of the experiment irrespective of treatments applied, and they recorded the lowest number of sprouts compared to tubers of the other cultivars (Fig. 1b). In general, tubers that sprouted during the later time of storage had fewer number of sprouts per tuber compared to tubers that sprouted earlier during the storage experiment. However, the number of sprouts per tuber increased greatly with storage duration (Fig. 1a–c). On Shangi tubers treated with PBZ, the number of sprouts per tuber were recorded after 6 weeks of storage and was the lowest among the three treatments. At 3 weeks of storage, sprout numbers were observed on tubers treated with ethephon and non-treated and the trend was similar until 6 weeks of storage (Fig. 1c).

For tuber applied suppressants at post-harvest, the number of sprouts per tuber was significantly ($P < 0.05$) influenced by the interactions of sprout suppressant treatment, cultivar and storage period and the non-treated tubers had the highest number of sprouts per tuber compared to CIPC and DMN treatments throughout the experimental period (Table 2). There was no difference in number of sprouts per tuber between CIPC and DMN treatment for cultivar Kenya Mpya. In treatments with DMN, the sprout numbers increased initially then decreased towards the end of the storage duration in tubers of cultivars Asante and Shangi. CIPC treatments produced the fewest number of sprouts per tuber and at the end of the experiment all cultivars had less than 0.3 sprouts per tuber (Table 2).

Sprout Development on Tubers (%)

Following treatments with ethephon, there were no differences in percent of tubers sprouted when compared to the non-treated tubers throughout the experimental duration. After 13 weeks of storage, all tubers treated with ethephon or left non-treated had sprouted regardless of cultivar. PBZ delayed sprouting by a minimum of 3 weeks in all cultivars compared with ethephon and the non-treated ones. The foliar application of PBZ resulted in tubers with 87%, 97% and 100% sprouting for cultivars Kenya Mpya, Asante and Shangi, respectively; after 13 weeks. There were no differences observed at the end of week 13 in all the treatments and cultivars (Table 3).

When DMN and CIPC treatments were compared to the non-treated, CIPC had the greatest sprout inhibitory effects, leading to 23.3%, 16.7% and 10% of sprout formation for tubers of cultivars Shangi, Asante and Kenya Mpya respectively; at 24 weeks of storage (Table 4). The treatment of DMN did not prevent the onset of sprouting in cultivars Shangi and Asante, but it greatly reduced sprout development when compared to the non-treated potatoes (Table 4). Tuber sprouting was 100% percent in the non-treated potatoes at the end of week 4 and 12 for tubers of cultivars Shangi and Asante; respectively. The DMN treatment was effective on suppressing sprouting only on tubers of Kenya Mpya.

Sprout Length (Mm) and Thickness

In foliar applied inhibitors, tuber sprouting in treatments of ethephon and the non-treated was observed at the beginning of the experiment for cultivar Shangi and had the greatest sprout length compared to the treated and non-treated tubers of cultivars Asante and Kenya Mpya. At the end of storage period, the lowest sprout length was recorded in PBZ treatment, on cultivar Kenya Mpya

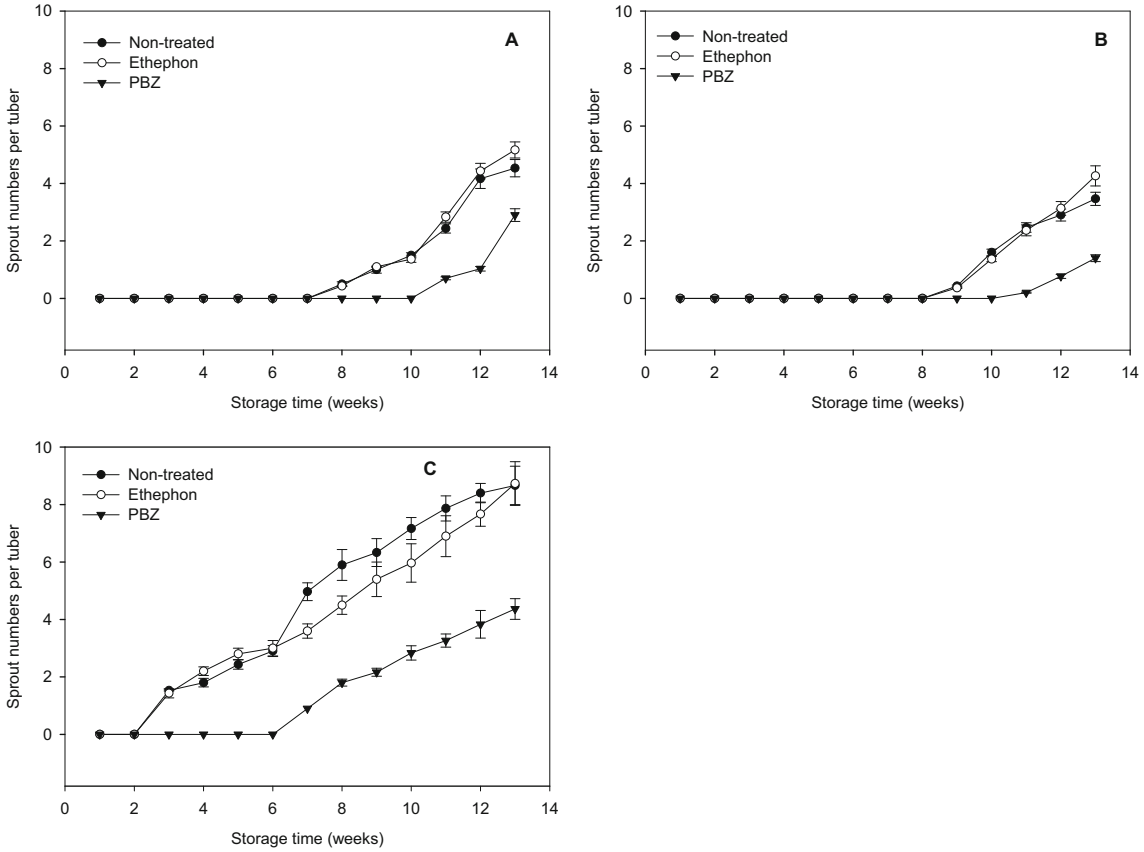

Fig. 1 Effect of foliar application of sprout suppressants ethephon (2-Chloroethylphosphonic Acid), PBZ (paclobutrazol, 1-(4-chlorophenyl) 4, 4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol) and non-treated on sprout numbers per tuber evaluated on tubers of three tropical-adapted potato cultivars stored at ambient temperatures. The cultivars are: A – Asante, B – Kenya Mpya, and C – Shangi

Table 2 Effects of foliar application of PBZ and ethephon on % of tubers from different potato cultivars that sprouted during storage at ambient temperature (23 C)

		Storage duration (weeks)												
Treatment[a]	Cultivar[b]	1[c]	2	3	4	5	6	7	8	9	10	11	12	13
Non-treated	Asante	0	0	0	0	0	0	0	50	83.3	100	100	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	43.3	86.7	100	100	100
	Shangi	0	0	66.7	96.7	96.7	100	100	100	100	100	100	100	100
Ethephon	Asante	0	0	0	0	0	0	0	53.3	933	96.7	100	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	33.3	83.3	96.7	100	100
	Shangi	0	0	53.3	83.3	83.3	96.7	100	100	100	100	100	100	100
PBZ	Asante	0	0	0	0	0	0	0	0	0	0	70	90	96.7
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	20	46.7	86.7
	Shangi	0	0	0	0	0	0	76.7	86.7	96.7	100	100	100	100
	HSD (0.05)	ns	ns	4.56	4.99	4.85	3.33	3.33	12.57	10.33	18.09	15.08	19.42	4.85

[a] PBZ refers to paclobutrazol, 1-(4-chlorophenyl) 4, 4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol. PBZ was applied at the rate of 250 mg L-1, and Ethephon, 2-Chloroethylphosphonic Acid applied at 2500 ppm as foliar sprays at tuber initiation period, and the non-treated = no tubers were treated

[b] At post-harvest, the number of tubers that sprouted were assessed weekly, HSD = Tukey's Honest Significant Difference, ns = non-significant

[c] Refers to weeks from 1 to 13 in which sprout development was evaluated during tuber storage

Table 3 Effect of tuber applications of Chloropropham (CIPC) and 1,4-Dimethylnapthalene (DMN) on sprouting % of potato tubers at ambient temperature of 23 C

		Storage duration (weeks)											
Treatment[a]	Cultivar[b]	2[c]	4	6	8	10	12	14	16	18	20	22	24
Non-treated	Asante	0	0	0	0	80	100	100	100	100	100	100	100
	Kenya Mpya	0	0	0	0	80	96.7	100	100	100	100	100	100
	Shangi	0	93.3	100	100	100	100	100	100	100	100	100	100
CIPC	Asante	0	0	0	0	0	0	0	0	0	3.33	6.7	16.7
	Kenya Mpya	0	0	0	0	0	0	0	0	0	3.33	6.7	10
	Shangi	0	0	0	0	0	0	0	0	0	10	13.3	23.3
DMN	Asante	0	0	0	0	60	63.3	63.3	63.3	63.3	63.3	63.3	63.3
	Kenya Mpya	0	0	0	0	0	0	0	3.3	6.7	13.3	16.7	20
	Shangi	0	3.3	16.7	73.3	76.7	76.7	76.7	76.7	76.7	76.7	76.7	76.7
	HSD (0.05)	ns	2.76	1.93	1.93	5.12	3.40	4.40	8.82	5.21	6.00	6.40	6.41

[a] Isopropyl N-(3-chlorophenyl carbamate) chloropropham = CIPC and 1,4-Dimethylnapthalene = DMN, Non-treated (no tubers were treated). CIPC was applied at the rate of 22 mg Kg −1 of tubers, while DMZ was applied at 100 mg Kg −1 of tubers

[b] Potato tubers evaluated for sprout development were obtained from the above cultivars, HSD = Tukey's Honest Significant Difference

[c] Refers to weeks 2 to 24 in which sprout development during tuber storage was evaluated, ns = non-significant

(5.1 mm), followed by cultivar Asante (7.2 mm). The sprout emergence in tubers from plants treated with PBZ in cultivars Asante and Kenya Mpya occurred at week 11, but tubers from cultivar Kenya Mpya maintained lower sprout length. Overall, the sprout length increased in all the treatments with increased duration of storage. At the end of storage, thicker sprouts of 6.85 mm were produced from tubers of cultivars Shangi (non-treated) while thinner sprout (2.5–3.7 mm) were observed on cultivar Kenya Mpya tubers irrespective of the treatment. Sprout thickness increased with increased storage time irrespective of treatment and cultivar (data not shown). At the end of storage, thicker sprouts were recorded in the non-treated and ethephon treatments compared to PBZ treated tubers in all the cultivars. Tubers of cultivars Shangi and Asante had significantly ($P < 0.05$) thicker sprouts than cultivar Kenya Mpya tubers in all the treatments.

For inhibitors applied on tubers, all treatments effectively suppressed sprout growth compared to the non-treated. CIPC treatment of tubers had the most effective sprout growth

Table 4 Effect of tuber applied sprout suppressants Chloropropham (CIPC) and 1,4-Dimethylnapthalene (DMN) on the number of sprouts per tuber in three potato cultivars stored at ambient temperature (23 C)

		Storage duration (weeks)[c]											
Treatment[a]	Cultivar[b]	2	4	6	8	10	12	14	16	18	20	22	24
Non-treated	Asante	0	0	0	0	1.3	1.8	3.0	4.2	5.6	6.3	7.9	7.9
	Kenya Mpya	0	0	0	0	1.3	3.2	5.1	7.6	8.6	12.3	13.5	15
	Shangi	0	1.8	6.7	13.1	4	13.7	13.9	14.0	14.3	14.5	15.0	15.1
CIPC	Asante	0	0	0	0	0	0	0	0	0	0.1	0.1	0.2
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0.1	0.1	0.2
	Shangi	0	0	0	0	0	0	0	0	0	0.2	0.2	0.3
DMN	Asante	0	0	0	0	1.8	1.8	3.3	4.4	4.9	4.8	4.1	4.1
	Kenya Mpya	0	0	0	0	0	0	0	0.1	0.1	0.2	0.4	0.5
	Shangi	0	0.1	0.4	3.2	3.3	3.8	4.8	4.6	4.2	3.6	3.4	3
	HSD (0.05)	ns	0.27	0.54	0.51	0.66	0.60	0.77	0.70	0.59	0.91	0.69	0.76

[a] Chlorpropham = CIPC and 1,4-Dimethylnapthalene = DMN, Non-treated (no tubers were treated). CIPC was applied at the rate of 22 mg Kg −1 of tubers, while DMZ was applied at 100 mg Kg −1 of tubers

[b] Cultivars on which tubers were evaluated for sprout development, HSD = Tukey's Honest Significant Difference

[c] Refers to weeks 2 to 24 in which sprout development during tuber storage was evaluated, ns = non-significant

suppression that resulted in sprout lengths of 2 mm, 1.67 mm and 1.77 mm for tubers of cultivars Shangi, Asante and Kenya Mpya; respectively after 24 weeks of storage. Sprout emergence was delayed until week 20 for tubers treated with CIPC in all cultivars. Sprout length increased with storage time until the completion of storage duration. Application of DMN maintained sprout length of <4 mm after 24 weeks of storage. Sprouts from the non-treated tubers averaged 20 mm, 18 mm and 23 mm in length for cultivars Shangi, Asante and Kenya Mpya; respectively.

Tuber Weight Loss

There was no difference in weight loss of tubers between the non-treated and ethephon treatments following application of sprout suppressant to foliage (Fig. 2). No treatment affected weight loss in tubers of Shangi or Asante. At the completion of storage experiment, tubers from plants treated with PBZ recorded the least tuber weight losses of 1.3%, 2.5% and 3.7% for cultivars Kenya Mpya, Asante and Shangi; respectively. Tubers treated with ethephon had 2.7%, 3.0% and 4.4% weight losses for cultivars Kenya Mpya, Asante and Shangi, respectively. There was no difference in weight loss between tubers of Asante and Kenya Mpya with the non-treated and ethephon, and with Asante treated with PBZ (Fig. 2). The weight loss of tubers was significantly ($P < 0.05$) greater on Shangi compared to tubers of other cultivars (Fig. 2).

When DMN and CIPC treatments were compared to the non-treated, the sprout suppressant applied to tubers resulted in a significant ($P < 0.05$) decrease in % weight loss for Kenya Mpya relative to the other cultivars. CIPC was significantly ($P < 0.05$) lower than DMN, which was lower than the non-treated (Fig. 3). The weight loss for tubers of Kenya Mypa following treatment with DMN and CIPC was lower than the other cultivars for those two treatments. There were significant ($P < 0.01$) correlation coefficients between weight loss and sprout growth as weight loss had a positive correlation coefficient with sprout length ($r = 0.907$) and between weight loss and sprout numbers ($r = 0.828$). Tubers with longer sprout lengths had greater weight loss than tubers with shorter sprouts. In addition, tubers with greater number of sprouts had substantially more weight loss than tubers with fewer sprouts.

Discussion

For inhibitor treatments applied to foliage, dormancy of tubers of all cultivars was greater with PBZ than with ethephon or in the non-treated tubers, suggesting that PBZ was more efficacious for sprout inhibition than ethephon (Table 1). In the tuber application experiment, the dormancy period after CIPC treatment was almost twice that of DMN treatment indicating it had superior suppression activity. Sprout inhibition was achieved under ambient storage temperatures (23 C) with a single application of CIPC at a dose of 22 mg Kg − 1. Mehta and Ezekiel (2010) reported over 95% sprout inhibition after 105 days in storage when potato tubers were treated with CIPC at the concentration of 20 and 30 mg Kg − 1 and stored at 17 to 33 C. Tuber sprouting increased with increased storage time. This could have resulted from decreasing DMN residue levels in the tubers that had minimum to that exhibited reduced inhibition of sprouts with storage time. Storage time has been shown to have a substantial reduction on the CIPC residue present in the potato tuber (Lewis et al. 1997). Similarly, DMN residue levels within tubers have been

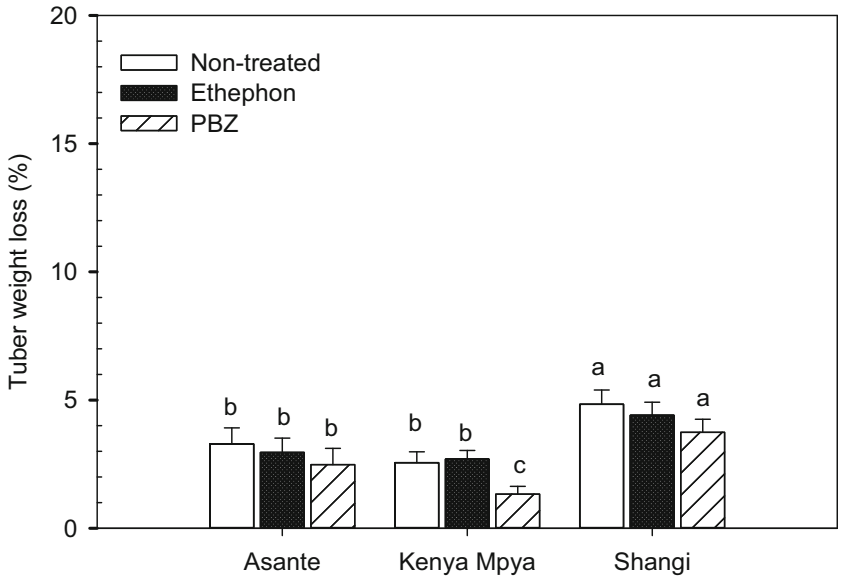

Fig. 2 Effect of PBZ PBZ (paclobutrazol, 1-(4-chlorophenyl) 4, 4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol) and ethephon 2-Chloroethylphosphonic Acid) treatment and non-treated on weight loss (%) of tubers of three tropical-adapted potato cultivars stored at ambient temperatures for 12 weeks

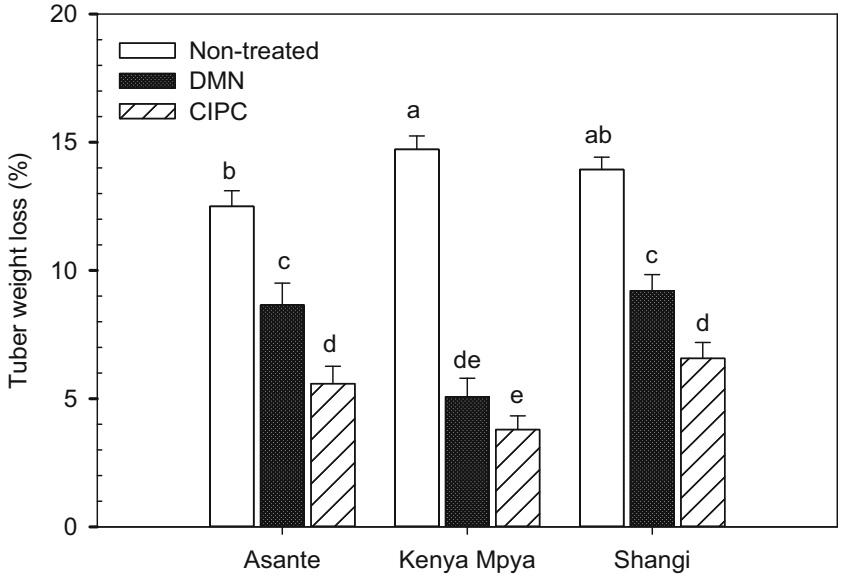

Fig. 3 Effect of DMN (1,4-Dimethylnapthalene) and CIPC (Isopropyl N-(3-chlorophenyl carbamate) chloropropham) application of tubers on weight loss (%) of tubers of three tropical-adapted potato cultivars stored at ambient temperatures for 24 weeks

reported to decrease with increasing storage time (Lewis et al. 1997; De Weerd et al. 2010).

DMN showed variable sprout suppression among the three cultivars (Table 1). Variability of sprout suppression with the DMN treatments among the cultivars may have been due to genetic differences (Lewis et al. 1997). Storage time has also been shown to have a substantial effect on the reduction of CIPC residue present in potato tubers (Mehta and Ezekiel 2010). De Weerd et al. (2010) tested critical DMN residue levels necessary for suppression of sprout development on three cultivars 'R. Norkotah', 'R. Burbank' and 'Shepody'. In order to maintain sprout control, tuber residues of 2.7 ppm for cultivar 'R. Norkotah', 1.6 ppm for cultivar 'Shepody' and 1.4 ppm for cultivar 'R. Burbank' were needed. This is an indication that different cultivars require different tuber residue levels to suppress sprouting in storage. DMN applied at the rate of 100 mg Kg −1 (Table 2) maintained a sprout length of <4 mm at the end of 24 weeks in storage while sprouts on the non-treated tubers averaged 20 mm, 18 mm and 23 mm in length for cultivars Shangi, Asante and Kenya Mpya, respectively. Similar results have been reported previously (Lewis et al. 1997; Knowles et al. 2005). In earlier studies, 1,4-dimethylnaphthalene and 1,6-dimethylnaphthalene have been shown to have suppressing ability comparable to CIPC (Meigh et al. 1973). Its mode of action is still not clearly understood but it has been suggested that the natural period of dormancy is extended through regulation of phytohormones (Campbell et al. 2010; Kleinkopf et al. 2003). The observations of DMN treated tubers (Table 4) from all the cultivars revealed that the tips of developing sprouts turned black and were necrotic after 90 days in storage. Similar observations were made by previous researchers (Lewis et al. 1997).

Foliar application of PBZ prolonged dormancy period by 21–31 days when tubers were stored at ambient conditions (Table 1). This is in agreement with results of other researchers (Tekalign and Hammes 2004; Bandara and Tanino 1995; Lim et al. 2004). The extension of dormancy length by PBZ treatment could be attributed to inhibition of gibberellic acid biosynthesis resulting in low gibberellic acid concentration within the tubers. It has been reported that abscisic acid inhibits sprouting by hindering DNA and RNA synthesis (Suttle 2004). Tubers from plants treated with paclobutrazol (Table 3) showed fewer sprouts per tuber and reduced sprout growth compared to the non-treated and those treated with ethephon. This could be due to the late sprouting of tubers from plants treated with PBZ compared with ethephon and non-treated ones within each cultivar. As with DMN, there were cultivar differences with response to PBZ. Boldt (2008) also cited that cultivars differ in sensitivity to PBZ treatment. The application of ethylene-releasing agent ethephon on dry onions was reported to enhance sprouting (Abdel-Rahman and Isenberg 1974). However, the application of ethephon during onion bulb development in the field reduced sprouting at storage (Thomas and Rankin 1982), indicating that ethephon in some instances may affect certain stages of crop development rather than plant cultivar.

In contrast, foliar-applied ethephon (Fig. 1) was not effective at suppressing or inhibiting sprouts to any degree, showing no difference between ethephon-treated and non-treated tubers for any parameters measured. Although some previous reports have indicated a significant prolonged dormancy of potato tubers with pre- or post-harvest applications of ethephon (Sonnewald 2001), there was no effect of pre-harvest ethephon treatments under the conditions of our study. The application of ethylene releasing compound such as ethephon (2-chloroethyl phosphoric acid) has been shown to vary on

plant species, chemical concentrations, timing and duration of applications. Since ethephon regulates various phases of plant growth (Khuankaew et al. 2009) and the compounds were applied to foliage of potatoes prior to harvest, it is possible that its activity on potatoes could have affected plant and stem elongation and increased stem strength. Our results differ from other research findings in which ethephon was shown to be effective. For example, the application of ethephon on potato tubers were reported to shorten duration of dormancy but inhibited elongation of sprouts during extended treatments (Rylski et al. 1974). In this study, ethephon was applied to foliage and it is possible that it could have been effective if it were applied on tubers instead of foliage. Similarly, the rates of applications and the timing of the applications were different from those of other previous studies.

In general, the percentage of weight loss reduction achieved on tubers treated with CIPC was the best among tuber applied treatments. The lower weight loss observed in tubers treated with CIPC as compared to non-treated tubers agrees with earlier findings (Vijay et al. 2016; Mehta 2005; Gautam et al. 2013). Similarly, previous research has indicated lower total weight loss of potato tubers due to foliar spray treatment with PBZ (Kumar et al. 2010). Potato tubers treated with sprout suppressants experienced less than 10% weight loss and therefore did not suffer sufficient moisture loss to affect their physical appearance. Consequently, the potato tubers could be sold for prices comparable to that of freshly harvested tubers. This suggests that potatoes of the same maturity group and dormancy may have similar reaction to suppressants applied to foliage in terms of weight loss. Therefore, the study findings may be applicable to topical-adapted cultivars with similar dormancy maturity groups. Weight loss showed a significant positive correlation with number of sprouts and sprout length (data not shown). Alexopoulos et al. (2008) reported that sprouting results in increased metabolic activity due to sprout growth leading to increased respiration and weight loss. Sprouting causes direct weight loss due to faster metabolic activity, high surface area and increased respiration resulting in increased starch breakdown leading to weight loss (Gautam et al. 2013; Benkeblia et al. 2009; Wustman and Struik 2007). Additionally, the presence of sprouts increases evaporation because the epidermis of the sprouts is 100 times more permeable to water than the tuber periderm (Benkeblia et al. 2009). Significant differences in weight loss among the cultivars were observed. Cultivar Shangi treated and non-treated tubers recorded higher weight loss than Asante and Kenya Mpya. Additionally, cultivar Kenya Mpya tubers recorded significantly lower weight loss. Pande et al. (2007) reported that tuber weight loss was cultivar dependent and the cultivars that exhibit longer dormancy with reduced sprout growth and less number of sprouts had restricted weight loss. Ezekiel et al. (2004) indicated that variations in weight loss during storage among cultivars are due to either their periderm characteristics or their sprouting behavior.

In conclusion, pre-harvest application of PBZ will be beneficial for short-term storage of ware potatoes, while CIPC applied on tubers will be for long-term storage of up to 6 months. The application of the study findings may be applicable to topical-adapted cultivars with the same dormancy category and similar maturity groupings. Cultivars differed with response to DMN treatment. When applied to cultivars with long dormancy, DMN showed sprout suppressant equal to CIPC. However, when applied to cultivars with short dormancy, DMN had limited sprout growth suppression.

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Compliance with Ethical Standards

Declaration The experiments comply with the current laws of Kenya and ethical standards or requirements were met.

References

Abdel-Rahman, M., and F.M.R. Isenberg. 1974. The role of exogenous plant regulators in the dormancy of onion bulbs. *The Journal of Agricultural Science* 82: 113–116.

Afek, U., J. Orenstein, and E. Nuriel. 2000. Using HPP (hydrogen peroxide plus) to inhibit potato sprouting during storage. *American Journal of Potato Research* 77: 63–65.

Alexopoulos, A.A., G. Aivalakis, K.A. Akoumianakis, and H.C. Passam. 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.

Balamani, V., and B.W. Poovaiah. 1985. Retardation of shoot growth and promotion of tuber growth of potato plants by paclobutrazol. *American Potato Journal* 62: 363–369.

Bandara, P.M.S., and K.K. Tanino. 1995. Paclobutrazol enhances minituber production in Norland potatoes. *Journal of Plant Growth Regulation* 14: 151–155.

Benkeblia, N., A.A. Alexopoulos, and H.C. Passam 2009. Physiological and biochemical regulation of dormancy ansd sprouting in potato tubers (*Solanum tuberosum* L.). *Fruit, Vegetable and Cereal Science and Biotechnology* 2(*Special Issue 1*): 54–68, Global Science Books.

Boldt, J.L. 2008. Whole plant reponse of chrysanthemum to paclobutrazol, chlormequat chloride, and (s)-abscisic acid as a function of exposure time using a split-root system. M.S. Thesis, University of Florida, Gainsville, FL, p. 61.

Campbell, M.A., A. Gleichsner, R. Alsbury, D. Horvath, and J. Suttle. 2010. The sprout inhibitors chlorpropham and 1, 4-dimethylnaphthalene elicit different transcriptional profiles and do not suppress growth through a prolongation of the dormant state. *Plant Molecular Biology* 73: 181–189.

Cvikrova, M., L.S. Sukhova, J. Eder, and N.P. Korableva. 1994. Possible involvement of abscisic acid, ethylene and phenolic acids in potato tuber dormancy. *Plant Physiological Biochemistry* 32: 685–691.

De Weerd, J.W., M.K. Thornton, and B. Shafii. 2010. Sprout suppressing residue levels of 1, 4 dimethylnaphthalene (1,4DMN) in potato cultivars. *American Journal of Potato Research* 87: 434–445.

Ezekiel, R, P.S. Dahiya, and G.S. Shekhawat. 2004. Traditional methods of potato storage in the Malwa region of Madhya Pradesh. Technical Bulletin No. 57, Central Potato Research Institute (CPRI), Shimla, India, p. 43.

Gautam, I.P., M.D. Sharma, B.B. Khatri, R.B. Thapa, and K. Shrestha. 2013. Storability and chips quality of chemical treated potatoes under ordinary condition. *Journal of Basic and Applied Sciences* 9: 1.

Jaetzold, R., H. Schmidt, B. Hornetz, and B. Shisanya. 2006. Farm management handbook of Kenya, Vol II. Nairobi, Kenya Ministry of Agriculture, Natural Conditions and Farm Management Information of Central Kenya, p. 573.

Janssens, S.R.M., S.G. Wiersema, and H.T. Goos. 2013. The value chain for seed and ware potatoes in Kenya: Opportunities for development (No. 13–080, p. 57). LEI Wageningen, Holland.

Kaguongo, W., G. Maingi, I. Barker, N. Nganga, and J. Guenthner. 2014. The value of seed potatoes from four systems in Kenya. *American Journal of Potato Research* 91: 109–118.

Khanbari, O.S., and A.K. Thompson. 1996. Effect of controlled atmosphere, temperature and cultivar on sprouting and processing quality of stored potatoes. *Potato Research* 39: 523–531.

Khuankaew, T., T. Ohyama, and S. Ruamrungsri 2009. Effecst of ethephon application on growth and development of *Curcuma akismatifolia* Gagnep. *Bulletin Faculty Agriculture Niigata University* 62: 9–15.

Kinyua, Z.M., M. Olanya, J.J. Smith, R. El-Bedewy, S.N. Kihara, R.K. Kakuhenzire, C. Crissman, and B. Lemaga. 2005. Seed plot technique: Empowerment of farmers in production of bacterial wilt-free seed potato in Kenya and Uganda. In *Bacterial wilt disease and the Ralstonia Solanacearum species complex*, ed. C. Allen, P. Prior, and A.C. Hayward. St. Paul: APS Press 510p.

Kleinkopf, G.E., N.A. Oberg, and N.L. Olsen. 2003. Sprout inhibition in storage: current status, new chemistries and natural compounds. *American Journal of Potato Research* 80: 317–327.

Knowles, N.R., L.O. Knowles, and M.M. Haines. 2005. 1, 4-Dimethylnaphthalene treatment of seed potatoes affects tuber size distribution. *American Journal of Potato Research* 82: 179–190.

Kumar, V., A. Kumar, V.K. Dohrey, V.K. Singh, and V. Umrao. 2010. Effect of foliar application of plant growth regulators on storage behavior of potato tubers. *Progressive Agriculture* 10: 282–287.

Lewis, M.D., G.E. Kleinkopf, and K.K. Shetty. 1997. Dimethylnaphthalene and diisopropyl naphthalene for potato sprout control in storage: 1. Application methodology and efficacy. *American Potato Journal* 74: 183–197.

Lim, H.T., C.S. Yoon, S.P. Choi, and S.P. Dhital. 2004. Application of gibberellic acid and paclobutrazol for efficient production of potato (*Solanum tuberosum* L.) minitubers and their dormancy breaking under soilless culture system. *Horticulture Environment and Biotechnology* 45: 189–193.

Lung'aho, C., S.K.N. Nderitu, J.N. Kabira, R. El-Bedewy, O.M. Olanya, and A. Walingo. 2006. Yield performance and release of late blight tolerant potato varieties in Kenya. *Journal of Agronomy* 5: 57–61.

Mehta, A. 2005. Commercial potential of CIPC for sprout inhibition in potatoes under heap storage. *Indian Journal of Potato* 32: 203–204.

Mehta, A., and R. Ezekiel. 2010. Non-refrigerated storage of potatoes. *Potato Journal* 37: 3–4.

Meigh, D.F., A.E. Filmer, and R. Self. 1973. Growth-inhibitory volatile aromatic compounds produced by *Solanum tuberosum* tubers. *Phytochemistry* 12: 987–993.

Nyankanga, R.O., H.C. Wein, O.M. Olanya, and P.S. Ojiambo. 2004. Farmers' cultural practices and management of potato late blight in Kenya highlands: implications for development of integrated disease management. *International Journal of Pest Management* 50: 135–144.

Nyankanga, R.O., W. Kiplagat, R. Narla, S. Shibairo, J. Kabira, J. Landeo, and M. Olanya. 2014. Effects of early and late harvest on agronomic performance and stability of late blight resistant (R-gene free) potato genotypes. *Journal of Crop Science and Biotechnology* 17: 89–96.

Olanya, O.M., R. Nyankanga, P. Ojiambo, B. Lemaga, R. Kakuhenzire, and D. Fontem. 2012. Optimization of late blight and bacterial wilt management in potato production systems in the highland tropics of Africa. In: He Z., Larkin, R.P., Honeycutt, C.W. (Eds). Sustainable potato production: Global case studies, Amsterdam, Springer. 509–531. (Book Chapter, peer reviewed).

Pande, P.C., S.V. Singh, S.K. Pandey, and B. Singh. 2007. Dormancy, sprouting behaviour and weight loss in Indian potato (*Solanum tuberosum*) varieties. *Indian Journal of Agricultural Science* 77: 715–720.

Rylski, I., L. Rappaport, and H.K. Pratt. 1974. Dual effects of ethylene on potato dormancy and sprout growth. *Plant Physiology* 53: 658–662.

Shibairo, S.I., P. Demo, J.N. Kabira, P. Gildemarcher, F. Gachango, M. Menza, R.O. Nyankanga, G.N. Chemining'wa, and R.D. Narla. 2006. The efefcts of gibberellic acid (GA3) on sprouting and quality of potato seed tubers in difussed light and pit storage conditions. *Journal of Biological Sciences* 6: 723–733.

Sonnewald, U. 2001. Control of potato tuber sprouting. *Trends in Plant Science* 6: 333–335.

Starman, T.W., and M.S. Williams. 2000. Growth retardants affect growth and flowering of scaevola. *Horticultural Science* 35: 36–38.

Suttle, J.C. 1998. Involvement of ethylene in potato microtuber dormancy. *Plant Physiology* 118: 843–848.

Suttle, J.C. 2003. Auxin-induced sprout growth inhibition: role of endogenous ethylene. *American Journal of Potato Research* 80: 303–309.

Suttle, J.C. 2004. Physiological regulation of potato tuber dormancy. *American Journal of Potato Research* 81: 253–262.

Tekalign, T., and P.S. Hammes. 2004. Response of potato grown under non-inductive condition paclobutrazol: Shoot growth, chlorophyll content, net photosynthesis, assimilate partitioning, tuber yield, quality, and dormancy. *Plant Growth Regulation* 43: 227–236.

Thomas, T.H., and W.E.F. Rankin. 1982. Effect of ethephon on bulbing, bull-necking, yield and sprouting during storage of two onion cultivars (*Allium cepa* L.). *Journal of Horticultural Science* 57: 465–467.

Vijay, P., R. Ezekiel, and R. Pandey. 2016. Sprout suppression on potato: need to look beyond CIPC for more effective and safer alternatives. *Journal of Food Science and Technology* 53: 1–18.

Wustman, R., and P.C. Struik. 2007. The canon of potato science: seed and ware potato storage. *Potato Research* 50: 351–355.