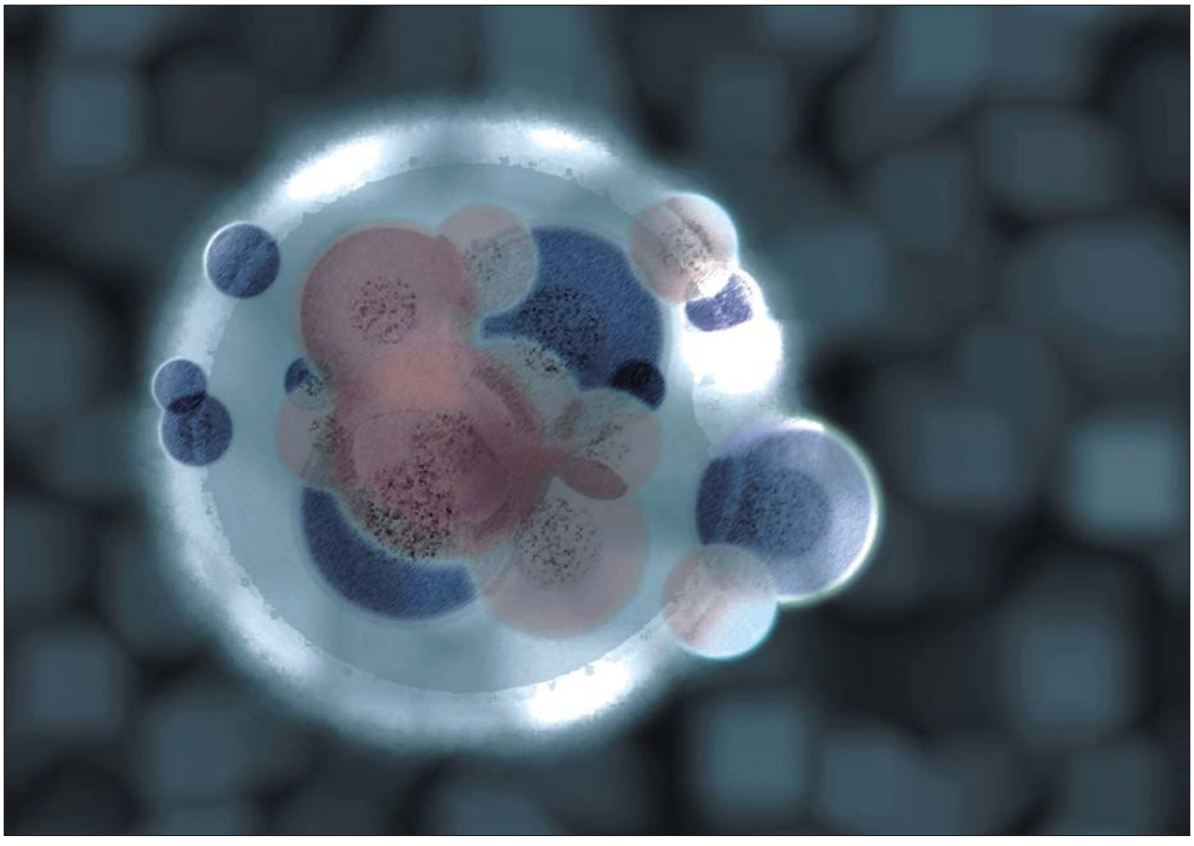

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Effects of Gibberellic Acid (GA_3) on Sprouting and Quality of Potato Seed Tubers in Diffused Light and Pit Storage Conditions

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Abstract: Effects of gibberellic acid (GA_3) on dormancy termination, sprouting and quality of potato (*Solanum tuberosum* L.) seed tubers stored for 12 weeks in Diffused Light Store (DLS) and for 2 weeks in pit were determined. Potato genotypes (Tigoni, Asante, Dutch Robyjn, Kenya Karibu and Kenya Sifa) and GA_3 at 0, 10, 20 and 30 mg kg^{-1} were used. Dormancy period was reduced to three weeks in all genotypes except Kenya Sifa, which sprouted after seven weeks following GA_3 treatments in DLS. Increasing GA_3 concentrations increased sprouting (%), number of sprouts per tuber, sprout length and vigor score. However differences among GA_3 concentrations for these parameters were not observed. In the pit, the potato seed tubers sprouted within the two weeks of storage. Except for Kenya Sifa, GA_3 had no effect on sprouting and vigor score; however, it increased number of sprouts per tuber and sprout length. Increase in GA_3 concentration led to increase in rotting at 30 mg kg^{-1} of GA_3 for Tigoni, Kenya Sifa and Kenya Karibu genotypes, under DLS. It is suggested that lower levels of GA_3 of up to 20 mg kg^{-1} should be adopted for promotion of sprouting of potato seed tubers.

Key words: Gibberellic acid, sprouting, potato, seed, pit, diffused light

INTRODUCTION

Lack of good quality seed among growers is a major problem adversely affecting the expansion of potato production in many developing countries such as Kenya (Crissman *et al*., 1993). One major problem facing production of quality potato seed is poor sprouting, due to dormancy, which leads to delayed planting and poor crop emergence and vigor (Wiersema, 1985). Timely availability of well-sprouted seed potato tubers at the on-set of rains is a pre-requisite for attaining high yields. In the traditional areas of potato production with a bimodal rainfall, the window of planting is two weeks. However, potatoes are dormant for longer than three weeks. Rindite (a 7: 3: 1 by volume mixture containing ethylene chlorhydrin, 1, 2-dichloroethane and carbon tetrachloride) was used extensively by the formal seed production systems to break potato seed tuber dormancy and promote sprouting. Though very effective, Rindite is toxic thus environmentally unfriendly and damaging to human health (Rehman *et al*., 2001) and hence its use is discouraged.

Diffused light storage (DLS) developed by the International Potato Centre (CIP) can be used for seed storage for up to five or six months (Demo *et al*., 2004). Storage in DLS has been found to delay the physiological ageing of potato seed tubers and reduce apical dominance, resulting in an increased number of stems per tuber, short and firm sprouts. In addition, less storage losses through pest and diseases and easier checking occurs when potato seed tubers are stored under DLS. However, the DLS delays sprouting by more than four weeks in most genotypes (Demo *et al*., 2004). Hence, there is need to hasten sprouting under DLS.

Resource poor farmers often promote potato sprouting by placing them in pits and trenches and use genotypes with very short dormancy. Medium to long dormancy genotypes are thus not easy to incorporate into the predominant cropping system in which farmers retain seed from the previous harvest for replanting the next season. Farmers mostly prefer the pit because it is cheaper to construct and maintain. Under pit conditions, potato seed tuber sprouting occurs quite fast within three weeks due possibly to the heat build up (Hunt, 1982; Bencini,

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1991) or modified air conditions created. Potato seeds sprouted in pits are, however, of poor quality due to apical dominance, rotting and shoot etiolation caused by the dark conditions. The challenge, therefore, is to improve the quality of the potato seed tubers produced under pit.

Use of low quantities of growth promoters such as thiourea, rindite, carbon disulphide and bromo-ethane (Bryan, 1989) and gibberellic acid (Carrera *et al*., 2000; Demo *et al*., 2004) to promote potato seed sprouting has been suggested. Under laboratory conditions, gibberellins have been shown to be more stimulatory to potato seed sprouting (Carrera *et al*., 2000) and maintenance of seed quality in terms of seed health and vigor (Demo, 2002) than other growth promoting substances. To date there are no reports on use of GA_3 for potato sprouting under DLS or pit conditions in Kenya. Therefore, the objective of this study was to determine the effects of GA_3 on dormancy termination, sprouting and quality of potato seed tubers in DLS and pit storage conditions.

MATERIALS AND METHODS

Potatoes genotypes (Tigoni, Asante, Dutch.Robyjn, Kenya Karibu and Kenya Sifa) were planted between October 2004 and February 2005 (season 1) and repeated between April and July in 2005 (season 2) at the National Potato Research Centre (NPRC)-Tigoni Kenya. Tigoni and Asante have short, while Kenya Karibu and Kenya Sifa have long dormancy periods. Dutch Robyjn is an old existing genotype. The NPRC-Tigoni lies 2100 m above sea level. The mean annual rainfall is 800 mm p.a and evaporation is 180 mm p.a. (Kabira, 2001). Potatoes tubers were planted in furrows at the recommended spacing of 0.75×0.30 m in 30×30 m plots and then covered with soil. A fertilizer diammonium phosphate (DAP) was applied at the rate of 500 kg ha^{-1}. Weeding, ridging and pest and disease control were done according to recommended practices. The crop was dehaulmed two weeks prior to harvesting.

The potatoes were hand-harvested after 112 and 104 days after planting, in season 1 and 2, respectively, placed in nylon woven mesh bags and transported to a DLS 0.2 km away. The freshly harvested tubers were immediately sorted out and the medium healthy seeds of 35-45 mm diameters were selected and subjected to gibberellic acid treatments.

Experiments in diffused light storage conditions: The potato seed tubers of the five genotypes were treated with four levels of GA_3 (SIGMA Company, Sigma-Aldrich Chemie GmbH, Steinheim, Germany) (0, 10, 20 and 30 mg kg^{-1}). The 5 × 4 factorial combinations of treatments were laid out in randomized complete block design (RCBD) and replicated four times. Tubers were sprayed to draining with the different GA_3 concentrations and allowed to dry for 10 min. Twenty tubers per treatment combination were weighed, put on 0.3×0.3 m paper trays and placed under DLS. The treated tubers were evaluated every two weeks for up to 12 weeks for sprouting (%), number of sprouts per tuber, sprout length, sprout vigor, potato tuber moth (PTM) incidence (%) and tuber rotting (%).

A tuber was considered sprouted when it had at least one visible sprout of at least 3 mm length (Wiersema, 1985). Sprouting was calculated as a percentage of the number of sprouted tubers in the sample. End of dormancy was defined as the period when 80% of the tubers (from a sample of, at least, 20 uniformly sized tubers) had sprouts of at least 3 mm long (Wiersema, 1985); it was extrapolated from the graph of sprouting (%) versus duration of storage. Sprout length was determined by measuring the length of the longest sprout of the potato seed tubers.

Sprout vigor score was evaluated based on the thickness of the base of the sprout. The evaluation was based on a 5-point rating scale where 1 = very low vigor (where more than half of the tubers in a sample had sprouts of ≤1 mm thick and a length of ≤3 mm), 2 = low vigor (where more than half of the tubers in a sample had sprouts of ≤2 mm thick and a length of ≤4 mm), 3 = good vigor (where more than half of the tubers in a sample had sprouts of ≤4 mm thick and a length of ≤4 mm), 4 = high vigor (where more than half of the tubers in a sample had sprouts of ≤4 mm thick and a length of ≥4 mm but were not firm and had not acquired the green coloration) and 5 = very high vigor (as described for score 4 but had acquired green coloration, were firm and had no visible defects).

Potato tubers were also evaluated for presence of PTM and rots. A tuber was considered infested when the characteristic tunnel of the tuber moth appeared on the surface or when tuber moth presence was observed on the sprouts. Number of tubers with tuber moths was recorded and the PTM incidence calculated as a percentage of total number of tubers in the sample. The presence of dry and soft rots on the potato surfaces were observed and their incidence calculated as a percentage of the total number of tubers in the sample. Causes of disease deterioration were identified using standard techniques for isolation and identification of fungal pathogens (Waller *et al*., 1998; Zitter and Loria, 2003).

Experiments in pit storage conditions: Due to lack of seeds only Tigoni, Dutch Robyjn and Kenya Sifa genotypes and the four levels of GA_3 concentrations (0, 10, 20 and 30 mg kg^{-1}) were used in season 1. In season 2 all the potato genotypes (Tigoni, Asante, Dutch Robyjn, Kenya Karibu and Kenya Sifa) and the four levels of GA_3 were used. The factorial combination of treatments of 3×4 (season 1) or 5×4 (season 2) were laid out in a RCBD and replicated four times. Pits of 1 m length × 0.6 m width × 0.6 m depth were dug. One layer of maize stovers was then put at the bottom of the pit. Potato seed tubers were sprayed to draining with the different GA_3 concentrations and allowed to dry for 10 min. Twenty-five tubers per treatment combination were then weighed and put in 0.5×0.4 m nylon woven mesh bags. The nylon woven mesh bags with potato seed tubers were then placed in the pit and covered with a layer of dry maize stovers. A thin layer of soil was put on top of the dry maize stovers to cover the pit. The tubers were removed from the pit after two weeks for determination of number of sprouted tubers, number of sprouts per tuber, sprout length, sprout vigor, presence of PTM and tuber rotting as described in the preceding DLS experiments.

Statistical analysis: Repeated measures analysis was performed on the data using the Genstat statistical program (Genstat, 1995). Mean differences among treatments were separated by Fisher's Least Significant Difference (LSD) procedure at 5% level of significance (Steel and Torrie, 1987).

RESULTS

Sprouting (%): In DLS experiment, tuber sprouting differed significantly ($p \leq 0.05$) among genotypes and GA_3 treatments in both seasons (Fig. 1). Tuber sprouting commenced in all genotypes by the second week of storage for all the treatments except in the controls (0 mg kg^{-1}) of Kenya Sifa, which sprouted after 4 weeks in both seasons. In all genotypes, potato tubers treated with GA_3 showed high levels of sprouting compared to their controls in both seasons. Tuber sprouting increased with increasing levels of GA_3 during the first 4 weeks of storage for most genotypes. However, there were no significant ($p \leq 0.05$) differences in sprouting among GA_3 treated potatoes in all genotypes after four weeks or more of storage in both seasons.

The GA_3 treated potatoes ended the dormancy period after 3 weeks in all genotypes, except Kenya Sifa. GA_3 treated tubers took long in Kenya Sifa by reaching 80% sprouting after 7 weeks. The untreated potato seed tubers (controls) took 5 weeks to sprout in all genotypes, except Kenya Sifa, which took 10 weeks to reach 80% sprouting level.

In the pit experiment, a significant ($p \leq 0.05$) interaction between GA_3 concentration and genotype in sprouting was observed in season 1 (Table 1). In season 2, potato tuber sprouting differed among genotypes and GA_3 treatments (Table 2). All GA_3 treatments had higher numbers of sprouted potato tubers than the control, in both seasons. In all genotypes, except Kenya Sifa, all potato tubers treated with GA_3 had sprouted at two weeks of storage (with ≥ 95% sprouting), Kenya Sifa tubers treated with GA_3 were at less than the 80% sprouting level, the level expected for end of dormancy.

Number of sprouts per tuber: In DLS experiment, the number of sprouts per tuber differed significantly ($p \leq 0.05$) among the genotype X GA_3 treatments in both seasons (Fig. 2). In genotypes Asante, Dutch Robyjn, Kenya Karibu and Kenya Sifa, the number of sprouts per tuber was higher in GA_3 treated tubers than in the controls for up to the 8th week of storage in season 1. There was no difference after the 10th week. Similarly in season 2, the number of sprouts per tuber was higher in GA_3 treated tubers than in controls for up to the 8th week of storage in genotypes Asante, Kenya Karibu and Kenya Sifa. There was no difference after the 10th week. However, in Dutch Robyjn, number of sprouts per tuber of potato seed tubers treated with GA_3 was always higher than those of control throughout the duration of the experiment. The number of sprouts per tuber did not differ among treatments throughout the storage duration in Tigoni. Genotype Kenya Sifa delayed in producing sprouts in the controls; sprouts were only observed after the 6th and the 4th week of storage in seasons 1 and 2, respectively. On average, Dutch Robyjn and Asante had the highest number of sprouts per tuber and more sprouts per tuber were observed in season 2 than in season 1.

In pit experiment, number of sprouts per tuber differed among GA_3 and genotype treatments in season 1 (Table 1). Generally the GA_3 treated potatoes had higher number of sprouts per tuber than the control for all genotypes in season 1. In season 2, the number of sprouts per tuber did not differ with GA_3 treatments (Table 2). In both seasons, the highest number of sprouts per tuber was observed in Dutch Robyjn compared to the other genotypes.

Sprout length: In DLS experiment, sprout length differed significantly ($p \leq 0.05$) among GA_3 treatments and genotypes in both seasons (Fig. 3). Sprout length

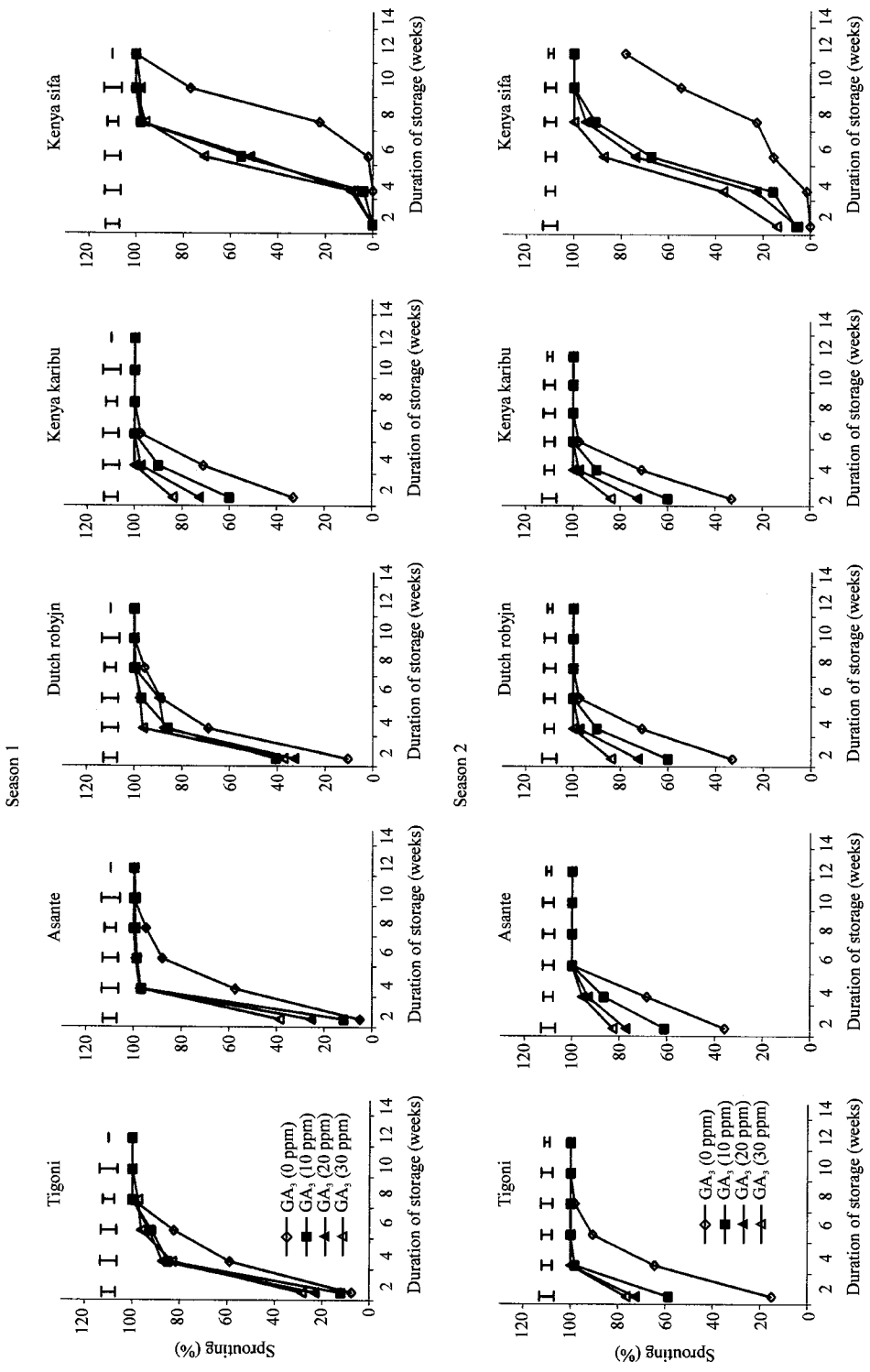

Fig. 1: Effects of gibberellic acid (GA_3) on sprouting (%) of potato seed tubers in diffused light storage conditions stored at 15.73±1.37°C and 77.35±5.64 RH (season 1) and 15.73±1.37°C and 77.35±5.64 RH (season 2). Vertical bars are SE of mean

Table 1: Effect of GA_3 concentration on sprouting, number of sprouts per tuber, sprout length, vigor score and tuber rotting in potato seed tubers stored for 2 weeks in a pit (season 1)

Genotype	GA_3 (mg kg^{-1})	Sprouting (%)	Sprouts per tuber	Sprout length (mm)	Vigor score	Rotting (%)
Tigoni	0	93	2.53	2.10	2.00	0.00
	10	99	4.48	3.60	2.00	0.00
	20	96	3.89	2.51	2.00	0.00
	30	100	7.19	3.30	2.00	0.00
Trend		N	L	N	N	N
Dutch robyjn	0	95	1.38	2.45	2.00	0.00
	10	100	3.60	4.80	2.00	0.25
	20	100	7.02	6.25	1.50	0.00
	30	100	4.10	4.90	1.75	0.00
Trend		N	L, Q	L, Q	N	N
Kenya sifa	0	23.00	1.37	2.10	2.00	0.00
	10	40.22	2.15	3.45	1.75	0.25
	20	46.74	2.15	2.40	1.25	0.50
	30	59.78	4.10	3.75	1.75	0.00
Trend		L	L	N	N	N
$LSD_{(p=0.05)}$: V		4.12*	1.17*	0.69*	0.33N	0.26N
$LSD_{(p=0.05)}$: GA_3		4.76*	1.36*	0.80*	0.38N	0.30N
$LSD_{(p=0.05)}$:V × GA_3		8.24*	2.35*	1.39*	0.65N	0.52N

L, Q, * and N are linear, quadratic and non-significant at $p \leq 0.05$, respectively. GA_3 = gibberellic acid and V = genotype

Table 2: Effect of GA_3 concentration on sprouting, number of sprouts per tuber, sprout length, vigor score, potato tuber moth and tuber rotting in potato seed tubers stored for 2 weeks in a pit (season 2)

Genotype	GA_3 (mg kg^{-1})	Sprouting (%)	Sprouts per tuber	Sprout length (mm)	Vigor score	Potato tuber moth (%)	Rotting (%)
Tigoni	0	95.0	4.05	23.00	1.75	2.56	0.00
	10	100.0	4.60	37.50	2.75	3.33	0.00
	20	100.0	5.55	45.25	1.75	0.83	0.00
	30	98.3	4.25	50.00	1.75	1.67	0.00
Trend		N	N	L, Q	Q	N	N
Asante	0	90.8	5.00	6.00	1.50	3.33	0.83
	10	100.0	7.15	37.00	2.25	2.50	0.00
	20	100.0	7.65	41.75	2.50	0.83	0.00
	30	99.2	8.05	44.25	2.50	0.83	0.83
Trend		Q	N	L, Q	L, Q	N	N
Dutch robyjn	0	97.5	9.10	19.00	1.50	2.50	0.00
	10	100.0	10.50	49.75	1.50	3.33	0.00
	20	100.0	7.70	59.50	2.0	0.83	0.00
	30	100.0	11.15	64.25	2.00	5.00	0.83
Trend		N	N	L, Q	Q	N	N
Kenya karibu	0	70.0	3.70	13.50	1.75	2.50	0.83
	10	100.0	5.45	28.50	2.75	0.83	0.00
	20	100.0	4.55	35.00	3.25	1.67	0.00
	30	100.0	4.15	40.75	3.25	5.00	0.00
Trend		L,Q	N	L, Q	L, Q	N	N
Kenya sifa	0	42.5	3.65	2.50	1.00	2.50	0.00
	10	68.3	2.95	19.50	1.25	4.17	0.00
	20	58.3	5.10	24.25	1.25	3.33	0.00
	30	61.7	3.90	29.50	1.50	3.33	0.83
Trend		Q	N	L, Q	Q	N	N
$LSD_{(p=0.05)}$: V		8.26*	1.48*	5.44*	0.42*	2.16N	0.52N
$LSD_{(p=0.05)}$: GA_3		7.39*	1.32N	4.87*	0.38*	1.93N	0.46N
$LSD_{(p=0.05)}$:V × GA_3		16.52N	2.95N	10.88N	0.85N	4.31N	1.05N

L, Q, * and N are linear, quadratic and non-significant at $p \leq 0.05$, respectively. GA_3 = gibberellic acid and V = genotype

increased in all treatments with increased duration of storage. In season 1, sprout length was not significantly different among the treatments for up to six weeks. An increase in sprout length with increase in GA_3 concentration was observed in Tigoni, Asante and Kenya Karibu genotypes from the 8th week onwards. In Dutch Robyjn, sprout length was only increased with the highest GA_3 treatment. Sprout length was highest in the GA_3 treated tubers compared to the control in Kenya Sifa; there was no statistical difference in sprout length among GA_3 treated tubers for this genotype. In season 2, sprout length was higher in GA_3 treated potatoes compared to the control in all genotypes. Among GA_3 treated potato tubers of all genotypes, except Kenya Sifa, sprout length was lowest in the treatments with 10 mg kg^{-1} compared to 20 and 30 mg kg^{-1}, which were not different in this parameter. In Kenya Sifa, potato seed tubers treated with 20 mg kg^{-1} GA_3 had the longest sprouts.

In pit experiment, there was a linear and quadratic increase in sprout length with increase in GA_3 concentration in genotype Dutch Robyjn only, in season 1 (Table 1). However, in season 2 (Table 2), sprout

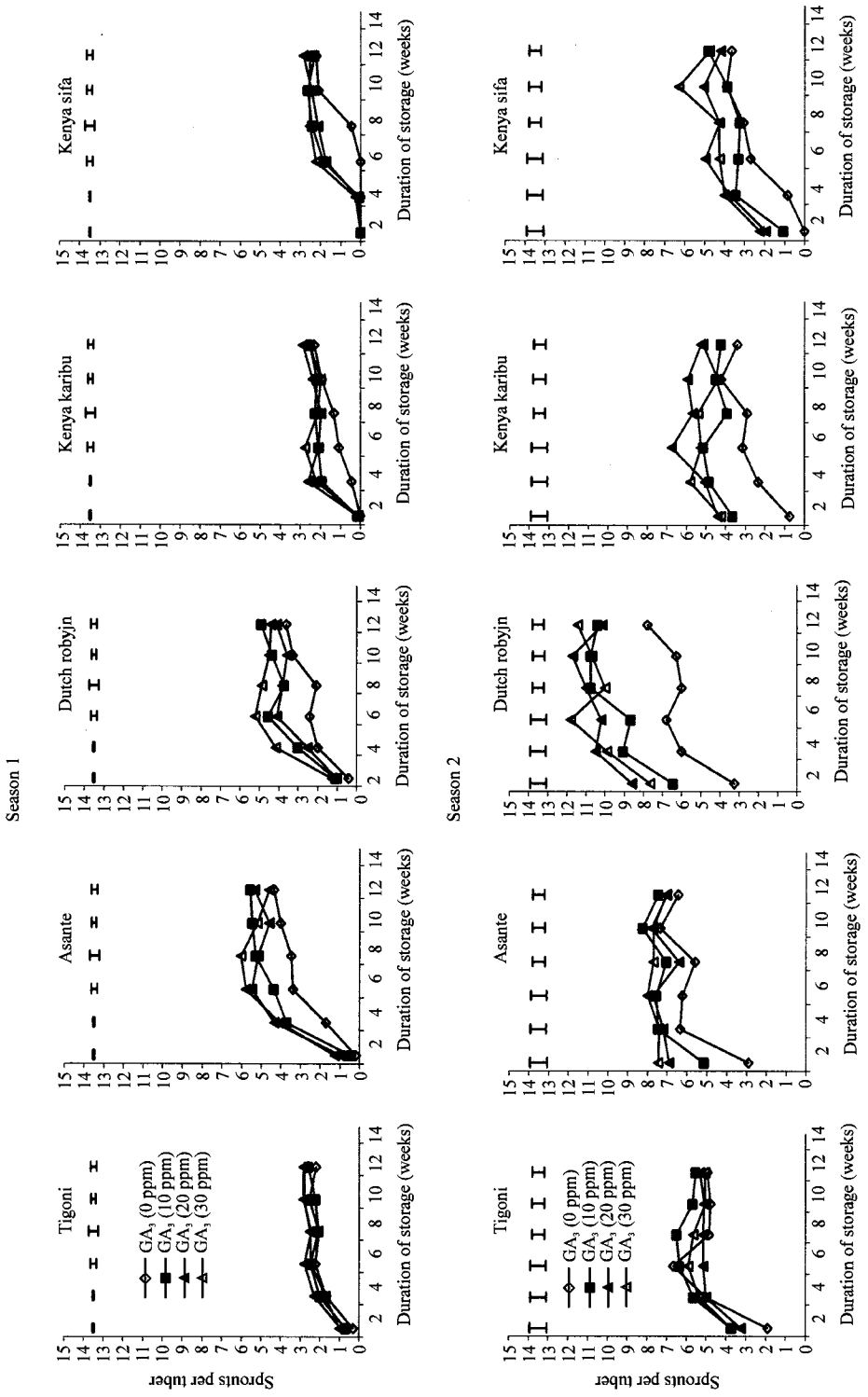

Fig. 2: Effects of gibberellic acid (GA_3) on number of sprouts per tuber of potato seed tubers in diffused light storage conditions stored at 15.73±1.37°C and 77.35±5.64 RH (season 1) and 15.73±1.37°C and 77.35±5.64 RH (season 2). Vertical bars are SE of mean

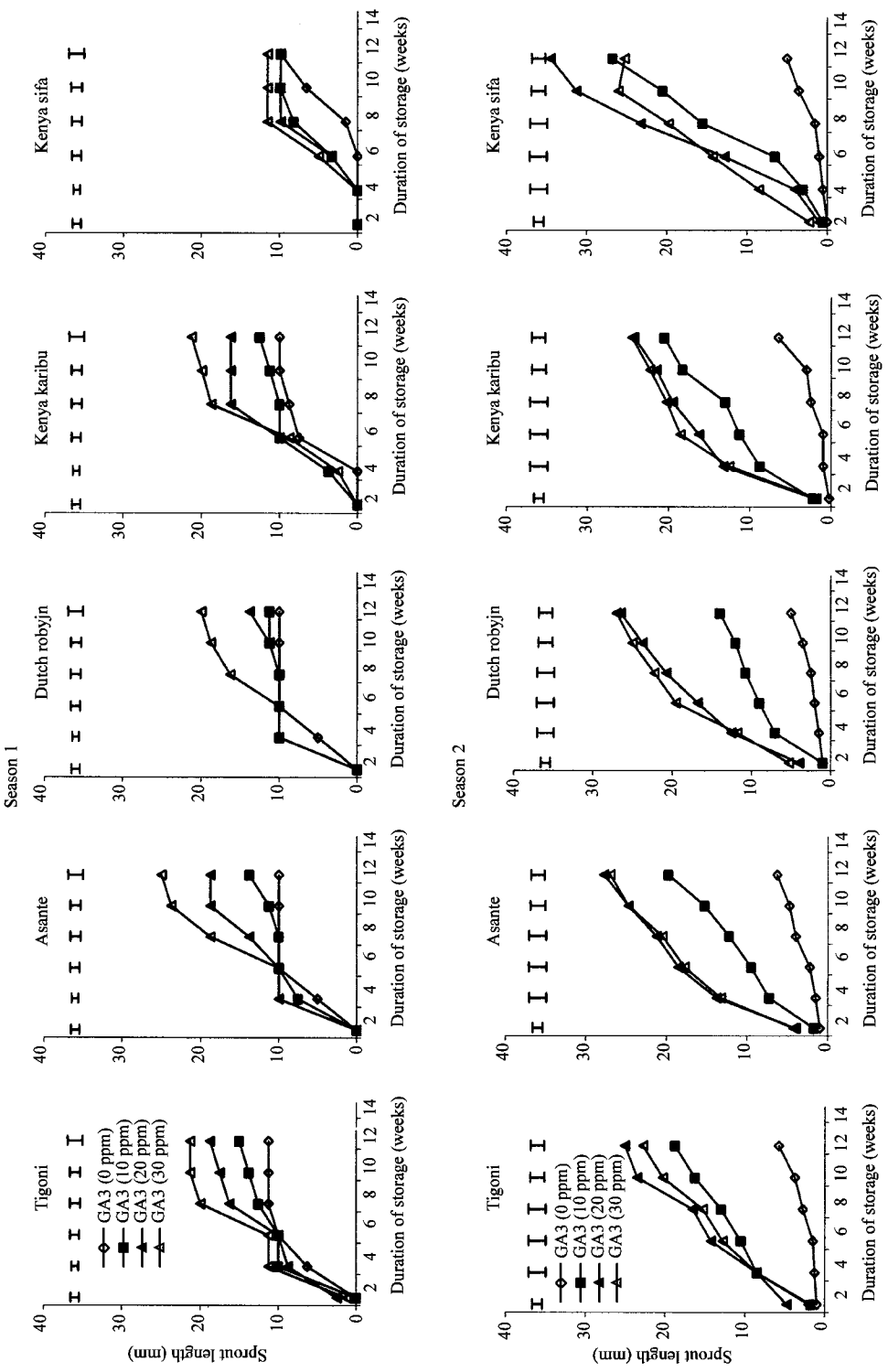

Fig. 3: Effects of gibberellic acid (GA_3) on sprout length of potato seed tubers in diffused light storage conditions stored at 15.73±1.37°C and 77.35±5.64 RH (season 1) and 15.73±1.37°C and 77.35±5.64 RH (season 2). Vertical bars are SE of mean

Table 3: Effects of GA_3 concentration on sprout vigor score of potato tubers during 12 weeks of diffused light storage conditions

		Season 1			Season 2		
		Storage duration (weeks)			Storage duration (weeks)		
Genotype	GA_3 (mg kg^{-1})	4	8	12	4	8	12
Tigoni	0	0.63	1	1.5	1.00	1.00	2.25
	10	1	1	1.88	1.00	2.00	3.25
	20	1	1.38	1.88	1.00	1.75	3.75
	30	0.88	1.5	2	1.00	2.00	3.25
Trend		N	L	N	N	L, Q	L, Q
Asante	0	0.5	1	1.25	1.00	1.00	1.50
	10	0.75	1	1.63	1.00	1.50	2.75
	20	0.88	1.25	1.88	1.75	2.50	4.25
	30	1	1.88	1.88	1.50	2.50	4.00
Trend		N	L, Q	L	L	L	L, Q
Dutch robyjn	0	0.63	1	1	1.00	1.00	1.25
	10	1	1	1.25	1.25	1.75	2.25
	20	1.13	1	1	1.25	2.00	3.00
	30	0.88	1	1.38	1.25	2.00	2.75
Trend		Q	N	N	N	L	L, Q
Kenya karibu	0	0	0.88	1.25	1.00	1.00	1.75
	10	0.38	1	1.88	2.00	3.25	4.50
	20	0.63	1.5	2.13	2.75	4.25	5.00
	30	0.25	1.75	2.5	2.75	4.00	5.00
Trend		Q	L	L	L	L, Q	L, Q
Kenya sifa	0	0.01	0	1.14	0.50	1.00	1.25
	10	0.01	0.62	0.97	1.00	2.00	3.75
	20	0.01	0.79	1.47	1.00	2.25	4.00
	30	0.01	1.12	1.81	1.00	1.75	3.50
Trend		N	L	L	N	L	L, Q
$LSD_{(p=0.05)}$: V		0.18*	0.17*	0.21*	0.30*	0.27*	0.42*
$LSD_{(p=0.05)}$: GA_3		0.16*	0.15*	0.19*	0.27*	0.25*	0.38*
$LSD_{(p=0.05)}$: V × GA_3		0.37N	0.34*	0.42*	0.59*	0.55*	0.84*

L, Q, * and N are linear, quadratic and non-significant at $p \leq 0.05$, respectively. GA_3 = gibberellic acid and V = genotype. Season 1 conditions were at 15.73±1.37°C and 77.35±5.64 RH, while season 2 at 15.73±1.37°C and 77.35±5.64 RH

length increased linearly and quadratically with increase in GA_3 concentration in all genotypes. Dutch Robyjn had the longest sprouts followed by Kenya Karibu, Asante and Dutch Robyjn in descending order. Kenya Sifa had the shortest sprouts.

Vigor score: Under DLS, vigor score differed significantly ($p \leq 0.05$) among treatments in both seasons (Table 3). Generally in all genotypes vigor score was lowest in the control compared to GA_3 treated potato seed tubers. By the 4th week of season 1, there was a quadratic increase of vigor score with increase in GA_3 concentration in only genotypes Dutch Robyjn and Kenya Karibu. Vigor score increased to a maximum at 20 mg kg^{-1} then decreased with 30 mg kg^{-1} GA_3 treatment in these genotypes. A linear increase in vigor score with increase in GA_3 concentration was observed in the seed potatoes of all genotypes, except Tigoni and Dutch Robyjn, during the 12th week of storage. In season 2, a linear increase in vigor score with increase in GA_3 concentration was observed in Asante and Kenya Karibu. By the 12th week, all potato seed tubers showed a linear and quadratic increase in vigor score with increase in GA_3 concentration. Vigor score of the potato seed tubers increased with increase in GA_3 concentration up to 20 mg kg^{-1} then leveled off. Vigor score was lowest in Kenya Sifa compared to the other genotypes in both seasons. Kenya Karibu had the highest vigor score on the 12th week of observation in both seasons.

In pit experiment, vigor score was not affected with treatments in season 1 (Table 1). In season 2 (Table 2), vigor score increased either linearly or quadratically with increase in GA_3 concentration in all genotypes. Kenya Karibu and Asante had higher vigor scores than the other genotypes while Kenya Sifa had the lowest vigor score.

Potato tuber moth (PTM) incidence (%): In season 1, low PTM incidences were observed after 8 weeks of storage (Table 4). By the 8th week, all genotypes, except Dutch Robyjn, showed PTM incidences. Significant ($p \leq 0.05$) differences in PTM incidence were observed among genotypes in the 12th week of storage (Table 4). Genotypes Kenya Sifa, Asante and Kenya Karibu had higher PTM incidences than Tigoni and Dutch Robyjn. In season 2, incidences of PTM were recorded earlier than in season 1 in all genotypes. GA_3 treatments had no effect on PTM of all cutivars except Tigoni and Kenya Karibu. In Tigoni and Kenya Karibu, GA_3 treatment led to a decrease in PTM incidences.

Table 4: Effects of GA_3 concentration on potato tuber moth and rotting of potato seed tubers during 12 weeks of diffused light storage conditions (season 1 and 2)

		Potato tuber moth incidence (%)						Rotting (%)		
		Season 1			Season 2			Season 2		
		Storage duration (weeks)			Storage duration (weeks)			Storage duration (weeks)		
Genotype	GA_3 (mg kg^{-1})	4	8	12	4	8	12	4	8	12
Tigoni	0	0.0	0.0	4.5	4.9	23.1	40.9	2.5	2.6	6.1
	10	0.0	0.0	10.0	5.8	11.7	22.7	1.7	1.7	6.2
	20	0.0	0.6	6.3	2.5	5.1	16.3	2.5	5.1	7.8
	30	0.0	0.0	21.9	5.0	10.1	29.6	4.2	5.9	11.5
Trend		N	N	N	N	Q	Q	N	L	L
Asante	0	0.0	4.4	48.9	4.9	12.0	21.8	0.8	0.9	4.3
	10	0.0	0.0	23.3	2.5	9.8	23.9	1.7	4.3	5.2
	20	0.0	0.0	34.8	3.3	13.2	44.8	1.7	1.7	3.6
	30	0.0	0.0	26.2	1.7	13.5	36.4	5.0	5.2	8.9
Trend		N	N	N	N	N	N	N	N	N
Dutch robyjn	0	0.0	0.0	23.6	6.6	13.6	21.4	0.0	2.5	3.4
	10	0.0	0.0	13.7	1.7	15.2	26.1	1.7	3.4	3.4
	20	0.0	0.0	17.1	0.9	10.9	33.8	1.7	1.7	3.3
	30	0.0	0.0	13.0	3.4	16.6	35.2	4.2	4.2	6.7
Trend		N	N	N	N	N	N	N	N	N
Kenya karibu	0	0.0	0.0	26.9	4.9	23.3	29.6	0.8	0.8	1.7
	10	0.0	0.6	21.6	9.1	14.6	25.2	1.7	1.7	3.4
	20	0.0	0.6	50.8	0.0	5.1	19.8	4.2	4.2	5.1
	30	0.0	0.0	25.2	0.0	3.4	25.6	4.2	5.1	8.5
Trend		N	N	N	L	L	L	N	L	L
Kenya sifa	0	0.0	0.0	34.5	2.5	11.0	26.2	0.0	0.0	3.5
	10	0.0	0.0	35.5	0.0	7.6	19.6	0.0	0.0	1.8
	20	0.0	2.0	23.4	3.5	15.5	37.8	2.7	4.8	7.6
	30	0.0	0.0	51.4	2.5	13.4	35.9	5.9	7.6	8.4
Trend		N	N	N	N	N	N	N	L	L
$LSD_{(p=0.05)}$: V			1.5N	14.5*	1.1*	2.8N	3.7	1.6N	1.9N	2.6N
$LSD_{(p=0.05)}$: GA_3			1.48N	12.9N	0.9*	2.5*	3.3*	1.4N	1.8*	2.3*
$LSD_{(p=0.05)}$: V × GA_3			3.1N	28.9N	2.2*	5.6*	7.4*	3.2N	3.9N	5.2N

L, Q, * and N are linear, quadratic and non-significant at $p \leq 0.05$, respectively. GA_3 = gibberellic acid and V = genotype. Season 1 conditions were at 15.73±1.37°C and 77.35±5.64 RH, while season 2 at 15.73±1.37°C and 77.35±5.64 RH

In pit experiments, no incidences of PTM were recorded in season 1 (data not shown). In season 2 (Table 2) a few incidences of PTM of up to 5% were recorded. Potato tuber moth did not differ among treatments.

Tuber rotting (%): In DLS, no incidences of tuber rotting were observed in all treatments in season 1 (data not shown). In season 2 in the 8th and 12th week of storage, a linear increase in rotting with increase in GA_3 concentration was observed in potato seed tubers of genotypes Tigoni, Kenya Karibu and Kenya Sifa; most rotting occurred with 30 mg kg^{-1} (Table 4). The fungi *Phytophthora infestans* was observed from tuber areas with wet rot and tissue browning. Fungi of *Fusarium* spp were observed from tuber areas that were dry shrunken and shriveled. Presence of either dry or soft rots was not affected by treatments.

In pit experiment, only a few incidences of tuber rotting (≤0.9%) were observed in both seasons (Table 1 and 2). There was no treatment effect on tuber rotting.

DISCUSSIONS AND CONCLUSIONS

Use of gibberellins to break dormancy and promote sprouting in potato seed tubers has been proposed (Suttle, 1996; Carrera *et al.*, 2000). In this study application of GA_3 led to early sprouting, in the 2nd week, while dormancy ended after three weeks of storage for potato seed tubers stored in DLS conditions for most genotypes. The results are in agreement with the findings of other researchers (Smith and Rappaport, 1965; Rehman *et al.*, 2001; Demo *et al.*, 2002). Smith and Rappaport (1965) had shown that increasing the concentration of GA_3 resulted in a decrease in number of days to 50% sprouting. The results of this study also agree with the findings of Rehman *et al.* (2001) who showed that a reduction in number of days required for 50% sprouting of potato seed minitubers occurred following application gibberellic acid under laboratory conditions. The results, therefore, suggest that GA_3 should be adopted for termination of dormancy and promotion of sprouting of potato seed tubers stored in DLS conditions.

Dormancy termination and sprouting occurred much earlier at the end of the 2nd week of storage in pit than in DLS. Faster sprouting under the pit is believed to occur due to build up of heat (Bencini, 1991) and low light penetration. The high temperatures cause an increase in growth rate while the low light intensities lead to etiolation. Pit temperature in this study rose to 23±5°C compared to 15.4°C in DLS and this may have led to the faster sprouting of the seed potatoes in all genotypes.

The results further showed that increase in GA_3 concentration led to increases in number of sprouts per tuber, sprout length and sprout vigor score in DLS. This agrees with the observations of Keller and Berces (1964) and Demo (2002) who reported that at high concentrations of GA_3 more sprouts were formed. Keller and Berces (1964) further suggested that the many sprouts formed eventually lead to increased potato yields. Lovato *et al.* (1994) found that due to increased potato seed tuber sprouting following GA_3 treatment, the yield obtained from plants treated seed was higher than that from plants grown from untreated seed by 44%. The pit results of season 1 (Table 1) also showed that increase in number of sprouts per tuber following GA_3 application occurred. This suggests that GA_3 application will break the apical dominance that is common to pit sprouted potato seed tubers. However, whether the increased sprouting following GA_3 application would result in increased yields was not determined in this study.

Although increases in sprouting, number of sprouts per tuber and vigor score occurred with increase in GA_3 concentration, there were no significant differences among the GA_3 treatment levels. It was further shown that there was a quadratic increase of vigor score with increase in GA_3 concentration to a maximum at 20 mg kg^{-1} then leveled off. These observations are in agreement with findings of Van Ittersum (1992) and Lovato *et al.* (1994) who showed only a small concentration of GA_3 could be used to break dormancy and promote sprouting of potato tubers. Similarly, Demo (2002) found out that use of GA_3 doses of less than 40 mg kg^{-1} gave sprouts with good vigor as opposed to, fair to poor vigor for tubers treated with ≥ 50 mg kg^{-1} in DLS. It thus shows that of only small amounts of GA_3 are needed for promotion of sprouting and good quality of potato tubers.

Differences among genotypes in response to GA_3 application were evident. In most cases potato seed tubers of genotype Kenya Sifa, responded the least to GA_3 application. It delayed in breaking dormancy, had the lowest sprouting (%), least number of sprouts per tuber and had the lowest vigor scores. The differences to responses to external GA_3 among genotypes suggest that there are other internal factors, which are responsible for commencement of sprouting. Internal giberrellic acid (GA) and other growth regulators such as abscissic acid and cytokinins have been suggested to terminate dormancy and promote sprouting of potato tubers (Carrera *et al.*, 2000). Carrera *et al.* (2000) showed that ectopic expression of the gene coding for the GA biosynthetic enzyme GA sub 20-oxidase resulted in elevated potato tuber GA content and premature sprouting. Genotypic differences could, therefore be attributed to inherent factors such as amounts of growth regulators present in each genotype. It is possible that the quantities of GA_3 present in genotypes with long dormancy durations may be too low and hence, to support subsequent sprout growth external supplementation is needed. This study did not establish whether inherent GA levels were different among genotypes. Whether the differences in internal GA_3 among plant genotypes may lead to differences in sprouting was also not determined in this study.

Pests and diseases are some of the major constraints to increased potato production amongst small-scale farmers (Hide and Lapwood, 1992; Kabira, 2001). In this study, in DLS, PTM was only affected with treatments in season 2 where increase in GA_3 concentration led to decrease in PTM incidences in Tigoni and Kenya Karibu genotypes. To the best of our knowledge, there is no work reported relating to the effects of GA_3 application on PTM. Hence, there is need to determine why a decrease in PTM may occur following GA_3 application in some potato genotypes.

The results further showed that only a few incidences of PTM of up to 5% were recorded in the potato seed tuber after 8 weeks in storage, in season 2. It is possible that PTM manifestation is time dependent; it appears when seed tubers are placed longer in storage. Hence sprouting tubers for less than two weeks for both DLS and the pit will not lead to tubers of poor quality.

One problem that affects potato seed tubers during sprouting is that they may be of poor quality due to rotting (Hunt, 1982; Bencini, 1991). In this study high rotting was observed in the 30 mg kg^{-1} GA_3 treatment in season 2 in potato seed tubers of most genotypes. These observations agree with the findings of Sungyeul *et al.* (1996) and Demo (2002) who observed rotting in potato seed tubers treated with ≥ 40 mg kg^{-1} GA_3 concentration. On further analysis fungi *Phytophthora infestans* and *Fusarium* sp. were identified to infect the potato seed tubers. The results, therefore, suggests that use of ≥30 mg kg^{-1} GA_3 in DLS conditions may be discouraged since it will lead to rotting of sprouting potato seed tubers.

Increasing GA_3 concentrations led to increase in sprouting (%), number of sprouts per tuber, sprout length and vigor score in DLS. Under pit conditions, except for

genotype Kenya Sifa, GA_3 had no effect on sprouting and sprout vigor score; however, it increased number of sprouts per tuber and sprout length. GA_3 treatment reduced sprouting dormancy to three and seven weeks for all other genotypes and Kenya Sifa, respectively. It is suggested that lower levels of GA_3 of up to 20 mg kg^{-1} should be adopted for promotion of sprouting in potato seed tubers.

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