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Ground cover, photosynthetic rate and tuber yield of potato (*Solanum tuberosum* L.) crops from seed tubers with different physiological age modified by foliar applications of plant growth regulators*

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Summary

The modifying effects of applying the plant growth regulators (PGRs) benzylaminopurine (BAP), gibberellic acid (GA_3) and BAP+GA_3 on physiological age were studied. Two experiments with two cultivars, differing in rate of physiological ageing (medium-early Pampeana, medium-late Huinkul) and two storage systems were performed during 1988/89 and 1989/90 in two different potato areas of Argentina.

In both seasons seed tubers stored in heaps reached an advanced physiological age at planting, compared with tubers from the cold store. Seed tubers of cv. Pampeana were older than those of Huinkul. Compared with control crops, those sprayed with BAP maintained ground cover and photosynthesis for longer, and those sprayed with GA_3 for a shorter period. Consequently tuber yield was decreased by GA_3 in 1988/89, but in 1989/90 all crops treated with PGRs outyielded the control. BAP could overcome effects of advanced physiological age on crop senescence and tuber yield.

Introduction

Health status, size and especially physiological age of seed tubers are crucial in modern potato production (van der Zaag, 1986). During the last 25 years much attention was paid to the effects of seed crop and storage environment on the physiological age of seed tubers (van der Zaag, 1973; Claver, 1975; Perennec & Madec, 1980; Caldiz et al., 1985; van der Zaag & van Loon, 1987; Caldiz, 1991). It was demonstrated by O' Brien et al. (1983) that early-potato growers could maximize their yield by planting physiologically old seed for the earliest harvest and progressively younger seed for later harvests. Many efforts have been carried out to provide potato growers with seed of suitable age according to cropping purpose. Seed age can be manipulated by production in special areas and seasons, by crop husbandry and storage management, and also by applying plant growth regulators (PGRs) either to the seed crop or the seed tubers (Bodlaender & van de Waart, 1989;

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Caldiz et al., 1989; van Ittersum et al., 1993).

PGRs are mainly used to break dormancy for rapid virus testing or in vitro production, and they are not commonly used in field crops (Bruinsma, 1982). However, CCC, GA, 2-4 D, B9 (Alar) and other PGRs have proved to be effective for different purposes in seed potato production (Marinus & Bodlaender, 1978; Bodlaender & van de Waart, 1989; van Ittersum et al., 1993; Mikitzel, 1995; Caldiz, 1996; Caldiz et al., 1996), while Iritani (1983) stated that the use of PGRs could be an important tool in potato production.

In the southeast area of the Province of Buenos Aires, Argentina, seed potatoes from cultivars with a long absolute dormant period are stored in heaps in the field from harvesting to planting. Hence, the physiological state of the tubers at planting depends on the environmental conditions experienced during the storage period which are not always suitable and tubers may reach the new planting season with inadequate physiological age (Caldiz et al., 1984; Escande et al., 1985, 1986). Cold storage facilities may not be available for all the seed that is being produced and cultivars sensitive to physiological ageing also reach the new planting season with too advanced physiological age; hence crops develop rapidly and yields are relatively low, given the long available growing period (Caldiz, 1991).

Therefore two experiments with two cultivars, differing in their rate of physiological ageing, and two storage systems were performed. The possibilities of modifying the effects of physiological age of the seed on the crop grown from it by PGRs applications were studied. Analysis focussed on ground cover, photosynthetic rate and tuber yield.

Materials and methods

Field experiments were carried out during 1988/89 at Lobería (38° 10' S) and in 1989/90 at La Plata (34° 54' S) both in the Province of Buenos Aires, Argentina, using certified seed tubers of cvs Pampeana INTA (medium-early) and Huinkul MAG (medium-late).

In both seasons seed tubers were harvested in the southeast of the Province of Buenos Aires during April–May and stored in: (a) a cold store at 2–4 °C (C) and (b) heaps in the field (H), until 4 weeks before planting. Seed tubers from both storage systems were then pre-sprouted under natural diffuse day-light. In 1988/89 the tubers were planted on 21st October 1988, with 0.75 m between rows and 0.25 m between plants within the row using a four-row planting machine. In 1989/90 the tubers were planted by hand on 4th October 1989 with the same plant arrangement. In both seasons, a sample of 50 tubers per treatment (2 cultivars × 2 storage systems) was taken at planting time to determine physiological age by assessing the length of the incubation period, following procedures described by Caldíz et al. (1984).

At the time of tuber initiation, foliar applications were made of: (a) BAP, 50 mg l^{-1}; (b) GA_3, 50 mg l^{-1} and (c) BAP+GA_3, 50 mg l^{-1}, with four replicates on rows of 6.25 m length of each treatment in a factorial design (2 cultivars × 2 storage systems × 4 chemical treatments). Untreated controls were included in the design. PGRs were applied with an ultra low volume spraying machine and the total volume of water applied to each plot was equivalent to 35 l ha^{-1}. Tween 80, 0.5% was added and the control treatment was sprayed with water.

For each plot ground cover was periodically measured (5 observations per replicate) with a rectangular frame described by CIP (1986), and the photosynthetic rate (Phrate) of the 5th leaf from the top was assessed on 5 plants per replicate using an infrared gas analyzer (Licor LI 6200, Lincoln, Nebraska, USA), as described by Caldiz & Beltrano (1992). Pests and diseases were controlled according to local practice and in both years 350 mm water were applied by sprinkler irrigation. Meteorological data for each year are shown in Fig. 1. Two weeks after natural haulm death each plot was harvested after discarding 0.5 m from each border, and tuber number and fresh yield in the fractions <80 g; 80–400 g and >400 g were determined. The statgraphics v. 2.0 computer program was used to perform an analysis of variance and averages were compared by Tukey's test (P<0.05).

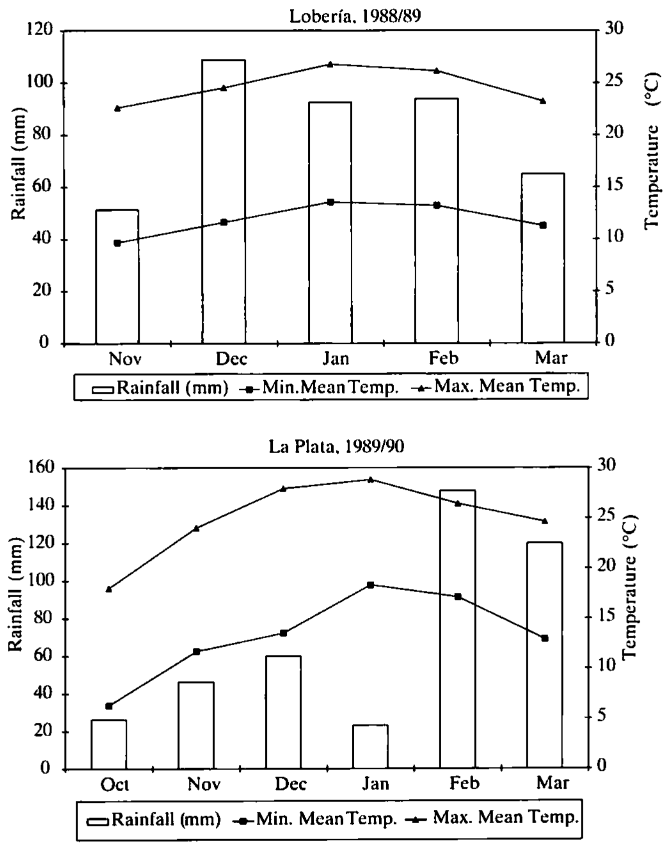

Fig. 1. Meteorological data from Lobería, 1988/89 and La Plata, 1989/90.

Table 1. Physiological age of seed tubers (days) of two cultivars at planting in 1988/89 and 1989/90.

Storage treatments	Pampeana INTA	Huinkul M.A.G.
1988/1989		
H	50 b	65 b
C	65 a	86 a
1989/1990		
H	41 b	62 b
C	61 a	82 a

H, storage in heaps, C, storage in cold store. Within each cultivar and year, means followed by the same letter do not differ (P < 0.05).

Table 2. Ground cover (%) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1988/89.

Treatments	Days after planting					
	47	54	62	73	87	103
Pampeana H						
Control	43.9 a	51.7 a	63.1 a	63.3 a	63.3 a	-
BAP		50.0 a	57.9 ab	60.8 ab	64.5 a	-
GA_3		49.3 a	58.1 ab	56.0 b	62.6 a	-
BAP + GA_3		47.5 a	54.3 b	55.4 b	59.3 a	-
Pampeana C						
Control	39.1 b	54.7 a	58.9 a	59.3 a	65.3 a	-
BAP		53.3 ab	58.6 a	61.1 a	60.0 a	-
GA_3		51.3 ab	63.1 a	61.0 a	61.3 a	-
BAP + GA_3		48.1 b	57.9 a	57.3 a	55.8 a	-
Huinkul H						
Control	35.8 b	43.3 b	55.1 a	54.2 a	55.1 a	11.9 a
BAP		42.1 b	55.3 a	56.0 a	58.7 a	13.2 a
GA_3		47.0 a	60.3 a	57.3 a	56.2 a	12.8 a
BAP + GA_3		43.1 b	53.8 a	53.5 a	55.7 a	8.3 b
Huinkul C						
Control	30.3 c	38.8 a	46.0 a	50.8 a	57.8 a	10.5 a
BAP		40.2 a	44.1 a	47.3 a	50.8 b	11.4 a
GA_3		40.2 a	45.3 a	48.0 a	51.5 ab	10.7 a
BAP + GA_3		37.5 a	45.3 a	46.2 a	52.6 ab	8.2 a

Within each cultivar, storage system and column and for the first date, means followed by the same letter do not differ (P < 0.05).

Results and discussion

Physiological age at planting
At planting in both seasons seed tubers of both cultivars stored in heaps in the field were older than those tubers held in the cold store. Seed tubers of Pampeana INTA, a cultivar ageing more rapidly than Huinkul (Caldiz, 1994), had a shorter incubation period and were older than those of Huinkul, stored either in heaps or in the cold store (Table 1).

Ground cover
1988/89 experiment. At the time of PGR application (47 days after planting, DAP) ground cover was largest in cv. Pampeana (H) treatments (Table 2). This agrees with the advanced physiological age of the seed tubers at planting and with the known behaviour that physiologically advanced seed promotes early canopy development (Perennec & Madec, 1980; O'Brien et al., 1983; Caldiz, 1991). Following this pattern, cv. Huinkul (C) was the treatment with the smallest ground cover 47 DAP (Table 2).

Table 3. Ground cover (%) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1989/90.

Treatments	Days after planting									
	33	40	47	54	61	68	75	83	87	97
Pampeana H										
Control	21 a	33 a	47 a	73 a	82 a	92 a	92 a	75 b	69 b	26 b
BAP	18 a	35 a	47 a	71 a	82 a	96 a	94 a	84 a	79 a	35 a
GA_3	16 a	31 a	45 a	64 b	81 a	91 a	95 a	79 ab	73 ab	29 b
BAP + GA_3	17 a	33 a	44 a	73 a	79 a	93 a	95 a	79 ab	73 ab	28 b
Pampeana C										
Control	18 a	31 a	47 a	77 a	82 a	98 a	90 a	73 c	66 b	32 b
BAP	17 a	33 a	48 a	76 ab	82 a	96 a	94 a	83 a	77 a	38 a
GA_3	13 b	30 a	45 a	68 c	78 a	95 a	93 a	78 ab	71 ab	30 b
BAP + GA_3	20 a	33 a	49 a	72 bc	81 a	96 a	91 a	75 bc	68 b	28 b
Huinkul H										
Control	6 a	17 ab	26 a	54 a	77 a	95 a	87 a	71 b	64 c	35 b
BAP	6 a	18 a	27 a	53 ab	77 a	96 a	87 a	87 a	81 a	45 a
GA_3	4 a	15 b	23 a	47 b	71 a	91 a	88 a	78 b	72 b	35 b
BAP + GA_3	7 a	18 a	26 a	55 a	72 a	96 a	90 a	76 b	70 bc	36 b
Huinkul C										
Control	8 ab	21 ab	33 ab	60 a	83 a	96 a	91 a	77 b	71 b	36 b
BAP	11 a	23 ab	36 a	59 a	81 a	96 a	94 a	88 a	82 a	47 a
GA_3	6 b	20 b	32 b	60 a	76 a	97 a	93 a	81 b	76 b	36 b
BAP + GA_3	8 ab	24 a	35 ab	65 a	83 a	97 a	93 a	80 b	73 b	42 ab

Within each cultivar, storage system and column, means followed by the same letter do not differ ($P < 0.05$).

From 62 DAP onward, neither BAP or GA_3 alone or combined increased ground cover of either cultivar compared with the control. The results obtained with GA_3 application contrast with those of Bodlaender & van de Waart (1989) and its application caused a temporary yellow discoloration of the leaves. As expected, in the medium-late cv. Huinkul natural haulm death occurred later than in cv. Pampeana (Table 2).

1989/90 experiment. In cv. Pampeana (H) and (C) and cv. Huinkul (H) and (C), BAP maintained a larger ground cover from 83 to 97 DAP, the end of crop growth (Table 3), while BAP+GA_3 only modified ground cover significantly in one case over the entire growing period (Table 3). In both cultivars the pattern of ground cover normal for physiologically old seed was modified by foliar applications of BAP, resulting in larger ground cover than in the control at the end of the season (Table 3).

Photosynthetic rate

1988/89 experiment. Mean Phrate was similar to previous values obtained by Caldiz &

Table 4. Photosynthetic rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1988/89.

Treatments	Days after planting				
	47	62	73	87	103
Pampeana H					
Control	17.1 b	14.8 b	11.1 b	11.5 c	-
BAP		22.8 a	15.4 a	16.1 a	-
GA_3		12.3 b	12.5 b	15.4 ab	-
BAP + GA_3		15.5 b	12.7 b	14.1 b	-
Pampeana C					
Control	23.1 a	20.2 b	17.2 b	15.5 b	-
BAP		29.1 a	21.8 a	16.6 a	-
GA_3		23.8 b	17.8 b	13.1 bc	-
BAP + GA_3		22.4 b	19.8 ab	12.2 c	-
Huinkul H					
Control	17.4 b	14.2 c	23.5 a	17.1 ab	4.5 b
BAP		24.4 a	21.6 ab	18.2 a	9.0 a
GA_3		18.8 b	21.2 ab	15.8 b	6.6 ab
BAP + GA_3		20.4 b	16.9 b	10.9 c	9.4 a
Huinkul C					
Control	18.0 b	22.9 a	18.6 a	15.2 ab	4.4 c
BAP		21.3 a	19.0 a	18.6 a	12.8 a
GA_3		14.4 c	18.8 a	16.0 ab	8.2 b
BAP + GA_3		17.4 bc	17.1 a	14.6 b	0.3 d

Within each cultivar, storage system and column and for the first date, means followed by the same letter do not differ ($P < 0.05$).

Beltrano (1992) with the same cultivars. After PGR application the Phrate was higher in Pampeana (C) than in other treatments and BAP increased Phrate in Pampeana (H) and (C) up to the end of crop growth (Table 4). In Huinkul (H), an increase in Phrate was observed 62 DAP following BAP application, while in Huinkul (H) and (C) BAP also increased the Phrate at 103 DAP. Occasionally also GA_3 or BAP+GA_3 affected photosynthesis.

1989/90 experiment. During this season BAP application increased Phrate (Table 5), from 78 to 99 DAP in cv. Pampeana (H) and (C), while in cv. Huinkul (H) and (C) it was maintained at a higher level until 106 DAP. No major differences were found between other treatments, except for GA_3 applied on Pampeana (C) and Huinkul (C), which decreased Phrate during the period 78–92 DAP. This could be associated with temporary yellowing of the leaves.

BAP promoted an increase in ground cover and Phrate in both seasons and cultivars. In cv. Pampeana this effect was noticed throughout crop growth in both seasons, whereas in cv. Huinkul this was true in 1989/90 and at the end of the season

Table 5. Photosynthetic rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1989/90.

Treatments	Days after planting						
	57	71	78	85	92	99	106
Pampeana H							
Control	25 c	20 a	12 d	17 b	10 b	–	–
BAP		22 a	17 b	24 a	14 a	9 a	–
GA_3		14 c	15 c	15 c	8 b	5 b	–
BAP + GA_3		18 b	20 a	15 c	9 b	6 b	–
Pampeana C							
Control	29 ab	19 b	18 b	12 c	9 b	4 c	–
BAP		24 a	21 a	20 a	10 a	9 a	–
GA_3		17 bc	15 c	7 d	8 c	7 b	–
BAP + GA_3		18 b	17 b	14 b	9 b	7 b	–
Huinkul H							
Control	30 a	20 a	15 b	17 b	12 b	8 b	–
BAP		20 a	20 a	19 a	16 a	10 a	4 a
GA_3		16 c	13 c	14 c	11 b	11 a	–
BAP + GA_3		18 b	13 c	15 c	9 c	10 a	2 b
Huinkul C							
Control	28 b	19 a	16 b	17 b	11 b	6 b	–
BAP		20 a	19 a	19 a	14 a	11 a	4 a
GA_3		19 a	11 d	14 c	9 c	7 b	–
BAP + GA_3		16 b	13 c	16 b	12 b	6 b	1 b

Within each cultivar, storage system and column and for the first date, means followed by the same letter do not differ ($P < 0.05$).

in 1988/89. Such effects modified the normal pattern of physiological ageing for these parameters.

Tuber number and tuber yield

1988/89 experiment. BAP+GA_3 increased total tuber number in Pampeana (H), Huinkul (H) and (C), while BAP and GA_3 increased it only in Huinkul (C). GA_3 effects are in agreement with those reported by Bodlaender & van de Waart (1989), Struik et al. (1989) and Caldiz (1996), but BAP treatments did not increase tuber number as effectively as shown by Caldiz (1996) in other cultivars. Consequently the number of tubers in the fraction <80 g was increased and the number and yield of tubers in the fraction 80–400 g were decreased when GA_3 or BAP+GA_3 was applied in Pampeana (H) and (C). In Huinkul BAP+GA_3 also increased tuber number in the fraction <80 g (Table 6).

With regard to tuber yield, as observed by Struik et al. (1989) foliar-applied GA_3 decreased total yield in Pampeana (H) and (C) and Huinkul (H). However, when

Table 6. Tuber number and tuber yield of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP + GA_3 in 1988/1989.

Treatments	Tuber number m^{-2}			Tuber yield (t ha^{-1})		
	< 80 g	80-400 g	Total	< 80 g	80-400 g	Total
Pampeana H						
Control	28.40 c	28.48 a	56.48 b	14.30 ab	38.00 a	52.30 a
BAP	26.23 c	26.84 a	53.07 b	11.00 b	38.80 a	49.80 ab
GA_3	39.48 b	21.13 c	60.61 ab	12.30 ab	24.00 b	36.30 c
BAP + GA_3	47.36 a	23.81 b	71.17 a	16.60 a	23.30 b	39.90 bc
Pampeana C						
Control	30.56 b	25.06 b	55.62 a	14.00 b	31.30 b	45.30 a
BAP	31.49 b	28.31 a	59.80 a	13.00 b	37.30 a	50.30 a
GA_3	41.90 a	20.10 c	62.00 a	15.30 b	24.80 c	40.10 b
BAP + GA_3	43.98 a	16.75 d	60.73 a	20.70 a	18.70 d	39.40 b
Huinkul H						
Control	11.60 c	22.60 a	34.20 b	7.00 b	26.60 bc	33.00 b
BAP	20.74 a	16.71 b	37.45 ab	7.20 b	31.20 a	38.40 a
GA_3	15.24 b	21.80 a	37.04 ab	5.50 c	23.70 c	29.20 c
BAP + GA_3	21.88 a	23.20 a	45.08 a	7.80 a	30.30 ab	38.10 ab
Huinkul C						
Control	15.12 b	17.40 a	32.52 b	5.30 b	21.00 a	26.30 a
BAP	20.71 ab	21.36 a	42.07 a	9.60 a	25.60 a	35.20 a
GA_3	21.49 a	20.77 a	42.26 a	9.00 a	24.10 a	33.10 a
BAP + GA_3	24.61 a	18.63 a	43.24 a	8.70 a	20.30 a	29.00 a

Within each cultivar, storage system and column, means followed by the same letter do not differ ($P < 0.05$).

applied in combination with BAP total yield was similar to the control in Huinkul (H) and (C). BAP increased total tuber yield only in Huinkul (H) (Table 6).

1989/90 experiment. PGR application increased tuber numbers in the fraction <80 g in all treatments (Table 7). However, when the crops originated from seed tubers stored in (C), no effects of PGRs were recorded in the fraction 80–400 g. With total tuber number and total yield, PGRs application always outyielded the control (Table 7).

Total tuber yields differed between years but PGR application increased it significantly in five of eight comparisons when BAP was applied. The beneficial effects of BAP on ground cover and Phrate were probably responsible for the increments in tuber yield. However, Dwelle & Hurley (1984) did not find beneficial effects on yield of cytokinins applied to cv. Russet Burbank.

Although effects were not always consistent between years, it was shown that BAP can reverse the effects of advanced physiological age on crop growth, senescence and yield (Table 6 and 7). It might be possible to obtain larger effects if differences in

Table 7. Tuber number and tuber yield of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3, and BAP + GA_3 in 1989/90.

Treatments	Tuber number m^{-2}			Tuber yield ($t\ ha^{-1}$)		
	< 80 g	80-400 g	Total	< 80 g	80-400 g	Total
Pampeana H						
Control	45.90 b	13.03 a	58.93 b	18.60 b	6.30 a	24.90 b
BAP	67.30 a	2.86 b	70.16 a	29.50 a	6.10 a	35.60 a
GA_3	64.40 a	2.44 b	66.84 a	27.20 a	3.60 b	30.80 a
BAP + GA_3	67.10 a	4.12 b	71.12 a	28.00 a	4.00 ab	32.00 a
Pampeana C						
Control	43.83 c	1.75 a	45.58 c	25.90 b	2.90 b	28.80 b
BAP	62.10 b	3.77 a	65.87 b	31.70 ab	6.70 a	38.40 a
GA_3	67.94 b	3.13 a	71.07 b	31.70 ab	5.90 a	37.60 a
BAP + GA_3	80.38 a	3.14 a	83.52 a	36.80 a	2.60 b	39.40 a
Huinkul H						
Control	16.68 c	5.37 a	22.05 b	17.50 c	9.40 b	26.90 c
BAP	33.02 b	6.10 a	39.12 a	21.90 b	13.00 a	34.90 a
GA_3	37.36 ab	4.87 a	42.23 a	20.40 bc	8.30 c	28.70 b
BAP + GA_3	42.08 a	4.26 a	46.34 a	25.80 a	8.10 c	33.90 a
Huinkul C						
Control	24.15 c	5.42 a	30.21 c	12.00 c	5.40 b	17.60 c
BAP	39.25 b	6.34 a	45.59 b	22.50 b	10.70 a	33.20 b
GA_3	59.65 a	6.40 a	66.05 a	29.10 a	12.70 a	41.80 a
BAP + GA_3	45.40 b	7.28 a	52.68 b	27.30 ab	10.90 a	38.20 a

Within each cultivar, storage system and column, means followed by the same letter do not differ ($P < 0.05$).

physiological age were larger (Caldiz et al., 1985; van der Zaag & van Loon, 1987). Nevertheless, other basic improvements in crop and storage management should be matched before deciding on the use of PGR in field crops.

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