CHAPTER 7

RESPONSE OF POTATO GROWN IN A HOT TROPICAL LOWLAND TO PACLOBUTRAZOL. III: TUBER ATTRIBUTES

7.1 ABSTRACT

The growth responses of potato to PBZ in the hot tropical conditions of eastern Ethiopia, was investigated in two field experiments during 2003. A month after planting PBZ was applied as a foliar spray or soil drench at rates of 0, 2, 3, and 4 kg a. i. PBZ per ha. PBZ increased tuber fresh mass, dry matter content, and specific gravity while promoting earlier tuber initiation and a reduction in tuber numbers. Root application of PBZ significantly increased crude protein content while both foliar and root PBZ applications extended the dormancy period. PBZ reduced the K and Mg contents of the tubers. Foliar applied PBZ increased the Ca content of tubers. Applying PBZ as a soil drench increased total tuber N. Both foliar and root applications increased tuber Fe content while reducing P levels. PBZ increased tuber yield, improved quality attributes such as dry matter content, crude protein content and Ca content, and extended the dormancy period of potatoes grown in the hot tropical lowlands of eastern Ethiopia.

Keywords: Crude protein**;** dormancy; dry matter; Ethiopia, nutrient composition; tuber quality, specific gravity; tuber yield

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7.2 INTRODUCTION

Potato tuberization is a complex developmental process that requires the interaction of environmental, biochemical, and genetic factors (Kolomiets *et al.,* 2001). Low mean temperatures (15-19 °C) under a short photoperiod (12 h) are optimal for tuber initiation and early tuber growth (Vandam *et al.,* 1996). High temperatures delay the onset of tuber initiation and bulking, decrease absolute tuber growth rate and favour assimilate partitioning to the aboveground parts (Nagarajan & Bansal, 1990; Gawronska *et al.,* 1992; Vandam *et al.,* 1996; Jackson, 1999). Under cool temperatures and short photoperiods a transmissible signal is activated that triggers cell division and elongation in the sub-apical region of the stolons to produce tuber initials (Xu *et al.,* 1998; Amador *et al.,* 2001). In this signal transduction pathway, perception of appropriate environmental cues occurs in the leaves and is mediated by phytochrome and GA (Van den Berg *et al.,* 1995; Jackson & Prat, 1996).

Potatoes grown under high temperatures are characterized by high levels of endogenous GA (Vreugdenhil & Sergeeva, 1999) that have a delaying or inhibitory effect on tuberization (Abdella *et al.,* 1995; Vandam *et al.,* 1996). In addition, GA accumulation in tuber tissue can specifically impede starch accumulation (Booth & Lovell, 1972; Paiva *et al.,* 1983; Vreugdenhil & Sergeeva, 1999), inhibit the accumulation of patatin and other tuber specific proteins (Hannapel *et al.,* 1985; Vreugdenhil & Sergeeva, 1999), and in combination with other inhibitors regulate potato tuber dormancy (Hemberg, 1970).

In addition to the involvement of several endogenous growth substances, Koda *et al.* (1988) reported the existence of a specific tuberization factor that is produced or activated in the leaves and translocated to the stolons where it exerts its effect. Hammes & Nel (1975) proposed that tuber formation is controlled by a balance between endogenous GA and tuber forming stimuli; for tuberization to occur the GA must be below a threshold level. This balance can be altered by the application of GA biosynthesis inhibitors such as 2-chloroethyl trimethyl ammonium chloride (CCC) (Menzel, 1980) and B-995 (Bodlaender & Algra, 1966). Recently, the *in vivo* and *in vitro* responses of potato to PBZ have been reported (Balamani & Poovaiah, 1985; Langille & Helper, 1992; Simko, 1994; Bandara & Tanino, 1995).

PBZ is a potent triazole plant growth regulator known to interfere with *ent*-kaurene oxidase activity in the *ent*-kaurene oxidation path to block gibberellin synthesis (Rademacher, 1997). PBZ treatment increase root-to-shoot ratio (Pinhero & Fletcher, 1994; Yim *et al.*, 1997), increase partitioning of assimilates to economically important plant parts such as bulbs (Le Guen-Le Saos *et al.*, 2002, De Resende & De Souza, 2002). Although some researchers reported that PBZ enhances tuberization (Balamani & Poovaiah, 1985; Pelacho *et al.*, 1994; Simko, 1994), information is lacking regarding the effect of PBZ on the productivity of potato grown under tropical condition. It is proposed that PBZ enhances assimilate diversion to the tubers and thereby increase productivity and improve quality of potato grown under in hot tropical conditions. Accordingly, this chapter reports the effect of PBZ application methods and rates on tuber yield, quality, nutrient composition and dormancy of potato grown in the hot tropical lowlands of eastern Ethiopia.

7.3 MATERIALS AND METHODS

7.3.1 Site description

Details of the site are presented in Chapter 5.

7.3.2 Plant culture

Cultural methods are described in Chapter 5.

7.3.3 Treatments

The treatments that were applied are presented in Chapter 5.

7.3.4 Tuber parameters

Tuber initiation was recorded as occurring when the swollen portion of stolon tip attained a size of at least twice the diameter of the stolon (Ewing & Struik, 1992). For this purpose three plants per plot were tagged and tuber initiation monitored every second day. Tubers fresh mass and tuber numbers represent the average of 15 plants sampled per plot. At harvest, samples of about 5 kg tubers of all sizes from each plot were washed and dried. Tuber specific gravity was determined using the weight in air weight in water method (Murphy & Goven, 1959). For dry matter content determination, 3 kg tubers were pre-dried at 60 ºC for 15h and further dried for 3h at 105 ºC in a drying oven. Tuber dry matter content is the ratio between dry and fresh mass expressed as a percentage. Separate samples of 1 kg were dried at 60 ºC to constant mass, grounded and analysed for macro and micronutrient contents. Total nitrogen was determined using the Macro-Kjeldahl method (AOAC, 1984) and multiplied by a conversion factor of 6.25 to estimate tuber crude protein content (Van Gelder, 1981). Following wet-ash digestion, phosphorus was determined by colorimetry, potassium by flame photometery, sulphur by turbidimetry, and calcium, magnesium, iron, copper, manganese and zinc by atomic absorption.

For dormancy evaluation, ten uniform (70-105 g) and healthy tubers were selected from each plot and labelled. The samples were stored in a naturally ventilated diffused light store in a randomised complete block design with three replications. The average daily minimum and maximum temperatures during the storage period were 13.6 ºC and 22.8 ºC, respectively and relative humidity ranged from 34 to 70%. The dormancy of a particular tuber was deemed to have ended when at least one 2 mm long sprout was present (Bandara & Tanino, 1995). The average dormancy period of the ten tubers was used to determine the dormancy period of a sample.

7.3.5 Statistical analysis

Described in Chapter 5.

7.4 RESULTS

Irrespective of the concentration, PBZ treated plants (Figure 7.1B, C and D) developed tuber initials about 17 days earlier than the control (Figure 7.1A). Regardless of the method of application, PBZ treatment increased tuber fresh mass, dry matter content, and specific gravity, and promoted early tuber initiation while reducing tuber number (Table 7.1). Fresh tuber yield per hill was increased from 195 g for untreated plants to 314 g by applying 3 kg a.i. PBZ. PBZ treatment reduced tuber numbers by about 21% as compared to the control.

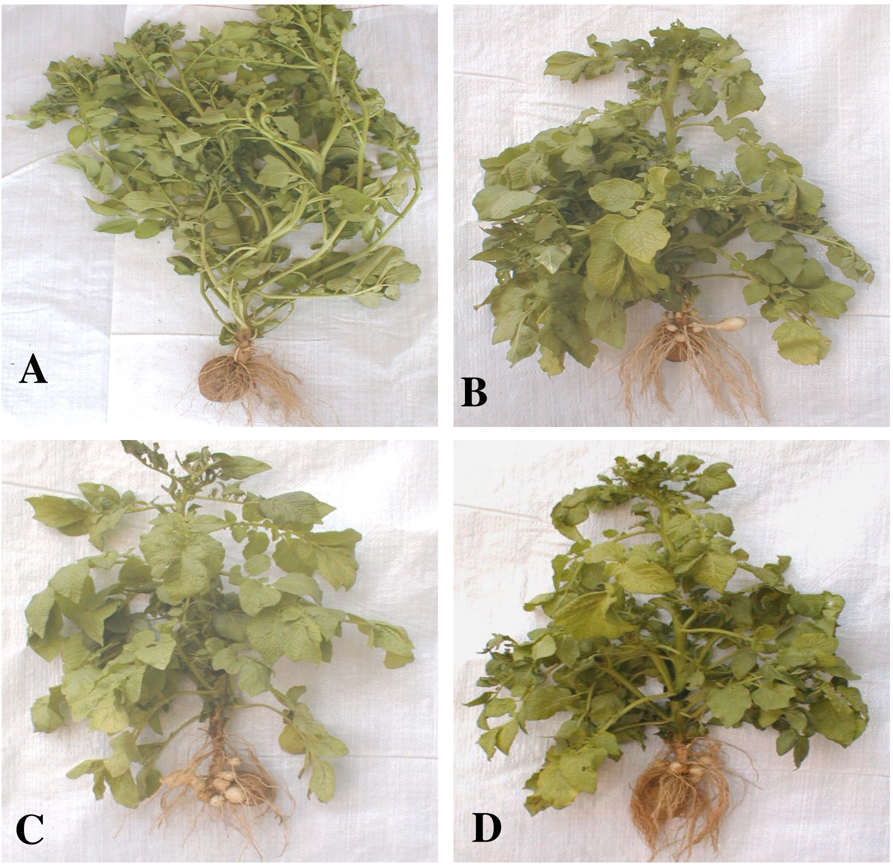

Figure 7.1 Potato plants two weeks after PBZ treatment at rates of 0 (A), 2 (B), 3 (C) and 4 kg a.i. ha^{-1} (D). The control plants had excessive top growth and no tuber formation, while the treated plants are characterized by reduced top growth and early tuberization

Table 7.1 Days to tuber initiation, fresh mass, number, dry matter content, and specific gravity of potato as affected by rates of PBZ

PBZ rate (kg a.i. ha^{-1})	Days to tuber initiation	Tuber fresh mass (g hill^{-1})	Tuber number (hill^{-1})	Dry matter content (%)	Specific gravity (g cm^{-3})
0 (Control)	54.0a	195c	7.6a	16.6c	1.061b
2	37.7b	300b	6.0b	17.5b	1.065a
3	37.3b	314a	6.1b	18.0a	1.068a
4	36.6b	305ab	6.0b	17.6ab	1.066a
SEM	0.48	3.26	0.09	0.09	0.004

SEM: standard error of the mean.

Means within the same column sharing the same letters are not significantly different ($P < 0.01$).

Average tuber fresh mass was negatively correlated with tuber number (r = - 0.98**). Tuber dry matter content varied from 16.6% (control) to 18.0% (3 kg a.i. PBZ), and specific gravity from 1.061 (control) to 1.068 (3 kg a.i. PBZ). Means of PBZ concentrations pooled over application method showed that application of 3 or 4 kg a.i PBZ increased dry matter content by about 7.2% and specific gravity was increased from 1.061 to mean value of 1.067 by PBZ.

Application method and PBZ concentration interacted significantly for tuber crude protein content and dormancy period (Table 7.2). Foliar spray of PBZ did not affect crude protein content, while applying 4 kg a.i. PBZ as a soil drench increased the protein content by about 12% compared to the control. Regardless of the concentration, foliar applied PBZ extended the tuber dormancy period by 17 days, while applying 3 or 4 kg a.i. PBZ as a soil drench prolonged dormancy by about 20 days.

Table 7.2 The effect of application method and rate of PBZ on the crude protein content and dormancy period of potato

Application method	PBZ rate (kg a.i. ha^{-1})	Crude protein (% DM)	Dormancy period (days)
Foliar spray	0 (control)	11.67b	45.64c
	2	11.46b	61.99b
	3	11.88b	62.63b
	4	11.67b	63.32b
Soil drench	0 (control)	11.88b	45.33c
	2	11.67b	63.27b
	3	11.88b	65.89a
	4	13.34a	65.08a
	SEM	0.08	0.39

SEM: standard error of the mean.

Means within the same column sharing the same letters are not significantly different ($P < 0.01$).

The tuber mineral composition was affected by both method of application and rate of PBZ (Table 7.3). Irrespective of the concentration, PBZ treatment reduced K and Mg contents of the tubers while Ca, S, Cu and Zn concentrations were unaffected. Compared to soil drench, foliar spray reduced K content but increased the Ca content of the tubers.

Table 7.3 Potassium, calcium, magnesium, sulphur, copper and zinc concentrations (dry matter basis) in potato tubers as affected by application method and concentration of PBZ

Treatment	K (%)	Ca (%)	Mg (%)	S (%)	Cu (ppm)	Zn (ppm)
Foliar spray	3.05b	0.14a	0.16a	0.52a	17.33a	34.16a
Soil drench	3.15a	0.13b	0.16a	0.53a	14.83a	34.75a
SEM	0.02	0.004	0.002	0.02	1.42	2.74
0 (control)	3.44a	0.13a	0.18a	0.55a	17.50a	31.33a
2 (kg a.i. ha^{-1})	2.98b	0.13a	0.15b	0.58a	15.50a	34.50a
3 (kg a.i. ha^{-1})	2.99b	0.13a	0.15b	0.50a	14.50a	40.33a
4 (kg a.i. ha^{-1})	2.99b	0.14a	0.15b	0.48a	16.83a	31.67a
SEM	0.03	0.005	0.004	0.03	2.01	3.88

SEM: standard error of the mean.

Means for the same main effect within the same column sharing the same letters are not significantly different ($P < 0.01$).

A significant interaction between application method and concentration of PBZ was observed with respect to N, P, Fe, and Mn content of the tubers (Table 7.4). Foliar spray of any PBZ concentration did not increase N content, while application of 4 kg a.i. PBZ as a soil drench increased N concentration by 12%. Irrespective of the rate, foliar application and soil drenching of PBZ reduced P concentration by about 11 and 6% respectively compared to the check. Foliar spray of 3 or 4 kg a.i. PBZ increased tuber Fe content by 64%, while drench applications of 2 or 4 kg a.i. increased Fe content by about 54% over the control. Treating plants with 3 kg PBZ as a foliar spray increased Mn concentration by about 52%, while soil drenching with 3 or 4 kg PBZ increased the Mn content by approximately 68% as compared to the control.

Table 7.4 The effect of application method and rate of PBZ on total nitrogen, phosphorus, iron and manganese content of potato tubers. Values are calculated on dry matter basis

Application method	PBZ rate (kg a.i. ha^{-1})	N (%)	P (%)	Fe (ppm)	Mn (ppm)
Foliar spray	0 (control)	1.87b	0.47a	60.33c	7.00d
	2	1.83b	0.41d	57.33c	6.67d
	3	1.90b	0.43bcd	102.00a	10.67ab
	4	1.83b	0.42cd	95.67ab	8.67bcd
Soil drench	0 (control)	1.90b	0.47a	70.67bc	7.33cd
	2	1.87b	0.44bc	101.33a	10.33bc
	3	1.90b	0.43bcd	91.67ab	11.00ab
	4	2.13a	0.45ab	115.67a	13.67a
	SEM	0.03	0.004	6.62	0.73

SEM: standard error of the mean.

Means of the same main effect within the same column sharing the same letters are not significantly different ($P < 0.01$).

7.5 DISCUSSION

For optimal yield and quality, potatoes prefer cool temperate climates with low mean temperatures and a short photoperiod (Vandam *et al.,* 1996). Nevertheless, potato has been produced in many tropical climates under high temperatures, resulting in yield reductions and quality deterioration. This is partly attributed to the synthesis of high levels of endogenous GA, which delays or inhibits tuber initiation, reduces partitioning of assimilates to the tubers, and impedes the synthesis of starch and tuber specific proteins. This study investigated the effect of applied PBZ on the tuber yield and quality of potato grown in hot tropical conditions of eastern Ethiopia to use as a possible intervention.

Crop yield is a function of canopy size (LAI) for intercepting solar radiation, the persistence of photosynthetically active leaf area (LAD), and the efficiency of net gain of assimilates (NAR). In spite of a reduction in LAI and total biomass (Chapter 6), PBZ increased tuber growth and resulted in about a 57% yield advantage over the control, which may be linked to early tuberization, increased leaf chlorophyll content, enhanced rate of photosynthesis, and delaying the onset of senescence (Chapter 5). The reduction in tuber numbers may be attributed to a decline in stolon number in response to a decrease in GA biosynthesis, but no specific observations in this regard were made. The involvement of GA in regulating stolon numbers through stolon initiation was reported by Kumar & Wareing (1972). Frommer & Sonnewald (1995) reported that the competition among tuber initials reduces the final tuber number. The strong negative association between tuber fresh mass and number signify that PBZ increased tuber yield by increasing tuber size. In agreement with this, Balamani & Poovaiah (1985) and Simko (1994) reported increased tuber dry weight per plant in response to PBZ, although it was not clear if the increase was a consequence of tuber size. In contrast, Bandara & Tanino (1995) reported that PBZ nearly doubled the number of tubers per plant without affecting the total fresh weight of the tubers. High temperature increases GA biosynthesis that reduces tuber sink strength to attract photoassimilates and may cause yield reduction (Booth & Lovell, 1972). Krauss (1978) reported that GA: abscisic acid (ABA) ratio controls tuberization and subsequent tuber growth; relatively higher GA levels reduce or stop tuber growth, while higher ABA levels promote tuber growth.

PBZ increased the dry matter content and specific gravity of the tubers. This may be attributed to reduced tuber GA levels with a subsequent increase in sink strength, enhancing starch synthesis and deposition. Booth & Lovell (1972) reported reduced sink strength of tubers due to GA_3 accumulation in tuber tissue. Under conditions favourable for tuberization the activity of enzymes involved in starch biosynthesis such as ADPG-pyrophosphorylase, starch phosphorylase and starch synthase increase (Visser *et al.,* 1994; Appeldoorn *et al.,* 1997). Mares *et al.* (1981) observed that exogenous application of GA_3 to growing tubers substantially reduced the activity of ADPG-pyrophosphorylase, while the activity of starch phosphorylase remained more or less constant. Similarly, Booth & Lovell (1972) observed that application of GA_3 to potato shoots reduced export of photosynthates to the tubers, decreased starch accumulation, increased sugar levels and resulted in cessation of tuber growth.

PBZ increased tuber crude protein content, probably due to blocking of GA biosynthesis that is known to inhibit tuber protein synthesis. The increased total nitrogen concentration in tubers from PBZ treated plants may be due to an increased uptake of nitrogen from the soil and/or remobilisation of nitrogen from other plant parts to the tubers. Park (1990) and Vreugdenhil & Sergeeva (1999) reported the negative effects of GA_3 on the synthesis of patatin and other tuber specific proteins. The involvement of GA in the regulation of potato tuber starch and protein synthesis, along with a strong association between starch and protein content is reported by Paiva *et al.* (1983).

PBZ extended tuber dormancy, probably by blocking GA biosynthesis and reducing ABA catabolism (Rademacher 1997) which could result in a low GA to ABA ratio in developing tubers. Dogonadze *et al.* (2000) observed that exogenous GA_3 treatment promoted tuber sprouting by enhancing RNA and DNA synthesis, and Hemberg (1970) reported an inhibitory effect of ABA to tuber sprouting through inhibited RNA and DNA synthesis. The regulatory effects of GA and ABA on RNA and DNA synthesis are probably the major contributors to delayed sprouting (Shik & Rappaport, 1970). It is suggested that the ratio of GA to ABA in the tuber is the most probable control mechanism of potato dormancy. Harvey *et al.* (1991), Simko (1994) and Bandara & Tanino (1995) also reported that PBZ treatment extended the dormancy period of the tubers.

PBZ influenced the anatomy and morphology of roots as described in Chapter 4 and this might have altered mineral uptake and hence, tuber nutrition. PBZ increased potato tuber yield by increasing tuber size and the observed reduction in some nutrient concentrations may be due to a dilution effect. Reports on the effects of PBZ on mineral element content are not consistent and mainly refers to fruit crops. For instance, Yelenosky *et al.* (1995) observed that leaves from PBZ treated citrus seedlings had higher concentration of N, Ca, B, Fe, and Mn. Wang *et al.* (1985) reported that PBZ treatment increased leaf N, P, K, Ca, Mg, Mn, Ca, Zn, and Sr concentration in apple while the contents of Fe, Si, and Pb were unaffected. In contrast, Wieland & Wample (1985) reported that PBZ did not influence N, P, K, and Mg content of apple leaves. It was also reported that the mineral composition of apple fruit was unaffected by PBZ treatment (Steffens *et al.,* 1985). Very recently, Yeshitela *et al*. (2004) reported that PBZ increased Mg, Cu, Zn, and Fe content of mango leaves without affecting the concentration of N, P, K, and Ca.

7.6 CONCLUSION

PBZ increased tuber yield and quality indicating its potential to improve potato production in the tropics. However, detailed investigations are essential to identify the correct time and rate of application, and analyse risks in terms of human health and environmental pollution. Prolonging tuber dormancy period with PBZ may be useful for the potato industry, particularly to reduce untimely sprouting of potato cultivars having a short dormancy period. However, the effect of residual PBZ on the performance the next generation must be investigated. For all the parameters considered, little significant difference was observed between foliar spray and soil drench applications. For ease of application and to reduce soil pollution foliar spray is suggested as the method of application.