

Research Article

The Effect of Paclobutrazol Application Time and Variety on Growth, Yield, and Quality of Potato (*Solanum tuberosum* L.)

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Received 2 December 2015; Accepted 11 January 2016

Academic Editor: Tibor Janda

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An experiment was set up to investigate the effect of time of paclobutrazol application and variety on growth, yield, and quality of potato in a greenhouse at 34°C (±3) and 21°C (±3) day and night temperatures, respectively, with 60% relative humidity. The experiment was set up as a 2 × 4 factorial design in a CRD with 3 replications. The first factor was potato variety and the levels were BPI and Diamond. The second factor was paclobutrazol application time and the levels were 28 (Days After Planting) DAP, 35 DAP, and 42 DAP and no paclobutrazol applied (control). Early application of paclobutrazol reduced stem length, number of tubers per plant, and sugar content of potato; furthermore, it increased starch content and yield compared to late application and no paclobutrazol treatments. Early application of paclobutrazol at 28 DAP is recommended in high temperature zones as it increased the yield by 108% and quality of potato.

1. Introduction

Potato is a cool season crop and the optimum temperature requirements for tuber development have been reported to be in the range of 14–22°C [1]. Potato production has been limited to cool regions in Zimbabwe and yet the country has more than 43% of semiarid area [2]. To increase food and nutrition security in the country, it is imperative to grow potatoes in high temperature regions. High temperatures cause a reduction in the rate of photosynthesis, translocation of assimilates to tubers, and conversion rate of sucrose into starch resulting in limited tuber formation and growth [3]. The yield reduction at high temperatures is partly due to reduced assimilate partitioning and delayed tuber initiation [4]. At high temperatures, foliage growth is vigorous and considerable amounts of carbohydrates are utilized for foliage growth at the expense of tuberization [5].

The total dry matter production and its distribution to the different plant organs is an important factor affecting tuber

yield in potato [6]. The transition of a stolon into a tuber at high temperatures is limited as there is an increase in the level of gibberellic acid in leaf buds limiting tuber production [3]. High levels of gibberellic acid lead to higher carbohydrate allocation to shoots at the expense of tubers [5].

One of the attempts to increase potato productivity in tropical climates where high temperatures are experienced is the use of plant growth regulators such as paclobutrazol [3]. The mode of action of paclobutrazol is the inhibition of gibberellic acid synthesis in plants. The inhibition of gibberellin production by paclobutrazol results in slow cell division and elongation without causing toxicity to cells [7].

Application time of paclobutrazol may affect potato yield in high temperature areas. Paclobutrazol treatment of potato plants promoted tuberization in vitro and under greenhouse conditions with cultivar response to the timing of treatment [8]. Tuberization is a continuous process and all the different developmental stages from stolon induction to tuber growth may occur at one plant but not all tubers will be able to

develop to usable tubers at harvest time [9]. The continuous appearance of stolons during tuber bulking period may not contribute to the number of tubers harvested as each variety has a time when stolon swelling ceases [10] and therefore timing of paclobutrazol application is critical.

Application of plant growth regulators at tuber initiation can alter photosynthetic partitioning in favour of tuber production and increase yields [7]. Celis-Gamboa et al. [11] found out that stolon formation occurred 29 DAP and the stolon tip swelling started from 29 to 36 DAP for the cultivars that were under study. Tubers that overly attain the greatest weight are usually produced by the lowest stolons and are formed at the beginning of tuber development [10]. However, there is limited information on the appropriate time of paclobutrazol application using our local varieties to maximise yield and quality of potato tubers under conditions of high temperatures.

2. Materials and Methods

2.1. Research Site and Characteristics. The research was carried out at Harare Research Station (31° 03' E and 17° 48' S). It is located within agroecological region IIa with an altitude of 1506 m above sea level. The research station receives annual rainfall of 820 mm. The experiment was conducted in a greenhouse and the day temperature was 34°C (± 3) and the night temperature was 21°C (± 3). The average relative humidity in the greenhouse was 60%. The experiment was set up in April to July 2014 and day length was characterised by short days and long nights.

2.1.1. Experimental Design and Treatments. The experiment was set up as a 4 × 2 factorial in a complete randomized design with 3 replications. The first factor was time of paclobutrazol application and the second factor was variety with the levels shown in Table 1.

2.1.2. Plant Culture. Two varieties of potato seed Diamond and BP1 were left to sprout in a dark room until the sprouts were about 2 cm in length. The sprouted seed tubers were then transferred to a room with diffuse light to harden sprouts for two weeks until the sprouts turned from white to green. The soils used for planting were predominantly red clays. Planting was done in 20 L black plastic pockets that were 50 cm × 40 cm. The pockets were initially half filled with soil to a height of 25 cm. Basal fertilizer was applied at a rate of 2000 kg/ha Compound S (7 : 21 : 7) and was incorporated into the pockets. Planting holes that were 10 cm deep were dug in each pocket and 1 tuber was placed in each pocket, covered with soil, and irrigated. One experimental unit was comprised of 5 pots.

Top dressing was done at four weeks after emergence using Ammonium Nitrate (34.5% N) at a rate of 200 kg/ha. Earthing up was done by filling up the pockets with the same soil that was used at planting. Preventative sprays for blights were done on a weekly basis using copper oxychloride. Weeding was done by pulling the weeds by hand from the pockets whilst they were still young. Watering was done when necessary depending on the stage of crop growth. Harvesting of the tubers was done after 120 DAP.

TABLE 1: Treatment structure for the effect of time of paclobutrazol application on growth, quality, and yield of potato.

Treatment	Variety	Time of paclobutrazol application
1	BP1	28
2	BP1	35
3	BP1	42
4	BP1	No paclobutrazol (control)
5	Diamond	28
6	Diamond	35
7	Diamond	42
8	Diamond	No paclobutrazol (control)

2.1.3. Treatment Application. Paclobutrazol 29.9% active ingredient was applied at a rate of 250 g/ha and was applied at 28, 35, and 42 DAP according to treatment structure shown in Table 1. A 15 litre knapsack sprayer was used for spraying to attain full cover spray.

2.1.4. Measurements and Data Analysis. Measurements taken included stem diameter at the base and length on two randomly sampled plants per experimental unit at 49 and 63 DAP, number of tubers per plant, yield, starch content, reducing sugar content of potato tubers [12], and grades of potato at the end of the experiment (120 DAP). The grades of potato were divided into small (56–63.9 mm), medium (64–75.9 mm), large (76–83.9 mm), and extra large (>84 mm diameter). Analysis of variance of data was done using Genstat Version 14. Treatment means were separated using the LSD at 5% level of significance.

3. Results and Discussion

3.1. Effect of Time of Paclobutrazol Application on Potato Stem Length (cm) at 49 and 63 DAP. Paclobutrazol treatment at 28 DAP resulted in stems that were shorter compared to delay in application of the growth regulator and no paclobutrazol treatments at 49 and 63 DAP (Table 2). Probably early application of paclobutrazol quickly arrested the activity of gibberellic acid inside plant cells which are responsible for stem elongation, hence reducing the length of stems. Gibberellic acid is responsible for stem elongation by increasing the internode length [13]. Paclobutrazol reduces the level of gibberellic acid inside plant cells by interfering with the oxidative steps of gibberellin precursor ent-kauren to ent-kaurenic acid blocking the synthesis of gibberellins in the early step of its biosynthetic pathway [14, 15]. These results are similar to findings by Bandara et al. [8] that application of paclobutrazol at early tuber initiation reduces the haulm growth significantly compared to when it is applied at late stolon initiation.

3.2. Effect of Time of Paclobutrazol Application on Potato Stem Diameter (cm) at 49 and 63 DAP. Early application

TABLE 2: Effect of time of paclobutrazol application on potato stem length (cm) at 49 and 63 DAP.

Time of paclobutrazol application (DAP)	Stem length (cm)	
	49 DAP	63 DAP
28	41.67 ^a	44.33 ^a
35	48.33 ^b	52.17 ^b
42	55.50 ^c	58.33 ^c
No paclobutrazol	61.33 ^d	74.00 ^d
<i>P</i> value	<0.001	<0.001
LSD	2.29	2.486

Means with the same letters in each column are not statistically different at 5% significance level.

TABLE 3: Effect of time of paclobutrazol application on potato stem diameter (cm) at 49 and 63 DAP.

Time of paclobutrazol application (DAP)	Stem diameter (cm)	
	49 DAP	63 DAP
28	1.173 ^a	1.643 ^a
35	1.057 ^b	1.455 ^b
42	0.975 ^c	1.378 ^c
No paclobutrazol	0.892 ^d	0.940 ^d
<i>P</i> value	<0.001	<0.001
LSD	0.03739	0.02321

Means with the same letters in each column are not statistically different at 5% significance level.

of paclobutrazol resulted in thicker and more compact stems than late application and no paclobutrazol treatments (Table 3). Similarly, early application of paclobutrazol increased the diameter of stems considerably compared to late applications. This may be explained by the low levels of gibberellic acid after early application of paclobutrazol as high levels of gibberellic acid limit radial expansion of plant organs [16]. Probably the reduction in stem length due to early application of paclobutrazol compared to late application of paclobutrazol may have resulted in increases in stem diameter for the former compared to the later. Paclobutrazol treatment increases the thickness of cortex, vascular bundles, and pith diameter resulting in thicker stems [17].

3.3. Effect of Time of Paclobutrazol Application on Total Number of Potato Tubers per Plant. Significant differences ($P < 0.05$) in time of paclobutrazol application were observed with respect to total number of tubers per plant. The least number of potato tubers was recorded in plots where paclobutrazol was applied at 28 DAP although it was not significantly different from 35 DAP (Figure 1). The reduction in the number of tubers per plant may be attributed to decrease in the number of stolons due to low levels of gibberellic acid after paclobutrazol application. The fewer numbers of stolons resulted in fewer numbers of tubers as they are formed after the differentiation of stolons into vegetative storage organs. These results agree with the findings by Vreugdenhil and Sergeeva [5] that application of gibberellic acid reduces number of tubers per plant.

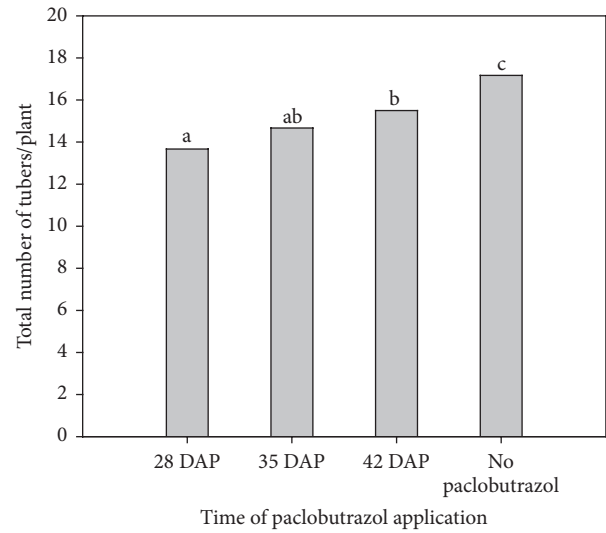


FIGURE 1: Effect of time of paclobutrazol application on total number of potato tubers per plant.

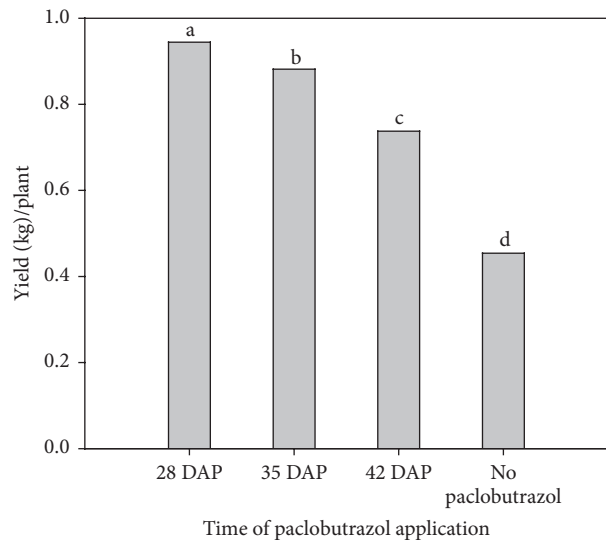


FIGURE 2: Effect of time of paclobutrazol application on potato tuber yield (kg) per plant.

3.4. Effect of Time of Paclobutrazol Application on Potato Yield (kg/Plant). The highest potato yield was observed in treatments where paclobutrazol was applied at 28 DAP. Yield of about 108% was recorded in early application when compared to no paclobutrazol treatments (Figure 2). The increase in yield may have been caused by the reduction of stem length that was observed in the experiment as more assimilates were channelled to tuber growth increasing yield [6]. The increase in yield in treatments where paclobutrazol was applied early may also be explained by early tuberization due to low levels of gibberellic acid. Application of paclobutrazol coinciding with tuber initiation resulted in more yields compared to application of paclobutrazol at late tuber initiation [8, 10].

3.5. Effect of Time of Paclobutrazol Application on Potato Tuber Grades per Plant. Plants treated with paclobutrazol at 28 and

TABLE 4: Effect of time of paclobutrazol application on potato tuber grades as per plant.

Time of paclobutrazol application in DAP	Extra large	Large	Medium	Small
28	5.167 ^a	4.500 ^a	2.500 ^a	1.500 ^a
35	3.333 ^b	3.833 ^a	4.500 ^b	3.000 ^b
42	2.333 ^c	3.000 ^b	5.333 ^c	4.833 ^c
No paclobutrazol	0.000 ^d	1.667 ^c	7.000 ^d	8.500 ^d
<i>P</i> value	<0.001	<0.001	<0.001	<0.001
LSD	0.661	0.79	0.707	0.707

Means with the same letters in each column are not statistically different at 5% significance level.

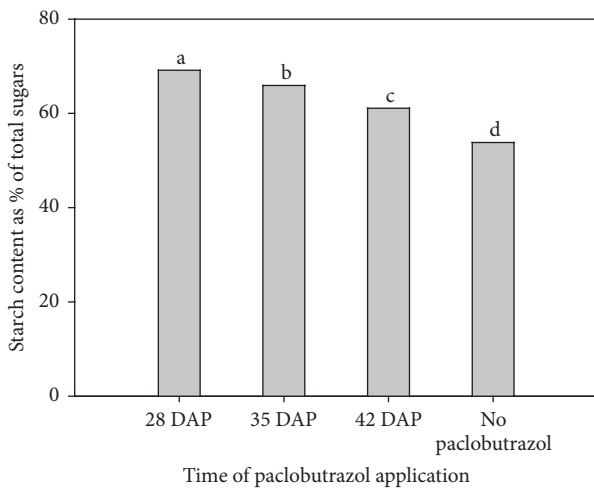


FIGURE 3: Effect of time of paclobutrazol application on potato tuber starch content as a % of sugars.

35 DAP had the biggest number of extra large and large tubers (Table 4). The increase in sizes of tubers may be as a result of low competition for assimilates since the early applied paclobutrazol plants had less numbers of tubers as shown in Figure 1. These results may also be explained by the reduction in stem length for early paclobutrazol treatments and hence more assimilates were partitioned to tuber growth compared to haulm growth resulting in increased size of tubers. The increase in potato size may also be linked to early tuberization in plants treated with paclobutrazol at 28 and 35 DAP [6].

3.6. Effect of Time of Paclobutrazol Application on Potato Tuber Starch Content as a % of Sugars. Application of paclobutrazol 28 DAP resulted in 28% increase in tuber starch content compared with treatments where paclobutrazol was not applied (Figure 3). The increase in starch content with early paclobutrazol application might have been caused by higher sink strength as evident on the increase in tuber size indicated by tuber grades shown in Table 4 enhancing starch synthesis and accumulation due to low levels of gibberellic acid. High levels of gibberellic acid during tuberization impede starch accumulation and hence low levels of starch in plants where paclobutrazol was not applied. The increase in starch content

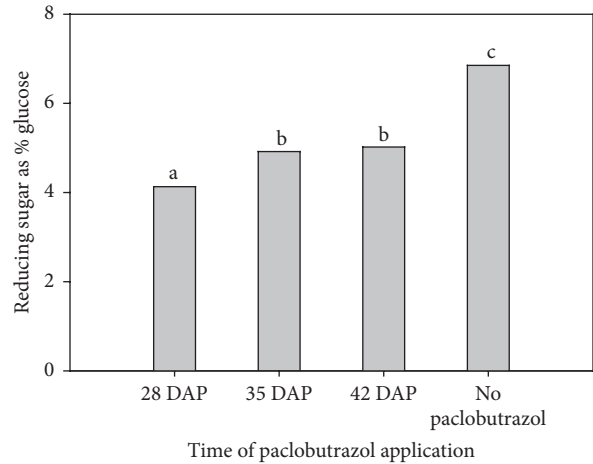


FIGURE 4: Effect of time of paclobutrazol application on potato tuber reducing sugar content as % glucose.

in early applied paclobutrazol plants may also have been caused by early tuberization. Early paclobutrazol applied plants had more time to attract assimilates resulting in increase in starch content compared to the late application. Treatment of plants with paclobutrazol causes an increase in the number of enzymes that are responsible for starch biosynthesis such as starch synthase, therefore increasing starch content in tubers [9]. Application of paclobutrazol results in increased starch synthesis and accumulation in tubers [17] and hence increased starch content in all plants where paclobutrazol was applied. The least starch content was recorded in tubers where paclobutrazol was not applied and this can be explained by high levels of gibberellins that impede starch accumulation in tubers.

3.7. Effect of Time of Paclobutrazol Application on Potato Tuber Reducing Sugar Content as % Glucose. The levels of reducing sugars were the lowest in plants treated with paclobutrazol at 28 DAP (Figure 4). The reduction in reducing sugar content may have been caused by increase in starch content in this treatment implying that most of the reducing sugars were converted to starch. This may be explained by low levels of gibberellic acid that stimulates enzymes such as starch synthase and starch biosynthesis that convert sugars to starch [9].

4. Conclusions

Early application of paclobutrazol at 28 DAP reduced the stem length and increased the stem diameter by 40% and 74%, respectively. Early application of paclobutrazol reduced the total number of tubers per plant and increased potato tuber yield. Late application of paclobutrazol at 42 DAP increased tuber reducing sugar content, reduced the grades of tubers, and decreased tuber starch content.

Conflict of Interests

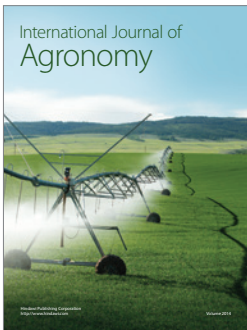
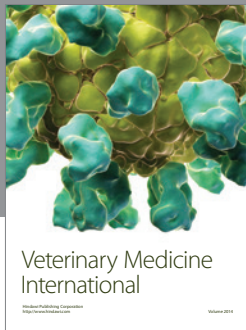
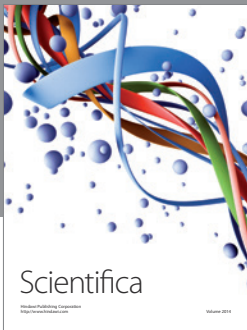
The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors also want to thank Dr. D. Rukuni for his assistance in coming up with the project proposal. Many thanks are due to the Department of Research and Specialist Services and Ms. O Mavhangeni in particular for allocating greenhouse space to carry out the project.

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