EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON GROWTH, QUALITY AND YIELD OF POTATO (*Solanum tuberosum* L.*)* IN THE LOWVELD OF ZIMBABWE

BY

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DECLARATION

I hereby declare that this dissertation, prepared for the Honours Degree in Agronomy , which I submitted to the Faculty of Agriculture and Natural Resources Management of Midlands State University of Zimbabwe is my original work. I also agree that the Midlands State University has the sole right to the publication of this dissertation.

Signed on .... at Midlands State University, Gweru, Zimbabwe

Signature..

Hillary Simeti

I declare and certify that I have supervised Hillary Simeti's thesis with the topic Effect of paclobutrazol application on growth, quality and yield of potato (*Solanum tuberosum* L.*)* in the lowveld of Zimbabwe.

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ABSTRACT

Irish potato is a cool season crop which require low temperatures for high yields. In potato production tuberisation is an important and complex process. High temperatures reduce successful cultivation of potato in the lowveld of Zimbabwe because they tend to promote vegetative growth at the expense of tuber production. High temperatures may increase in gubberellin activity that inhibits tuberisation.To overcome this problem paclobutrazol can be used to overcome the inhibitory effect caused by gibberellins. The effect of paclobutrazol was tested under field conditions. An experiment was set up at Chiredzi Research Station to investigate the effect of paclobutrazol on growth, yield and quality of potatoes. A total of eight treatments were used for this experiment ,which were replicated three times in a Complete Randomised Design to investigate the effect of time of paclobutrazol application on the growth, yield and quality of potato. Paclobutrazol was applied at 28 DAP, 35DAP, 42DAP,49DAP,56DAP,63DAP,70DAP and 77DAP. Early application of paclobutrazol at 28DAP and35 DAP increased potato stem diameter and diameter of tubers compared to late application of paclobutrazol. Early application of paclobutrazol at 28 DAP and 35 DAP reduced the number of tubers ,reduced sugar content ,potato stem length compared to late application of paclobutrazol.

DEDICATION

This work is dedicated to the Almighty God whose support makes all things possible for me in life and to my mother ,Ruzayi Chikamhi for her unconditional love and support during my entire education .To my brother Progress Munyaradzi Zanga and sister Aggnes Chikamhi thank you for your encouragement in difficult times. You are all special to me and stay blessed.

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ABBREVIATIONS

DAP	Days after planting
%	Percentage
ºC	Degrees Celsius
a.i	Active ingredient
PBZ	Paclobutrazol
CRD	Completely Randomized Design
C.V	Coefficient of variation
ANOVA	Analysis of Variances

CHAPTER 1

1.0 INTRODUCTION AND BACKGROUND

Irish potato is an important crop for nutritional value (Ngwerume, 2002, Dean,1994)and food security . Irish potato contains high quality proteins and a substantial amount of essential vitamins, minerals, high carbohydrate content, calcium, potassium and vitamin (Ngwerume, 2002).Potato has become the cornerstone for human nutrition because of its nutritional quality and is considered as a source of many nutrients .According to the national database, potato contents would be 2.4g vitamin C,2,4g dietary fibre,15,7g carbohydrates,1,7g vitamin C each per 100g of white, raw potato(Singh and Kaur,2009).Potatoes are also sources of antioxidant compounds ,such as polypheriod, caretoids and vitamins leading to their relevance not only as starchy food, but also as a vegetable.(Burlingame *et al*.,2009)

Production of potato is mainly limited by season and area in Zimbabwe. Environmental conditions like temperature and photoperiods affect the physiological processes of the potato plant (Tsegaw *et al*., 2005). Crops that continue to be grown in a location will be determined by changes in climate and the seasonal distribution of rainfall and temperature that they experience (Woodward,1988),thus climate influences what to be grown in a certain location. Potato is mainly grown in winter in places which do not experience high temperatures ,since this is important in tuberization (Levy et al.,2007). The optimum temperature for photosynthesis is between 20-24 ^{0}C and 14-22 ^{0}C for the development of tubers (Schafleinter, 2013). High temperatures tend to promote vegetative growth at the expense of tuber production.(Tsegaw and Hammes,2004).Temperature affect the growing period duration and also processes linked with the accumulation of dry matter such as leaf area expansion, photosynthesis, respiration, evapotranspiration, photosynthesis and respiration (Woodward,1988). Tuberization of potato plants is strongly influenced by day length, with short days in general promoting tuber formation. At high temperatures yield and quality of potato tends to be reduced as compared to low temperatures ,since low temperatures promote tuberization and increase dry matter content of tubers(Tsegaw & Hammes, 2004).

Paclobutrazol is a plant growth retardant and triazole fungicide. Paclobutrazol is a plant growth regulator which removes unnecessary vegetative growth and send assimilates to the reproductive growth leading to increased yield and quality under high temperatures . (Lever, 1986; Davis & Curry, 1999). Paclobutrazol reduces plant height and increases chlorophyll content of leaves (Hawkins *et al*., 2006).It does so by inhibiting gibberellins biosynthesis ,reducing the internodal growth to give increasing root growth. Paclobutrazol is normally applied to the soil to be taken up by the roots and transported via xylem to the upper parts of the plant.(Amador et.al,2001).

Response of plants to paclobutrazol applications differs depending on the time of application (Tsegaw *et al*., 2005). Time of paclobutrazol application is important so as to match with the beginning of tuber formation thus maximizing on tuberization because the lowest stolons formed at the beginning of tuber induction will attain the greatest tuber weight (Levy *et al*., 2007).

Alternatively ,tuber formation in potato can be controlled using paclobutrazol(Simko1994).A chemical called paclobutrazol can be used on potato grown in high temperature zones thereby breaking the barriers of seasonality and area preferences .Paclobutrazol (2*S*,3*S*)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol) is a triazole broad spectrum gibberellic acid biosynthesis inhibitor widely used as a plant growth regulator (Davis & Curry, 1991). Paclobutrazol inhibits gibberellins biosynthesis and abscisic acid catabolism by interfering with ent-ksuretene oxidase activity in the ent-kaurene oxidation pathway which are the key steps in gibberellic acid biosynthesis.[Rademacher,1997].

1.1 Main Objective

1.1.1 To investigate the effects of time of paclobutrazol application on the growth, yield and quality of potato.

1.2 Specific Objective

1.2.1 To determine the effect of application time of paclobutrazol on growth parameters of potato (stem height, stem diameter)

1.2.2. To determine the effect of application time of paclobutrazol on yield components of potato(number of tubers per plant, size of tubers, weight of tubers and reducing sugar content).

1.2.3. To determine the effect of application time of paclobutrazol on tuber diameter of potato

1.3 HYPOTHESES

1.3.1 Time of application of paclobutrazol has a significant effect on growth parameters of potato (stem height, stem diameter)

1.3.2 Time of application of paclobutrazol has a significant effect on yield components of potato (number of tubers per plant, weight of tubers and reducing sugar content).

1.3.3 Time of application of paclobutrazol has a significant effect on tuber diameter of potato

CHAPTER 2

2. O LITERATURE REVIEW

2.1. Origin and distribution of potato

Potato (*Solanum tuberosum* L.) originated in the Andes of South America, a region characterized by short day length, high light intensity, cool temperatures and relatively high humidity (Levy et al., 2007). Later it was introduced into Ireland and since then potato production increased in Asia ,Africa and Latin America .China is now the biggest potato producer ,in Zimbabwe potato crop was introduced in the early 20^{th} century. Potato production is now practiced under different climatic conditions such as high temperatures (Levy et al., 2007).

2.2 Economic importance of Potato

Potato is currently the fourth most important food crop in the world after maize ,wheat and rice with a production of 329 million tons(Food and Agriculture Organisation ,2009).Looking at the harvested area potato ranks 7^{th} after wheat ,rice ,maize ,barley ,sorghum worldwide and as for consumption it ranks third after rice and wheat (Burlingame et al.,2009).

Potato cultivation is expanding strongly in Zimbabwe where the cultivation and nutritive content has made it a valuable food security and cash crop for most famers (Dean, 1994). Potato are sources of antioxidant compounds including polypheriod , caretoids and vitamins leading to their relevance as a vegetable (Burlingame et al.,2009).

Once harvested, tenth of potato goes to the industry for producing variable products like French fries and chips whereas the rest consumes freshly (Singh and Kaur,2009). Potato peels has also been studied as feed for pigs after further treatments. Potato has high carbohydrate with low fat and this makes it an important energy source for human consumption (Dean, 1994).

2.3 Challenges associated with potato production in Zimbabwe

Storage facility is a challenge in potato production. Storage facilities need to be carefully designed to keep the potatoes alive and slow the natural process of decomposition which involves the breakdown of starch .It is crucial that the storage area is dark ,well ventilated and for long -term storage maintained at temperatures near 4 degrees .Among other challenges production of potato is mainly limited by season and area. Photoperiods, low light intensity and high soil and air temperature are adverse to potato production as they alter hormonal balance and delay tuberization (Tsegaw et al., 2005).Potato production has been restricted in hot climates of approximately 12 hrs with minimum night temperature and maximum day temperature as high as 40 degrees due to unfavorably high temperatures (Tsegaw et al., 2005). Potato is a cool season crop and high temperatures are inhibitory to tuberization resulting in low yields. This is mainly due to production of high levels of gibberellins at high temperatures that promote vegetative growth at the expense of tuberization .The ability to tuberize also tends to decline with an increase in the level of nitrogen .Increase in nitrogen fertilization enhances partitioning of assimilates to the shoots instead of the tubers (Benond and Vos,1992).

2.4 Effects of temperature on tuberization of potato

An important factor that has a major influence in tuberization is temperature .Tuberization is a process which leads to the formation of specialized storage organ by the differentiation of the underground stolon .It is a complex process involving anatomical, enzymatic, biochemical and hormonal changes leading to the differentiation of the stolon into a vegetative storage organ (Tsegaw et al., 2005). Cool temperatures inhibits tuberization under both short and long photoperiods, however the intensity of inhibitory is greater under long days. (Wheeler et al., 1986)Cool air temperature induces tuberization and high soil temperature block the expression of tuberization stimulus on the nodes (Reynolds & Ewing, 1989). Tuberization begins with the inhibition of the longitudinal growth at stolon tip followed by the swelling at the sub apical region. (Jackson, 1999).

High temperature directly or indirectly mediates changes in hormonal concentrations in the plant (Ewing, 1990).Cool seasons with an optimum temperature of 15-25^{0}C for foliage growth and 14-22^{0}C for tuberization are the favorable conditions for potato production (Levy, 1992). At high temperatures above 25^{0}C foliage growth is promoted at the expense of tubers thus tuberization is inhibited (Wolf et., al 1990).Rising of temperatures above the minimum point where carbohydrate is consumed by respiration exceeds the amount of carbohydrate produced by photosynthesis ,tuber growth is completely inhibited. This will result in less starch available to promote tuber growth.

Potato grown under high temperatures have tall plants with long internodes ,because assimilates are partitioned to foliage growth (Tsegaw et al,2005).High temperatures decrease the rate of photosynthesis, tuber production as well as tuber weight assimilate partitioning to the tubers is reduced (Schafleinter et al,2003).Exposing plants to high temperature will result in big and healthy vines with low yields (Thornton,2002).Inhibitory effects of high temperature are mediated through the production of high levels of gibberellin like compounds that are known to inhibit tuberization (Menzel , 1983).Temperature has effect on the number of tubers than on yield, thus the main effect seemed to be on tuber initiation than on subsequent growth of tubers (Ewing, 1990).High soil temperature reduces tuber yield than high day temperature, whereas low night temperature reduce tuberization (Ewing, 1990).The physiological basis for tuberization under long-day conditions involves biochemical and molecular signals that link photoperiod perception in leaves to changes in cellular growth patterns in stolons (Rodriguez-Falcon et al. 2006).

2.4.1 Effects of temperature on reducing sugar content of potato

Environmental factors such as temperature affect the chemical composition of potato both in production and storage (Levy et al., 2006). Dry matter of potato tubers and chip color are genetically controlled and influenced by environmental conditions during growing season and storage temperature (Kawchuk et al., 2008). Low reducing sugars and phenol contents are required to avoid dark color and bitter taste of processed products, which negatively affect consumer acceptance (Wiltshire and Cobb, 1996). Potatoes for fresh chips production must have reducing sugar content below 0.35mg/g of the fresh tuber weight whilst those for French fries should have sugar content less than 12mg/g of the tuber fresh weight (Stark et al., 2003).Temperature and photoperiod during the growing season affect sugar and dry matter content of potatoes and therefore the chipping quality ,sugar content increase. If the tuber is exposed to soil temperatures of below 8-12^{0}C or above 25-30^{0}C(Kumar et al.,2007)Even temperature gradient within a hill affects the sugar content in tubers .Yamaguchi et al.,(1964) noted that sugar content was lowest when tubers were grown in soil temperatures between 15 and 24^{0}C compared to tubers grown in higher temperatures .Low temperatures during the final growing stage season gives rise to an increase in sugar levels because increased respiration has a negative effect on the rate of starch biosynthesis.(Stark et al., 2003).

2.5 Role of plant hormones in tuberization of potato

Tuber initiation in the potato plant is accompanied by extensive morphological and biochemical changes above and below ground. Plants that are capable of tuber initiation are said to be "induced" to tuberize. It has long been noted that the changes leading to induction are mediated hormonally. All classes of hormones have some effect on one of the different stages of tuberization in potato (Appeldoorn, 1997).Growth regulators in potato tuberization shows that gibberellins inhibit and abscisic acid promotes tuber induction (Alexious et al., 2006).Application of gibberellins promotes development of new stolons and increase plant height and internode length (Tsegaw & Hammes, 2004).

2.5.1 Role of gibberellins in tuberization of potato

Gibberellins (GA) are a group of hormones that plays an important role in tuberization. Tuberization is controlled by the balance between endogenous gibberellins and a tuber forming stimulus and the level of gibberellins should be below the threshold levels (Tsegaw et al., 2005). Gibberellic acids are a large group of tetracyclic diterperonoid carboxylic acids that functions as growth hormones in higher plants (Sponsel et al., 2004). Several plant hormones have been implicated in tuber initiation, in particular gibberellic acid was shown to have a strong inhibiting effect, and degradation of active gibberellic acid in the stolon tip at tuber formation is important for tuberization to proceed normally (Ewing and Struik, 1992). The application of GA-biosynthesis inhibitors promoted tuber initiation (Balamani & Poovaiah, 1985; Simko, 1994). GA inhibits tuberization and appears to play a role in the photoperiodic control of tuberization by preventing tuberization in long day (Jackson, 1999). Accumulation of gibberellic acid in tuber tissue increases starch accumulation and other proteins (Vreugdenhil et al., 1999). The inhibition of tuberization by gibberellic acid is partly attributed to its effect on carbohydrate metabolism especially the utilization of sucrose (Jackson, 1999).

Yim et al., (1997) noted that high gibberellic acid activity leads to higher carbohydrate allocation to the shoots, while low gibberellic acid level resulted in more dry matter allocation to the roots. GA increases sink strength at the point of application (Mulligan & Patrick, 1979).

2.6 Paclobutrazol

Paclobutrazol is a growth stimulator with wide spectrum activities and various functions. The most activity is of paclobutrazol is the inhibition of gibbrellic synthesis in plants. (Davis & Curry, 1991) Paclobutrazol [2RS,3RS]-1-[4-chlorophenyl]-4,4-dimethyl-2-(1H-1,2,4triazol-1-yl) pentan-3-ol, consists of a triazole ring and a benzene ring-chloro linked to a carbon chain open. The inhibition of biosynthesis is due to slow cells division and elongation without resulting in toxicity to cells (Fletcher et al., 1986).

2.6.1 Mode of action of paclobutrazol in potato production

Paclobutrazol is a plant growth regulator used in many crops in order to produce fruit throughout the year by inhibiting gibberellin synthesis. It belongs to the triazole compounds that are characterized by a ring structure containing three nitrogen atoms, chlorophenyl and carbon side chains (Fletcher et al., 1986). Its direct effects include inhibited plant vegetative growth. Gibberellin is a hormone responsible for the vegetative plant growth .Studies are showing that paclobutrazol remains active in the soil for a long time, affecting the growth and development of subsequent crops by reducing plant vigor (Tsegaw et al., 2005). Application of paclobutrazol in plants induces stress protection against drought and temperature because it increases the levels of abscisic acid (Zhu et al., 2004). Paclobutrazol induces shoot growth reduction and assimilate partitioning to underground parts (Tsegaw & Hammes, 2004). Paclobutrazol increases dry matter content ,partitioning of assimilates in the plant and it also regulates hormonal balance(Tsegaw et al., 2005). Among those are improved resistance to drought stress, darker green leaves, higher resistance against fungi and bacteria, and enhanced development of roots. Cambial growth, as well as shoot growth, has been shown to be reduced in some plant species. (Grossman, 1990). Treatment of plants with paclobutrazol result in darker leaves due to high chlorophyll and thick stems (Tsegaw et al., 2005.It also affects the sugar content and partitioning between soluble sugars and starch (Okazawa, 1962). In high temperatures paclobutrazol has been reported to increase yield and quality of potato tuber because it reduces gibberellin that are inhibitory to protein and starch accumulation (Tsegaw & Hammes, 2004). 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

2.6.2 Effect of time of application of paclobutrazol on potato

Application time of paclobutrazol may affect potato yield in high temperature areas.(Mabvongwe et al.,2016).Paclobutrazol reduced haulm length in both cultivars significantly, particularly when the treatment was applied at early stolon initiation, but the late treatment reduced haulm length only when growing in large pots (Bandara et al., 1999). Application of paclobutrazol at both early and late tuber initiation reduces vegetative growth significantly particularly when the treatment is applied at early stolon initiation (Bandara et al., 1999). Paclobutrazol applied at early stolon initiation increased usable tuber number by 330 and 67% , Paclobutrazol applied at late stolon initiation increased usable tuber number by 230%

Mabvongwe et al. ,(2016) revealed that applying paclobutrazol early results in potato plants with thicker and compact stems than late application, also early application of paclobutrazol increased the diameter of stems compared to late applications .Bandara et al. (1999) concluded that paclobutrazol should be applied at relatively early stage to improve on quality and yield of potato .Mabvongwe et al.,(2016) also concluded that early application of paclobutrazol at 28 DAP is recommended in high temperature zones as it increased the quality and yield of potato.

CHAPTER 3

3.1 MATERIALS AND METHODS

3.1.2 Research Site and Characteristics

The study was carried out at Chiredzi Research Station (CRS) in the fieldon an open space. Chiredzi Research Station lies between 21 ^{0}33 S and 31 ^{0} 30E in Masvingo Province of Zimbabwe.It is located near buffalo range air port between Triange and Chiredzi. It has an altitude of 429 m above sea level. Chiredzi research station is characterized by hot , dry conditions and low rainfall of 500 mm on average per annum.

3.1.3 Experimental Design and treatments

The trial was laid out in a Completely Randomized Design replicated 3 times. The treatments of application time of paclobutrazol on potato are shown in Table 3.1.

Table 3.1: Treatment structure for the effect of time of paclobutrazol application on growth, quality and yield of potato.

Treatment	Time of paclobutrazol application(DAP)
1	28
2	35
3	42
4	49
5	56
6	63
7	70
8	77

3.2 Trial management

Potato variety Amythest was treated with gibberellic acid and left to sprout in a dark room until the sprouts were about 2cm in length. Amythest was used because it has a high degree of tolerance to late blight and also perform well in all regions. 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 a 50 kg Burlap sacks. The sacks were initially half filled with soil to a height of 25cm. Compound S (7:21:7) was used as basal dressingat a rate of 2000kg/ha and was incorporated into the sacks. Planting holes that were 10cm deep were dug in each sack and 2 tubers were placed in each sack, covered with soil and irrigated.

Top dressing was done at four weeks after emergence using Ammonium Nitrate (34.5% N) at a rate of 200kg/ha. Earthing up was done by filling up the sacks 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 sacks whilst they were still young. Watering was done when necessary depending on the stage of crop growth.

3.3 Treatment application

Paclobutrazol 29.9% active ingredient was applied at a rate of 250g/ha and was applied at periods as per treatment (Table 3.1). A 15 litre knapsack sprayer was used for spraying to attain full cover spray.

3.4Measurements taken

3.4.1Stem length (cm)

Two plants per sack were sampled for measuring of stem length. A 1m ruler was used for measuring stem length and was measured from the base of the stem to the apex of the plant. Measurements for stem length were done at 28 DAP and weekly thereafter till end of experiment.

3.4.2 Diameter of stems (cm)

The diameter of stems was measured using a Vernier caliper. Two plants per sack were sampled for measuring diameter and measured at the base of the stem. Diameter was measured at 28 DAP and weekly thereafter till end of experiment.

3.4.3 Number of tubers per sack

The total number of tubers harvested in each sack were counted and recorded at 112 DAP.

3.4.4 Yield of potato (g) per sack

All plants in each sack were harvested ,washed and weighed on a digital scale.

3.4.5 Potato diameter (cm) per sack

Tubers harvested from each sack were randomly selected and took the diameter by taking the circumference of the potato and dividing it by two.

3.4.6 Reducing sugar content of tubers as % glucose

Three tubers per plot were sampled for reducing sugar testing. The tubers were washed to remove all foreign material, then cut it into 2 halves. After cutting the tubers juice was drained and reducing sugar content were determined using the Brix refractometer.

3.5 Data analysis

One way analysis of variance was done using Genstat 14th edition. Separation of means was done out using Least Significant Difference at 5% level.

CHAPTER 4

4.0 RESULT

4.1 Effect of time of paclobutrazol application on potato stem lenght (cm) at 35 , 49 and 70 dap

There were significant differences (p<0,05)in time of paclobutrazol application with regards to stem length as shown in Table 4.1.Paclobutrazol treatment at 28 and 35 DAP resulted in shorter stems . The longest potato stem length was recorded in plants were paclobutrazol was applied at 77DAP and was not different from 70,63 and 56 DAP.

Table 4.1: effect of time of paclobutrazol application on potato stem length (cm)

Time of paclobutrazol	**Stem length (cm)**		
application (DAP)	**35 DAP**	**49DAP**	**70DAP**
28	9.67^{d}	10.33^{d}	11.00^{d}
35	11.33^{d}	15.00^{cd}	17.00^{c}
42	16.33^{c}	16.33^{cd}	17.00^{c}
49	18.33^{bc}	19.33^{bc}	20.33^{bc}
56	22.33^{ab}	22.67^{ab}	23.33^{ab}
63	23.00^{ab}	25.33^{ab}	26.00^{ab}
70	24.67^{a}	25.33^{ab}	26.33^{a}
77	25.67^{a}	26.67^{a}	26.67^{a}
P value	<.001	<0.001	<.001
LSD0.05	4.753	6.251	5.752
CV%	14.5	17,9	15.8

Table 4.2 effect of time of paclobutrazol application on diameter of stems (cm) at 35, 49 and 70dap

Significant differences (P<0.05) in time of paclobutrazol application was observed with respect to diameter of stems as shown in Table 4.2 below. Application of paclobutrazol at 28 DAP resulted in thicker stems and were not statistically different from 35 , 42 and 49DAP. Application of paclobutrazol at 77 DAP resulted in thinner stems and was not statistically different from 70, 63 and 56 DAP.

Table 4.2: effect of time of paclobutrazol application on diameter of stems

Time of paclobutrazol	Stem diameter (cm)		
application (DAP)	35 DAP	49DAP	70 DAP
28	0.8533[a]	0.9277[a]	0.9650[a]
35	0.8533[a]	0.8603[ab]	0.9303[ab]
42	0.7433[ab]	0.7843[abc]	0.8500[ab]
49	0.7367[ab]	0.7770[abc]	0.7813[bc]
56	0.6940[ab]	0.7487[bc]	0.7763[bc]
63	0.6460[b]	0.6783[cd]	0.6787[cd]
70	0.6280[b]	0.6280[cd]	0.6287[cd]
77	0.5753[b]	0.5813[d]	0.5857[d]
P value	0.005	0.001	0.001
LSD	0.1726	0.1611	0.1683
CV%	13.9	12.4	12.6

Table 4.3 effect of time of paclobutrazol on number of tubers per sack

There was significant difference (p<0,05)on time of paclobutrazol application on number of potatoes per sack as shown in Table 4.3. Paclobutrazol at 28,35 and 42 DAP has the least number of tubers . Highest number of tubers was observed at paclobutrazol application at 42, 56 ,63 ,70 and 77 DAP.

Table 4.3: effect of time of paclobutrazol application on number of tubers

Treatment	Number of tubers
28DAP	2.667[a]
35 DAP	3.667[a]
42 DAP	4.333[a]
49DAP	6.333[b]
56DAP	6.333[b]
63DAP	7.000[b]
70DAP	7.333[b]
77DAP	7.667[b]
P value	<0.01
L.S.D.	1.870
C.V.%	19.1

Table4.4 effect of time of paclobutrazol application on potato tuber yield per sack (g)

Significant differences ($P<0.05$) on time of paclobutrazol application were observed with regards to the yield as shown in Table 4.4 below. The highest yield was observed in treatments where paclobutrazol was applied at 77,70 ,63 although it was significantly different from 56 and 49 DAP .The least yield was observed in treatments where paclobutrazol was applied at 28 DAP and 35 DAP although it was not statistically different from 42,49 and 56 DAP.

Table4.4: effect of time of paclobutrazol application on potato tuber yield per sack (g)

Treatment	Yield of tubers (g)
28DAP	54.33[a]
35 DAP	57.67[a]
42 DAP	67.33[ab]
49DAP	80.33[abc]
56DAP	94.33[abc]
63DAP	95.00[c]
70DAP	96.33[c]
77DAP	101.00[c]
P value	<0.01

Table 4.5 effect of time of paclobutrazol application on potato diameter

Significant differences ($P<0.05$) on time of paclobutrazol application were observed with regards to diameter of tubers as shown in Table 4.5 below .Highest potato diameter was observed in treatments where paclobutrazol was applied at 28 and 35 DAP .Treatments 42,49,56,63,70 and 77 DAP had the least tuber diameter.

Table 4.5:effect of time of paclobutrazol application on potato diameter

Treatment	Diameter of tubers
28DAP	96,67[a]
35 DAP	86,67[a]
42 DAP	63,33[b]
49DAP	60,00[b]
56DAP	55,00[b]
63DAP	55,00[b]
70DAP	55,00[b]
77DAP	50,00[b]
P value	<0.01
L.S.D.	27,07
C.V.%	19,4

4.6. Effects of time of paclobutrazol application on reducing sugars

There were significant differences in time of paclobutrazol application (P <0,05) with regards to percentage sugar content of tubers as shown in Table 4.6.Highest reducing sugar content was recorded where paclobutrazol was applied at 77,70,63 and 56 although it was not significantly different from 49 DAP. The lowest tuber reducing sugar content was recorded in treatment where paclobutrazol was applied at 28DAP.

Table 4.6: Effect of time of paclobutrazol application on reducing sugars

Treatment	Reducing sugar content
28 DAP	3.000^{a}
35 DAP	5.000^{b}
42 DAP	5.000^{b}
49 DAP	6.333^{bc}
56 DAP	6.667^{c}
63 DAP	7.000^{c}
70 DAP	7.000^{c}
77 DAP	7.333^{c}
P value	<0.01
L.S.D.	1.619
C.V. %	15.8

CHAPTER 5

5.0: DISCUSSION

5.1 : Effect of time of paclobutrazol application on potato stem length (cm) at 35,49 and 70 dap

Early application of paclobutrazol at 28 and 35 days after planting resulted in shorter stems than late application. This is because early application of paclobutrazol quickly restricted the activity of gibberellic acid which is responsible for cell elongation, Late application of paclobutrazol resulted in long stems because of the presence of high levels of gibberellic acid before the application which are responsible for cell elongation up to a point when paclobutrazol was applied. Paclobutrazol is a plant growth retardant that is responsible for blocking three steps in the terpenoid pathway for the production of gibberellins(Fletcher et al.,2000).Gibberellins are responsible for the stimulation of cell elongation, so when the production of gibberellins is inhibited ,cell division occurs but they do not elongate ,resulting in shorter internodes hence reduce plant height(Pinto et al.,2006).In another experiment where paclobutrazol was applied in potato ,early application resulted in shortening stem length due to the reduction of the internode length.(Mabvongwe et al.,2016)

5.2: Effect of paclobutrazol on diameter of stems (cm) at 35,49 and 70 dap

An increase in stem diameter was observed in plants where paclobutrazol was applied early at 28DAP compared to plants where paclobutrazol was applied late .Early application quickly lowered gibberellic acid level increasing radial expansion within the plant cell because high levels of gibberellic acid limit radial expansion, Late application of paclobutrazol resulted in thinner stems due to the presence of high levels of gibberellic acid before paclobutrazol application which limited the radial expansion hence thinner stems. This could be attributed by the low levels of gibberellic acid after application of paclobutrazol as high levels of gibberellic acid limit radial expansion of plant organs (Wenzel et al .2000).Paclobutrazol increases the breadth of cortex ,vascular bundles and pitch diameter resulting in thicker stems(Tsegaw and Hammes 2004).Thickness of stems could also attributed to the initiation of a thicker cortex , well developed vascular bundles and a larger pith diameter in reaction to the treatment .In support of this view ,Swain et al ,(2005) found out that paclobutrazol treatment resulted in shorter stems than the control ,because internodes were compressed resulting in compact and short plants. This was also found by Thongbai et al,(2007) in jatropha.

5.3 Effect of paclobutrazol on number of tubers

Early application of paclobutrazol of paclobutrazol at 28,35 and 42 DAP resulted in the least number of tubers than late application at 77,70,65. This could be attributed to the fact that early application of paclobutrazol caused a reduction in gibberellins which are responsible for stolon initiation ,hence few number of stolons lead to few tuber number because numbers are formed when stolons differentiate into vegetative storage organs. Late application of paclobutrazol had the highest number of tubers due to high levels of gibberellic acid before the application of paclobutrazol which then resulted in more stolon formation hence high numbers of tubers after the differentiation of stolons into the vegetative organs. By reducing gibberellins ,paclobutrazol reduces photosynthetic substances in the underground parts of the plant such as bulbs and tubers. Reduction in tuber number is attributed to the decline in stolon number due to a decrease in Gibberellic acid which maybe in relation with stolon initiation(Kumar and Wareing 1972)Former and Sonnewald (1995) revealed among other factors competition among tuber initials reduces final tuber number. This is based on the explanation that upon induction to tuberization ,multiple tuber primordials are formed and during early growth stage some of the tubers get a competitive advantage over others and thus out compete other primordials and stop their further development.

5.4 Effect of paclobutrazol on tuber yield (g)

In this project early application of paclobutrazol at 28 and 35 DAP resulted in low yield than late application of paclobutrazol at 7770 and 63 DAP. It is possible that these treatments had the least weight because they had the least number of potatoes ,late application resulted in more potato numbers leading to increased weight. However in some researches done by Mabvongwe et al.,(2016) the highest yield was recorded in treatments where paclobutrazol was applied 28 DAP because the highest stem reduction was observed in plants treated with paclobutrazol at 28DAP and hence more assimilates were channeled to tuber growth increasing yield.

5.5 Effect of paclobutrazol on potato diameter

Early application of paclobutrazol at 28 and 35 DAP had potatoes with the largest diameter compared to late application of paclobutrazol at 77,70,63,56,49 and 42 DAP. Increase in potato diameter in early application may be as a result of low completion for assimilates because these treatments had tubers with few number of tubers hence low completion of assimilates leading to large potatoes compared to late application of paclobutrazol. Late application of paclobutrazol had low yield because they more tuber number which resulted in more competition for assimilates hence small sizes. This could have also been caused by early tuberization, in early applied plants as tubers produced at the establishment of tuber induction usually attain the greatest size because they will have more time to be a magnet for assimilates during tuber bulking stage. To support this idea Simko (1994) reported increased tuber weight per plant in response to paclobutrazol although this was not clear if the increase was a consequence of tuber size.

5.6 Effect of paclobutrazol on potato reducing sugars

Early application of paclobutrazol at 28 and 35 DAP lowered reducing sugar content than late application at 77,70,63 and 56 DAP . Low levels in reducing sugar content in early application could have been caused by low levels of gibberelic acid that stimulates enzymes such as starch synthesis and starch biosynthesis that convert sugars to starch (Appeldoorn et al.,2007). Early application of paclobutrazol quickly resulted in converting of sugars to starch than late application .Reducing sugars are important substances which determines the quality of potato chips and French fries. Low reducing sugars are required to avoid dark color and bitter taste of processed products, which negatively affect consumer acceptance (Wiltshire and Cobb, 1996).Potatoes for chip production are required to have reducing sugar content below 0,35mg/g of fresh tuber weight whereas for French fries tubers must have 12mg/g reducing sugar content. These results concurs with those of Mabvongwe et al. ,(2016) who found application of paclobutrazol at 28 DAP had low levels of reducing sugar content.

CHAPTER 6

6.0CONCLUSION AND RECOMMENDATIONS

The conclusions from this study are:

- Early application of paclobutrazol at 28 and 35 DAP reduced the stem length.
- Early application of paclobutrazol at 28 and 35 DAP increased stem diameter.
- Late application of paclobutrazol at 77,70,63,56 and 42 DAP had the highest number of tubers.
- Early application of paclobutrazol at 28 and 35 DAP increased potato diameter.
- Late application of paclobutrazol at 77,70 and 63 DAP had the highest yield.
- Early application of paclobutrazol at 28 DAP had the least reducing sugar content.

The recommendations derived from this study are:

- If farmers are interested in bigger tubers, they should apply paclobutrazol early although this will result in few tubers

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APPENDICES

A 1: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 28 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatment	7	771.167	110.167	14.61	<.001
Residual	16	120.667	7.542		
Total	23	891.833			

A2: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 35 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatment	7	721.96	103.14	7.91	<.001
Residual	16	208.67	13.04		
Total	23	930.62			

A3: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 42 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatment	7	721.26	103.14	7.91	<.001
Residual	16	208.67	813.04		
Total	23	1930.62			

A4: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 49 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatment	7	707.17	101.02	9.15	<.001
Residual	16	176.67	11.04		
Total	23	883.83			

A5: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 56 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	721.96	103.14	7.91	<.001
Residual	16	208.67	13.04		
Total	23	930.62			

A6: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 63 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	630.29	90.04	2.95	0.035
Residual	16	488.67	30.54		
Total	23	1118.96			

A7: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 70 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	692.667	98.952	10.06	<.001
Residual	16	157.333	9.833		
Total	23	850.000			

A8: ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON STEM LENGHT (cm) AT 77 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	692.667	98.952	10.06	<.001
Residual	16	157.333	9.833		
Total	23	850.000			

A:9 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 28 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	0.215429	0.030776	3.10	0.029
Residual	16	0.159035	0.009940		
Total	23	0.374465			

A:10 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 35DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	0.282274	0.040325	4.66	0.005
Residual	16	0.138570	0.008661		
Total	23	0.420844			

A:11 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 42 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	0.392607	0.056087	5.74	0.002
Residual	16	0.156229	0.009764		
Total	23	0.548835			

A:12 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 49 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	0.397302	0.056757	6.00	0.001
Residual	16	0.151282	0.009455		
Total	23	0.548584			

A:13 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 56 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	229038	32720	6.42	0.001
Residual	16	81583	5099		
Total	23	310622			

A:14 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 63 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	229038	32720	6.42	0.001
Residual	16	81583	5099		
Total	23	310622			

A:15 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 70 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	229038	32720	6.42	0.001
Residual	16	81583	5099		
Total	23	310622			

A:16 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON DIAMETER OF STEMS (cm) AT 77 DAP

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	229038	32720	6.42	0.001
Residual	16	81583	5099		
Total	23	310622			

A:17 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON NUMBER OF TUBERS PER SACK

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	72.668	10.381	8,90	<001
Residual	16	18.667	1.167		
Total	23	91,333			

A:18 ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON POTATO TUBER YIELD PER SACK

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	7354.0	1050.6	4.30	0.007
Residual	16	3912.0	244.5		
Total	23	11266.0			

A.19:ANOVA OF THE EFFECT OF TIME OF PACLOBUTRAZOL APPLICATION ON POTATO DIAMETER

Source of Variation	Df	Ss	Ms	Vr	Fpr
Treatments	7	6073.96	867.71	8.96	<.001
Residual	16	1550.00	96.87		
Total	23	7623.96			

A:20 ANOVA OF THE EFFECTS OF TIME OF PACLOBUTRAZOL APPLICATION ON REDUCING SUGARS

Source of Variation	Df	Ss	ms	vr	Fpr
Treatments	7	45.8333	6.5476	7.48	<.001
Residual	16	14.0000	0.8750		
Total	23	59,8333			