EFFECT OF TIME AND METHOD OF PACLOBUTRAZOL APPLICATION ON GROWTH, QUALITY AND YIELD OF POTATO (*Solanum tuberosum* L.)

BY

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DECLARATION

I hereby declare that this dissertation, prepared for the Masters of Science degree in Crop Sciences, which I submitted to the Faculty of Agriculture and Natural Resources Management of Midlands State University of Zimbabwe is my original work. All sources of literature and materials used for this study have been duly acknowledged. 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...

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The undersigned certify that they have read and recommended for submission to the department of Agronomy, in partial fulfilment of the requirements of the Master of Science Degree in Crop Science, a dissertation by Mabvongwe Ottilia entitled: Effect of time and method of Paclobutrazol application on growth, quality and yield of potato (*Solanum Tuberosum* L.*)*.

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ABSTRACT

Potato is one of the most widely grown tuber crop that contribute significantly to human nutrition and food security. 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 balance of hormones that control tuberization can be managed by using anti-gibberellin synthesis such as paclobutrazol to overcome the inhibitory effect caused by gibberellins. Two experiments were set up in a greenhouse with 60% relative humidity, 34 ^{0}C(±3) and 21 ^{0}C(±3) day and night temperature respectively at Harare Research Station to investigate the effect of paclobutrazol on growth, yield and quality of potatoes. The first experiment was set up as a 4 x 2 factorial design in a CRD with 3 replications to investigate the effect of time of paclobutrazol application on the growth, yield and quality of potato. The first factor was potato variety and the levels were BP1 and Diamond. The second factor was paclobutrazol application time and the levels were 28 DAP, 35DAP, 42DAP and no paclobutrazol applied (control). Early application of paclobutrazol at 28DAP increased yield and starch content by 108% and 28% respectively compared to the no paclobutrazol treatments. The second experiment was set up as a 4 x 2 factorial design in a CRD with 4 replications to evaluate the effect of method of paclobutrazol application and variety on growth, yield and quality of potato. The first factor was potato variety and the levels were BP1 and Diamond. The second factor was paclobutrazol application method and the levels were drench, foliar and no paclobutrazol applied (control). Regardless of the method of application, paclobutrazol increased yield, grades and tuber starch content of potato but the effect was more in drench applied plots compared to foliar applied treatments. Drench application increased stem diameter and yield by 85% and 120% respectively.

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DEDICATION

I dedicate this work to my mother, Monica Bayanai, my father, Phillip Mabvongwe, and my husband Owen, you are so precious to me. May the good Lord continue to bless you.

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ABBREVIATIONS

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

CHAPTER 1

1.0 INTRODUCTION AND BACKGROUND

Irish potato (*Solanum tuberosum* L.) is one of the most widely grown tuber crop in the world and contributes immensely to human nutrition and food security (Miguel, 1985; Steven, 1999; Karim *et al.*, 2010). Potato contains high quality proteins and a substantial amount of essential vitamins, minerals, high carbohydrate content, calcium, potassium and vitamin (Ngwerume, 2002). Potato has high carbohydrate and low fat content and makes it an excellent energy source for human consumption (Dean, 1994). It produces more edible energy and protein per unit area of land in less time and grows even under unfavourable conditions than other food crops (Paul, 1985).

Despite the economic importance of potato, its production is faced with a number of environmental challenges that reduce the productivity of the crop. Among the environmental factors, temperature is known to affect the physiological processes of the potato plant (Tsegaw *et al*., 2005). Potato is a cool season crop requiring an optimum soil temperature of between 15-18 ^{0}C for tuberization (Levy *et al.*, 2007). The optimum temperature for photosynthesis is between 20-24 ^{0}C and 14-22 ^{0}C for the maximum development of tubers (Schafleinter, 2013). High temperatures are inhibitory to tuberization under both long and short photoperiod though the inhibition is greater under long days (Wheeler *et al.*, 1986). High temperatures at tuberization cause the stolons to grow upward and emerge out of the soil to form new shoots instead of forming tubers (Jackson, 1999).

The yield and quality of potato is reduced at high temperatures as compared to low temperatures since the latter promote tuberization and increase dry matter content of tubers (Tsegaw & Hammes, 2004). The lower yield of potato grown at high temperature has been attributed to partitioning of assimilates to stems and leaves at the expense of tubers as the conditions promote foliage growth (Tsegaw *et al*., 2005). High temperatures affect dry matter partitioning to below ground plant parts and the net amount of photosynthesis available for the whole plant (Ewing, 1985). At temperatures above 30 ^{o}C, the rate of dark respiration increases and the net assimilation falls to zero resulting in the reduction of yield (Levy *et al.*, 2007). The inhibitory effect of high temperatures to tuberization is believed to be mediated by the production of endogenous gibberellins which promote stem elongation, shoot growth and delay tuberization (Lovel & Booth, 1967; Menzel, 1983).

Gibberellic acid functions as plant growth regulators in higher plants responsible for stimulating growth of plant organs through enhanced cell division and cell elongation throughout the life cycle of a plant (Colebrook *et al*., 2014). High temperature directly or indirectly mediates changes in hormonal concentrations in the plant (Ewing, 1990).There is compelling evidence that indicate that gibberellic acid plays a very vital role in tuberization in potato (Tsegaw *et al*., 2005). Gibberellic acids are inhibitory to tuberization and play a role in the photoperiodic control of tuberization by preventing tuberization under long days (Jackson, 1999).

High levels of endogenous gibberellins promote shoot growth, delay or inhibit tuberization, impede starch and protein accumulation (Vandam *et al.*, 1996).Tuber formation is controlled by the balance between endogenous gibberellic acid and the tuber forming stimulus and the level gibberellic acid should be below the threshold for tuberization to occur (Hammes *et al*., 1975). The level of endogenous gibberellins can be moderated by application of anti-gibberellin biosynthesis such as paclobutrazol to reduce foliage growth and induce tuberization in potato (Tsegaw *et al*., 2005).

Plant growth regulators such as paclobutrazol are known to decrease the level of endogenous gibberellic acid and abscisic acid catabolism under high temperatures to improve yield and quality of potato (Rademacher, 1997). 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 in horticulture as a plant growth regulator (Davis & Curry, 1991). The principal mode of action reported for paclobutrazol is through the inhibition of gibberellin biosynthesis and abscisic acid catabolism through its interference with ent-kaurene oxidase activity in the ent-kaurene oxidation pathway which are the key steps in gibberellic acid biosynthesis (Rademacher, 1997).

Paclobutrazol is an effective plant growth regulator that reduces unnecessary vegetative growth and diverts assimilates to reproductive growth giving increased yield under conditions of elevated temperatures (Lever, 1986; Davis & Curry, 1991). Paclobutrazol reduces plant height and increases chlorophyll content of leaves (Hawkins *et al*., 1985). Elsewhere, paclobutrazol has been used as a successful means of restricting vegetative growth and increasing fruit production in fruit crops (Richardson & Quinlan, 1986).

The response of plants to paclobutrazol applications differs depending on the time of application, method of application, concentration and plant species (Tsegaw *et al*., 2005). Application of paclobutrazol soon after tuber induction result in a decrease in shoot growth and increase in tuber growth by increasing the mobilization of assimilates to tuber formation (Balamani *et al*., 1985). Time of paclobutrazol application is important so as to coincide with the beginning of tuber formation so as to maximise on tuberization because the lowest stolons formed at the beginning of tuber induction overally attain the greatest tuber weight (Levy *et al*., 2007).

The most efficient and economical method of paclobutrazol application is important so as to maximise on crop production (Tsegaw *et al*., 2005). Triazoles have high chemical stability and the rate of metabolism in the plant is slow and depends on the site of application (Davis *et al*., 1991). There is need to establish the best time of application and the most efficient method of paclobutrazol application using our local varieties as there is limited information in the area. The information on the best application time and method of paclobutrazol may help to increase the area and productivity of potato in the warm areas of Zimbabwe which represent about 43% of the land (Gore *et al*., 1992). If the yield of potato can be increased in the warmer areas, it could lead to food and nutrition security in Zimbabwe.

1.1 Main objective

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

1.2 Specific Objectives

1.2.1. To determine the effect of time of application of paclobutrazol and variety on stem length, stem diameter, number of tubers per plant, size of tubers, yield, starch and reducing sugar content of potato.

1.2.2. To evaluate the effect of method of paclobutrazol application and variety on stem length, stem diameter, number of tubers per plant, size of tubers, yield, starch and reducing sugar content of potato.

1.3 Hypotheses

1.3.1 Time of application of paclobutrazol and variety has a significant effect on the stem length, stem diameter, number of tubers per plant, size of tubers, yield, starch and reducing sugar content of potato.

1.3.2 Method of spraying paclobutrazol and variety has a significant effect on the stem length, stem diameter, number of tubers per plant, size of tubers, yield, starch and reducing sugar content of potato.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1. Origin and distribution of potato

Potato (*Solanum tuberosum* L.) originated in the Andes of South America (Hawkes, 1992) where it was cultivated mostly at altitudes between 2 000m and 4 000m, in a region characterized by short day length, high light intensity, cool temperatures and relatively high humidity (Levy *et al*., 2007). Potato is now widely grown under different climatic conditions such as high temperatures and long photoperiod (Levy *et al.*, 2007).

2.2 Economic Importance of potato

Potato ranks number one amongst the root crops in terms of volume produced and consumed (FAOSTAT, 2004) contributing immensely to human nutrition and food security (Karim *et al*., 2010). Cultivated potato is one of the most important vegetable in the world that supplies at least 12 essential vitamins, minerals, proteins, carbohydrates and iron (Blackman & Overall, 2001). Potato has high carbohydrate with low fat and this makes it an important energy source for human consumption (Dean, 1994). Potato is one of the crops that have a high efficiency in converting natural resources, capital and labour into quality food with widespread consumer preference (Horton, 1980).

2.3 Challenges in potato production

High nitrogen levels, long photoperiods, low light intensity and high soil and air temperature are detrimental to potato production as they alter hormonal balance and delay tuberization (Tsegaw *et al*., 2005). The induction of the tuberization stimulus decline with increasing nitrogen levels as it enhances partitioning of assimilates to shoots rather than to the tubers (Biemond, 1992). Tuberization of potato plants is strongly influenced by day length and the induction to tuberize is promoted by short photoperiod (Tsegaw & Hammes, 2004). Long photoperiods delay the onset of tuber growth and bulking as it reduces the partitioning of assimilates to the tubers (Vandam *et al.*, 1996; Wolf *et al.*, 1990). One of the major causes of low yields in the tropics is heat stress and result in yields that are 30% of the global mean (Schafleinter *et al.*, 2013). High temperatures are inhibitory to potato tuberization under both short and long photoperiods (Wheeler *et al.*, 1986). The inhibition effect to tuberization under high temperatures is more pronounced under long photoperiods (Tsegaw *et al*., 2005).

2.4 Temperature and potato production

2.4.1 Effect of temperature on growth and assimilate partitioning of potato

Potato is a cool season crop which requires an optimum temperature range of 15-25^{0}C for foliage growth and 14-22^{0}C for tuberization (Levy, 1992). At high temperatures, foliage growth is promoted and the rate of dark respiration increases resulting in low yields (Thornton *et al.*, 1996). The growth of tubers comes to a halt when the temperature exceeds 29^{0}C as carbohydrate consumed by respiration exceeds that produced by photosynthesis (Levy, 1992).

The partitioning of assimilates to different plant sink organs is regulated by the environment and hormonal balances (Almekinders, 1996). When temperature increase above the point where the carbohydrate consumed by respiration exceeds the amount of carbohydrate produced by photosynthesis, tuber growth will be completely inhibited (Burton, 1972). Respiration rates increase at elevated temperatures resulting in a negative carbon balance and the dark respiration rate of potato doubles for each 10^{0}C increase in temperature (Schafleinter *et al.*, 2013). The net result is less starch available to drive plant and tuber growth.

The growth and development of different potato plant parts is affected by total assimilate production and partitioning among sink organs (Tsegaw *et al*., 2005). When more assimilates are partitioned to haulm growth, tuber formation is restricted as shoot and tuber formation are considered to be competing processes (Tsegaw & Hammes, 2004). At low temperatures haulm growth is restricted and this promotes accumulation of dry matter to tubers and vice versa happens at high temperatures (Menzel, 1985. There is a tendency to assimilate more of the available starch for growth to go towards the vines at the expense of tuber growth at high temperatures (Thornton, 2002). Potato grown under high temperatures are characterised by tall plants with long internodes, increased leaf and stem growth as more assimilates will be partitioned to foliage growth (Tsegaw *et al.*, 2005). Where temperatures are in excess of 30^0C, the net assimilation for potato falls to zero resulting in the reduction of yields (Burton, 1981).

Temperature plays a very important role to the onset of tuber growth and the subsequent dry matter partitioning to storage organs (Kooman & Haverkort, 1994). Exposure of potato plants to high temperatures for a long period during tuber initiation result in very big and healthy vines with low yields (Thornton, 2002). The partitioning of assimilates to the tubers depends on sucrose translocation and its subsequent metabolism within the starch biosynthetic and respiratory pathways and this process is impaired at high temperatures (Sterret, 1985) resulting in the shoot becoming sink for photosynthesis instead of the tubers (Schafleinter *et al.*, 2013).

The reduction of tuber development under high temperatures results in smaller sink for photosynthesis lessening the photosynthetic rate (Basu *et al.*, 1999). The decline of photosynthetic rate is secondary as it results from reduced sink strength under high temperatures (Schafleinter *et al.*, 2013). Short days and low temperatures induce tuber initiation and increases the number of tubers formed (Levy *et al.*, 2007) as these conditions triggers cell division and elongation in the sub apical regions of the stolons to produce tubers (Amador *et al.*, 2001).

2.4.2 Effect of temperature on tuberization

Potato tuberization 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). Potato tubers are shortened and modified thickened stems that bear scale leaves with buds on the axil formed on the tip of a stolon (Tsegaw *et al.*, 2005) formed by inhibition of longitudinal growth of the stolon tip (Cutter, 1992). The swelling of the tuber starts when the stolon ceases to elongate and the cells in the pith and cortex enlarge and divide transversely (Jackson, 1999). The cells in the perimedullary region later enlarge and divide to form the bulk of the mature tuber (Jackson, 1999). Formation of stolons occur both in tuber inducing and non inducing conditions but the amount of stolon growth is dependent on the strength of the tuber inductive signal (Jackson, 1999).

Tuberization is delayed by one week at temperatures lower than 15^0C and by three weeks at temperatures above 25^0C (Levy *et al.*, 2007). The slower tuberization at low temperatures results from slow metabolism and growth, whereas the delayed tuberization at high temperatures is due to the specific inhibitory effects of the high temperature on the tuberization process (Levy *et al.*, 2007). Low night temperatures result in increased number of tubers per plant whilst higher temperatures result in fewer and large tubers per plant (Levy *et al.*, 2007). Although increase in either day or night temperatures above optimal level reduce tuber yield, high night temperatures seem to be more deleterious (Gregory, 1965). Under conditions of high temperatures, the stolons often grow upwards and emerge out of the soil to form a new shoot (Jackson, 1999). High soil temperatures do not prevent induction of the tuberization signal but it prevents stolons to develop into tubers (Jackson, 1999).

High temperature reduces the rate of photosynthesis, tuber production and tuber weight and is thought to be a result of hormones (Schafleinter *et al.*, 2013). High temperature has a large effect on tuberization and translocation of sugars to the tubers compared to the production of sugars from photosynthesis (Schafleinter *et al.*, 2013).

2.4.3 Effect of temperature on starch and reducing sugar content of potato

The chemical composition of potato is greatly affected by environmental factors such as temperature both in production and in storage (Levy *et al.*, 2006). The tuber solids are about 20% of the tuber fresh weight and starch contributes to 70% of the tuber solids and is the primary determinant of tuber density since starch is heavier than water (Stark *et al.*, 2003). High temperature reduce specific gravity of potato by reducing the total amount of starch available for transport from leaves to tubers, and the rate of incorporation of that starch into the tuber tissue (Thornton, 2002).

The tuber sugar content is very important as it influences the colour of the fried potato because when sugars levels are high, they combine with amino acids forming dark coloured compounds that are associated with burnt food (Stark *et al.*, 2003). High temperature result in tubers with low specific gravity and high reducing sugar content that make poor quality product after processing (Stark *et al.*, 2003).Low specific gravity in the stem-end of the tuber is often associated with high levels of reducing sugars and makes poor quality potato when processed as they make sugar end fries (Thornton, 2002). Sugar ends are common to potatoes that have been exposed to high temperatures during the early part of tuber bulking (Thornton, 2002). Potatoes that are intended for chip production should 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). High temperature during growth has been observed to increase the level of steroidal glycoalkaloids in tubers which results in a bitter taste to the tubers (Dimenstein *et al.*, 1997).

2.4.4 Effect of temperature to appearance and dormancy of potato tuber

Tuber size, shape, appearance, flavour and the cooked texture all contribute to the quality of potato (Stark *et al.*, 2003). External tuber disorders reduce marketability, storability and processing quality of potato (Stark *et al.*, 2003). High temperatures cause various tuber disorders, including irregular tuber shape, chain tuberization or secondary tuber formation often associated with excessive stolon elongation and branching reducing dry matter content (Levy *et al.*, 2007). The low availability of starch at high temperature may temporarily stop tuber growth and when tuber growth resumes, it occurs at the site of active cell growth resulting in malformed tubers (Thornton, 2002). Tubers develop some physiological disorders that are closely related to heat stress such as internal brown spots in the tuber parenchyma (Iritani *et al.*, 1984).

Exposure of potato to high temperatures results in a high proportion of misshapen tubers such as pointed ends, knobs and dumb bells (Stark *et al.*, 2003). High temperatures during tuber maturation may interfere with the onset of tuber dormancy, shorten their rest period, or even release the inhibition of tuber buds, resulting in pre-harvest sprouting (Levy *et al.*, 2007). This is as a result of an increase of endogenous content of growth-promoting substances such as gibberellins under high temperatures. Tuber dormancy has been shown to be mediated by a balance between growth-promoting and growth-inhibiting compounds (Levy *et al.*, 2007). A remarkable increase in the level of gibberellic acid and a decrease in the level of abscisic acid were found in potatoes that have been subjected to high temperatures (Krauss & Marschner, 1982).

2.5 Role of plant hormones in tuberization

Hormones play a very important role in communication signals between plant organs (Tsegaw *et al*., 2005). All classes of known hormones have some effect on one of the different stages of tuberization in potato (Appeldoorn, 1997). The balance between the different plant hormones is important rather than the concentration of a single hormone (Okazawa *et al.*, 1962). Studies that were done on plant growth regulators in potato tuberization propose that gibberellins inhibit and abscisic acid promotes tuber induction (Alexious *et al.*, 2006). Auxins and cytokinins influence tuber size whereas ethylene inhibits tuber induction. It was found out that potato yields were not affected by exogenous application of 6-benzyl amino purine or inclole 3 acetic acid but were reduced by gibberellic acid (Alexious *et al.*, 2006). Exogenous 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

Gibberellic acids are a large group of tetracyclic diterperonoid carboxylic acids that functions as growth hormones in higher plants (Sponsel *et al.*, 2004). They act throughout the life cycle of a plant to stimulate growth of most of the plant organs through enhanced cell division and cell elongation (Colebrook *et al.*, 2014). Among the plant hormones that affect tuberization, there is compelling evidence that indicate that gibberellic acid present in leaves, stems and below ground parts play a pivotal role in tuberization (Tsegaw *et al*., 2005).

It was observed that gibberellic acid is among the inhibitory signals of tuberization under long days (Menzel, 1983) and application of exogenous gibberellic acid in potato inhibited tuberization (Xu *et al.*, 1998). The inhibitory effect of gibberellic acid was deduced from the high levels of the hormone under non-inductive conditions compared to the lower levels found under inductive conditions (Appeldoorn, 1999). The inhibitory effect of gibberellic acid was also deduced from the ability of gibberellic acid to prevent tuber induction and to stimulate stolon elongation after exogenous application of the growth hormone and the induction of tuberization after application of an anti-gibberellin synthesis (Jackson, 1999).

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). High levels of gibberellic acid were found in potato grown under non-inductive conditions under long photoperiods and high temperatures (Menzel, 1983). Gibberellic acid that is formed endogenously under long days and high temperatures inhibit tuberization whilst cytokinins and abscisic acid resulted in the promotion of tuber formation (Levy *et al.*, 2007). Accumulation of gibberellic acid in tuber tissue impedes 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).

High ratio of gibberellic acid to abscisic acid promote haulm growth, impede starch accumulation inhibiting tuber formation whilst a lower ratio result in limited top growth and promotes tuber formation (Levy, 2007). High level of endogenous gibberellic acid causes a reduction in the activity of ADPG pyrophosphorylase in tubers which catalyses the conversion of Glucose-1-P into ADPGlucose causing a reduction in tuber growth (Mares *et al.*, 1981). High level of gibberellic acid results in higher carbohydrate to shoots than that is allocated to the roots (Yim *et al.*, 1997). Under inductive conditions during tuberization, the levels of gibberellic acid decreases in the stolon resulting in accumulation of starch and storage protein (Tsegaw *et al*., 2005).

High levels of gibberellic acid were found in potato that were grown under non inductive conditions and low levels were in detected in plants that were exposed to short days (Tsegaw *et al*., 2005). The production of dry matter and its distribution to various plant organs is important as determines the tuber yield (Balamani *et al.*, 1985). The balance of hormones that control tuberization can be altered by using anti-gibberellin synthesis such as paclobutrazol to overcome the inhibitory effect caused by gibberellins (Simko, 1994).

2.6 Paclobutrazol

2.6.1 Mode of action of paclobutrazol in potato production

Chemical plant growth regulators have been used by scientists as a way of improving crop productivity and among them, paclobutrazol is widely a used growth retardant in horticulture. Paclobutrazol is a triazolic group of fungicides with plant growth regulating properties through interfering with the *ent*-kaurene oxidase activity in the *ent*-kaurene oxidation pathway which is a key step in gibberellic acid biosynthesis resulting in a decrease of gibberellic acid levels (Tsegaw *et al*., 2005; Schafleinter *et al.*, 2013). It inhibits the three oxidative steps of the gibberellin precursor ent-kauren to ent-kaurenoic acid blocking the synthesis of gibberellins in the early step of its biosynthetic pathway (Hedden *et al.*, 1985). The inhibitory effect of paclobutrazol on gibberellic acid synthesis is supported by the fact that treated plants had lower levels of gibberellic acid and some of the effects of paclobutrazol can be reversed by gibberellic acid application (Tsegaw *et al*., 2005). The application of paclobutrazol in plants induces stress protection against drought and temperature as it increases the levels of abscisic acid (Zhu *et al*., 2004).

Paclobutrazol induces shoot growth reduction, increase chlorophyll synthesis and assimilate partitioning to underground parts (Tsegaw & Hammes, 2004). Application of growth retardants soon after tuber induction results in a decrease in shoot growth and increase in tuber production as more assimilates will be channelled to tuber production (Balamani *et al.*, 1985). Paclobutrazol treatment increases the fresh mass, dry matter content, specific gravity of tubers and regulates hormonal balance and influences assimilate partitioning in the plant (Tsegaw *et al*., 2005).

Treatment of plants with paclobutrazol result in compact darker leaves due to high chlorophyll, thicker epicuticular wax layers short and thick stems (Tsegaw *et al*., 2005). Paclobutrazol increases yield and quality of tubers under high temperatures as it reduces levels of gibberellin that are inhibitory to starch and protein accumulation (Tsegaw & Hammes, 2004). Some reports indicate that paclobutrazol increases the photosynthetic efficiency of plants whilst some contrary reports indicate that paclobutrazol reduces whole plant photosynthesis as it reduces the leaf surface area (Tsegaw *et al*., 2005). The most notable morphological response of plants treated with paclobutrazol is reduction of stem internode growth (Grossman, 1990). It was also observed that paclobutrazol affects the sugar content and partitioning between soluble sugars and starch (Okazawa, 1962).

2.6.2 Effect of time of application of paclobutrazol

The application of paclobutrazol at both early and late tuber initiation reduces haulm growth significantly particularly when the treatment is applied at early stolon initiation (Bandara *et al*., 1999). In experiments that were conducted on time of paclobutrazol application and pot size, Bandara *et al*. (1999) found out that paclobutrazol applied at early stolon initiation increased total usable tubers by 330% in small pots compared to the control plants. In this experiment, he also found out that application of paclobutrazol at late tuber initiation increased usable tuber numbers by 230% in small pots compared to the control plants in small pots. Bandara *et al.* (1999) concluded that paclobutrazol should be applied at relatively early stage to improve on quality and yield of potato. Paclobutrazol applied at early tuber initiation for fast maturing determinant varieties produce the most pronounced effect compared when applied at late tuber initiation (Bandara *et al*., 1999).

2.6.3 Effect of method of application of paclobutrazol

Method of paclobutrazol application determines movement of the growth retardant in the plant and therefore influences the effectiveness of the chemical (Tsegaw *et al*., 2005). It was previously believed that triazoles are transported acropetally in the xylem of plants. However, the triazoles were later detected both in xylem and phloem indicating that they can be transported acropetally and basipetally (Tsegaw & Hammes, 2004). Triazoles have high chemical stability and the rate of metabolism in the plant is slow and depends on the site of application (Davis *et al.*, 1991). Different responses in plants were observed after foliar and drench applications depending on concentration and plant species (Tsegaw *et al*., 2005).

The height of potted *Mussaenda erythrophylla* was significantly reduced by drench application of paclobutrazol compared to foliar applications (Cramer *et al.*, 1998). The application of paclobutrazol using foliar applications may not result in uniform size if the spraying application coverage is not adequate (Barrett *et al.*, 1994). Paclobutrazol is more effective when applied as a drench to the media as it gives longer absorption time of the active ingredient compared to the foliar spray (Tsegaw *et al*., 2005). Plant roots synthesize large amounts of gibberellins and drench applications of paclobutrazol may directly inhibit synthesis of this hormone in the roots (Sopher *et al.*, 1999).

CHAPTER 3

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

ABSTRACT

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 ^{0}C(±3) and 21^{0}C(±3) day and night temperatures respectively with 60% relative humidity The experiment was set up as a 4 x 2 factorial design in a CRD with 3 replications. The first factor was potato variety and the levels were BP1 and Diamond. The second factor was paclobutrazol application time and the levels were 28 DAP, 35DAP, 42DAP and no paclobutrazol applied (control). Paclobutrazol was applied to plants at a rate of 250g/ha active ingredient using foliar application method. Application of paclobutrazol 28 DAP reduced stem length, number of tubers per plant and reducing sugar content by 40%, 20% and 40%, respectively. Application of paclobutrazol at 28 DAP increased stem diameter at 63 DAP, yield and starch content by 74%, 108% and 28%, respectively compared to the no paclobutrazol treatments. Early application of paclobutrazol at 28 DAP is recommended in high temperature zones as it increases the quality and yield of potato.

3.1 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 ^{0}C (Schafleiter *et al.*, 2013). Potato production has been limited to cool regions in Zimbabwe and yet the country has more than 43% of semi-arid area (Gore *et al.*, 1992). To increase food and nutrition security in the country, it is imperative to grow potatoes in high temperature regions. High temperature cause a reduction in the rate of photosynthesis, translocation of assimilates to tubers, conversion rate of sucrose into starch resulting in limited tuber formation and growth (Rosanna *et al*., 2014). The yield reduction at high temperatures is partly due to reduced assimilate partitioning and delayed tuber initiation (Vandam *et al*., 1996). At high temperatures, foliage growth is vigorous and considerable amounts of carbohydrates are utilized for foliage growth at the expense of tuberization (Tsegaw *et al*., 2005).

The total dry matter production and its distribution to the different plant organs is an important factor affecting tuber yield in potato (Balamani *et al*., 1985). 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 (Rosanna *et al*., 2014). High levels of gibberellic acid lead to higher carbohydrate allocation to shoots at the expense of tubers (Tsegaw e*t al.*, 2005).

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 (Rossana *et al.*, 2014). 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 (Manjula *et al.*, 1999).

Application time of paclobutrazol may affect potato yield in high temperature areas. Paclobutrazol treatment of potato plants promoted tuberization in vitro and under green house conditions with cultivar response to the timing of treatment (Bandara *et al*., 1998). 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 (Appeldoorn, 1999). 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 (Levy *et al*., 2007) 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 (Manjula *et al.*, 1999). Celis-Gamboa *et al*., 2003 found out that stolon formation occurred 29 DAP and the stolon tip swelling started from day 29 to 36 DAP for the cultivars that were under study (Celis-Gamboa *et al.*, 2003). Tubers that overally attain the greatest weight are usually produced by the lowest stolons and are formed at the beginning of tuber development (Levy *et al*., 2007). However, there is limited information on the appropriate time of paclobutrazol application using our local varieties to maximise on yield and quality of potato tubers under conditions of high temperatures.

3.2 MATERIALS AND METHODS

3.2.1 Research Site and Characteristics

The research was carried out at Harare Research Station (31^0 03′E and 17^0 48′S). It is located within agro ecological region IIa with an altitude of 1506m above sea level. The research station receives annual rainfall of 820mm. The experiment was conducted in a greenhouse and the day temperature was 34^0C (±3) and the night temperature was 21^0C (±3). The average relative humidity in the greenhouse was 60%.

3.2.2 Experimental Design and treatments

The experiment was set up as a 4 x 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 3.1.

Table 3.1: 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)

3.3 Plant culture

Two varieties of potato seed Diamond and BP1were left to sprout in a dark room until the sprouts were about 2cm 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 were sent for analysis at the Department of Research and Specialist Services and the soil had a pH of 6,2. The soils used for planting were predominantly red clays. Planting was done in 20L black plastic pockets that were 50cm x 40cm.The pockets were initially half filled with soil to a height of 25cm. Basal fertilizer was applied at a rate of 2000kg/ha Compound S (7:21:7) and was incorporated into the pockets. Planting holes that were 10cm 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 200kg/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.

3.4 Treatment application

Paclobutrazol 29.9% active ingredient was applied at a rate of 250g/ha and was applied at 28, 35 and 42 DAP as according to treatment structure shown in Table 3.1. A 15 litre knapsack sprayer was used for spraying to attain full cover spray.

3.5 Measurements

3.5.1 Stem length (cm)

Two pots per plot were randomly 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 49 and 63 DAP.

3.5.2 Diameter of stems (cm)

The diameter of stems was measured using a Vernier calliper. Two plants per plot were randomly sampled for measuring diameter and measured at the base of the stem. Stem diameter was measured at 49 and 63 DAP and the same plants were used for measuring stem diameter.

3.5.3 Number of tubers per plant

The total numbers of tubers harvested in two sampled pots were counted and recorded. The tubers that were counted had a diameter above 56cm according to the grades of Potato Growers Association Standards (2005).

3.5.4 Yield of potato (kg)

All plants in each plot were harvested and the tubers weighed on a digital scale. The average yield per plant was calculated by dividing the total harvested yield for the plot by the total number of pots.

3.5.5 Grades of tubers per plant

Tubers harvested from two pots that were randomly selected from each plot were graded using the standards below. The average number of grades per plant was calculated by dividing the number of tubers in each grade by two.

Size	Diameter of tuber
Small	56-63.9mm
Medium	64-75.9mm
Large	76-83.9mm
Extra large	>84mm

Source: Seed Potato Growers Association Standards (2005)

3.5.6 Starch content of tubers as % total sugars

Three tubers per each experimental unit were randomly selected for reducing sugar testing. The tubers were washed to remove all foreign material, chopped without removing the outer skin and placed in the oven at 105 ^{0}C for 24hrs. The chopped tubers were pounded to make flour and placed in the oven at 105 ^{0}C for 24hrs to make the flour dry. The starch content of the tubers was determined by Hydrochloric acid dissolution.

3.5.7 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, chopped without removing the outer skin and placed in the oven at 105 ^{0}C for 24hrs. The chopped tubers were then pounded to make flour and placed in the oven at 105 ^{0}C for 24hrs to make the flour dry. The reducing sugars were then determined by the Gravimetric copper reduction method by Munson and Walker (1906). The reducing sugars were determined by weighing the cuprous oxide produced by reduction of Fehling's solution under standardised conditions.

3.6 Data analysis

Analysis of Variance of data was done using Genstat Version 14. Treatment means were separated using the LSD at 5% level of significance.

3.7 RESULTS

3.7.1 Effect of time of paclobutrazol application on potato stem length (cm) at 49 and 63 DAP

There was no interaction between time of paclobutrazol application and variety on potato stem length. However, there were significant differences ($P<0.05$) in time of paclobutrazol application with regards to stem length as shown in Table 3.2. Paclobutrazol treatment at 28 DAP resulted in stems that were 32% and 40% shorter than the no paclobutrazol treatments at

49 and 63 DAP, respectively. Application of paclobutrazol at 42 DAP resulted in stems that were 9% and 21% shorter than the control plants at 49 and 63 DAP. The longest potato stem length was recorded in plants where paclobutrazol was not applied.

Table 3.2: 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]
P value	<0.001	<0.001
LSD0.05	2.29	2.486
CV%	3.6	3.6

3.7.2 Effect of time of paclobutrazol application on potato stem diameter (cm) at 49 and 63 DAP

There was no interaction ($P>0.05$) between variety and time of paclobutrazol application with respect to stem diameter at both 49 and 63 DAP. However, time of application of paclobutrazol had a significant effect ($P<0.05$) on the stem diameter of potato plants both at 49 and 63 DAP as shown in Table 3.3. Application of paclobutrazol at 28 DAP resulted in thicker and more compact stems that were 31% and 74% thicker than treatments where paclobutrazol was not applied at 49 and 63 DAP, respectively. The stem diameter for plants where paclobutrazol was applied at 35 and 42 DAP were 54% and 46% thicker, respectively than treatments where paclobutrazol was not applied at 63 DAP. The smallest stem diameter was recorded in plants where paclobutrazol was not applied at both 49 and 63 DAP as shown in Table 3.3.

Table 3.3: 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]
P value	<0.001	<0.001
LSD 0.05	0.03739	0.02321
CV%	3	3

3.7.3 Effect of time of paclobutrazol application on total number of potato tubers per plant

There was no interaction (P>0.05) between time of paclobutrazol application and variety on total number of potato tuber per plant. However, significant differences (P<0.05) in time of paclobutrazol application were observed with respect to total number of tubers per plant. The highest number of tubers per plant recorded was in treatments where paclobutrazol was not applied. The least number of potato tubers were recorded in plots where paclobutrazol was applied at 28 DAP although it was not significantly different from 35 DAP. Treatment with paclobutrazol at 28, 35 and 42 DAP resulted in a reduction in tuber number by 20%, 14% and 9% respectively compared to treatments where it was not applied.

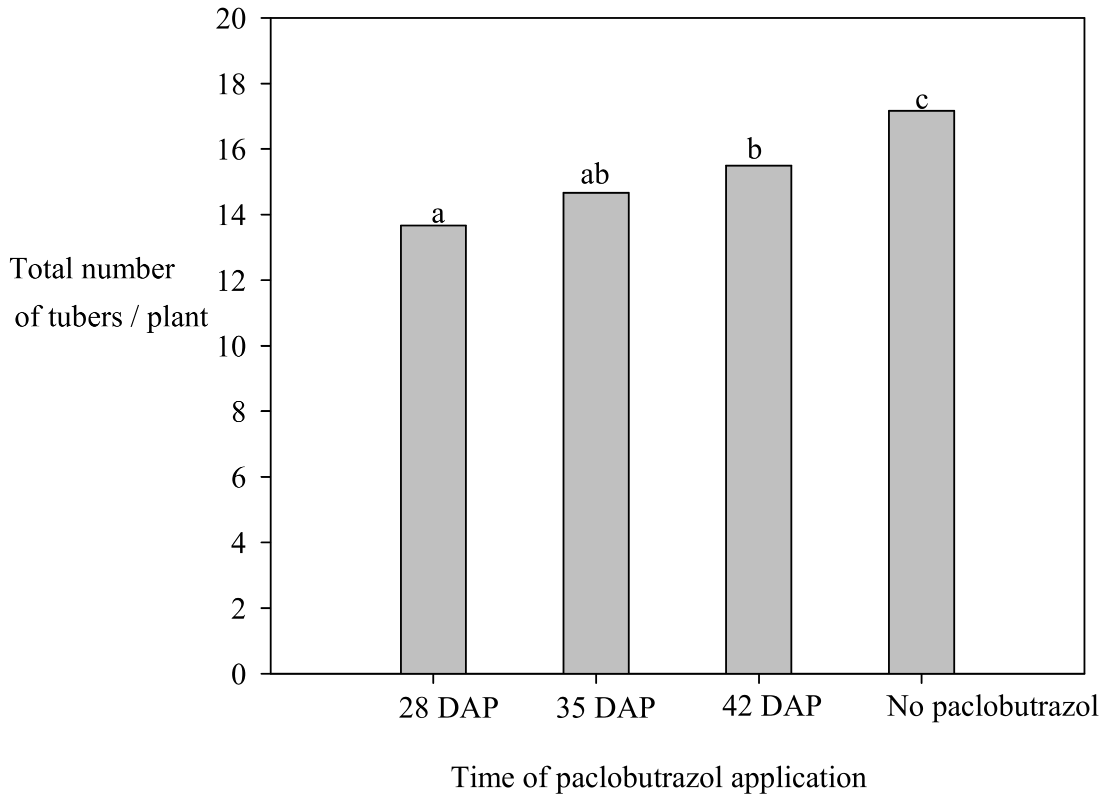

Figure 3.1: Effect of time of paclobutrazol application on total number of potato tubers per plant

3.7.4 Effect of time of paclobutrazol application on potato yield (kg/ plant)

There was no interaction between variety and time of paclobutrazol application with respect to tuber yield. However, significant differences ($P<0.05$) on time of paclobutrazol application with respect to tuber yield per plant were observed. The highest yield was observed in treatments where paclobutrazol was applied at 28 DAP and the yield was 108% more than in no paclobutrazol treatments. The yield in treatments where paclobutrazol was applied at 35 DAP and 42 DAP was 94% and 62% respectively more than that of the control treatments where paclobutrazol was not applied.

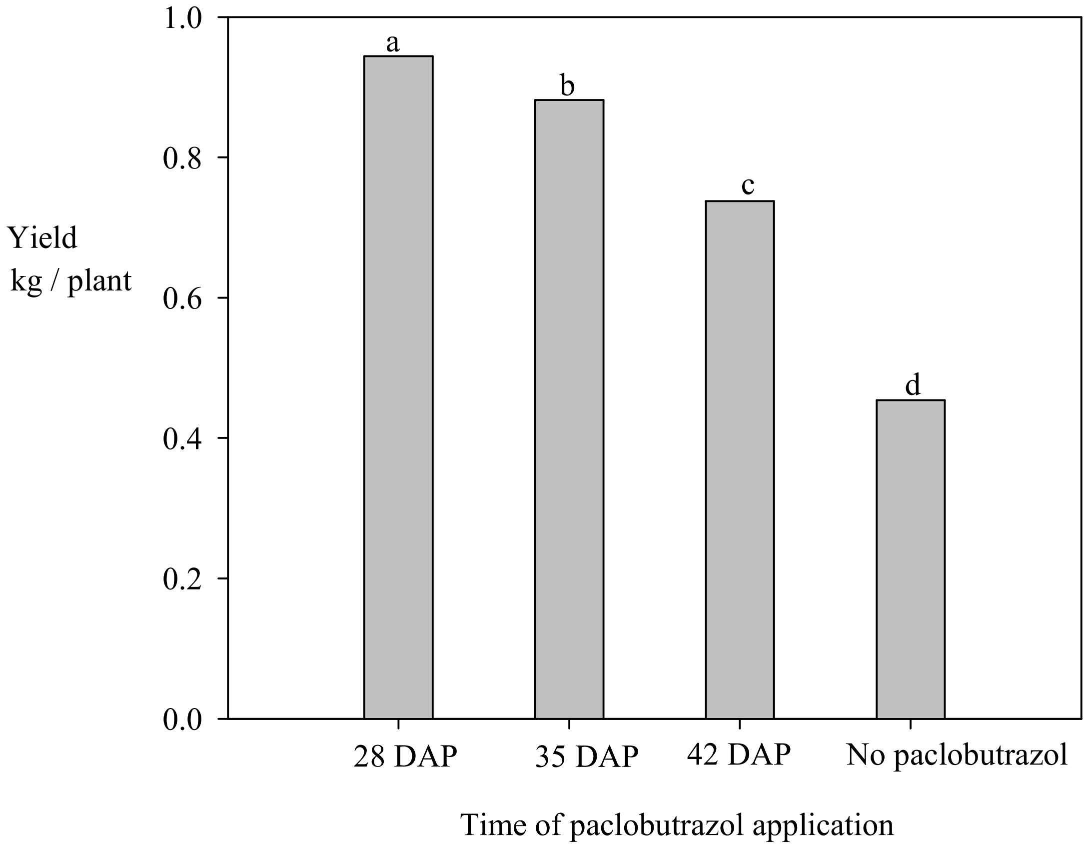

Figure 3.2: Effect of time of paclobutrazol application on potato tuber yield per plant (kg)

3.7.5 Effect of time of paclobutrazol application on potato tuber grades per plant

There was no interaction between time of paclobutrazol application and variety on grades of tubers per plant. Significant differences ($P<0.05$) on time of paclobutrazol application were observed with regards to the grades of tubers. The number of large tubers per plant for treatments where paclobutrazol was applied at 28 DAP was not significantly different from application at 35DAP. Treatments with paclobutrazol at 28 DAP resulted in the largest number of extra large potatoes that contributed to 37% of the total tubers. Application of paclobutrazol at 35 DAP recorded 22% of extra large tubers as a proportion of the total number of tubers. Medium and small potatoes dominated in treatments where paclobutrazol was not applied contributing to 90% of the total tubers and no extra large potatoes were recorded in these treatments.

Table 3.4: 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]
P value	<0.001	<0.001	<0.001	<0.001
LSD	0.661	0.79	0.707	0.707
CV %	19.9	19.9	11.9	12.9

3.7.6 Effect of time of paclobutrazol application on potato tuber starch content as a % of sugars

Time of paclobutrazol application had a significant effect ($P<0.05$) on the starch content of tubers. The highest starch content was observed in tubers where paclobutrazol was applied at 28DAP as shown in Figure 3.3. Application of paclobutrazol 28 DAP resulted in 28% increase in tuber starch content compared with treatments where paclobutrazol was not applied which had the least tuber starch content.

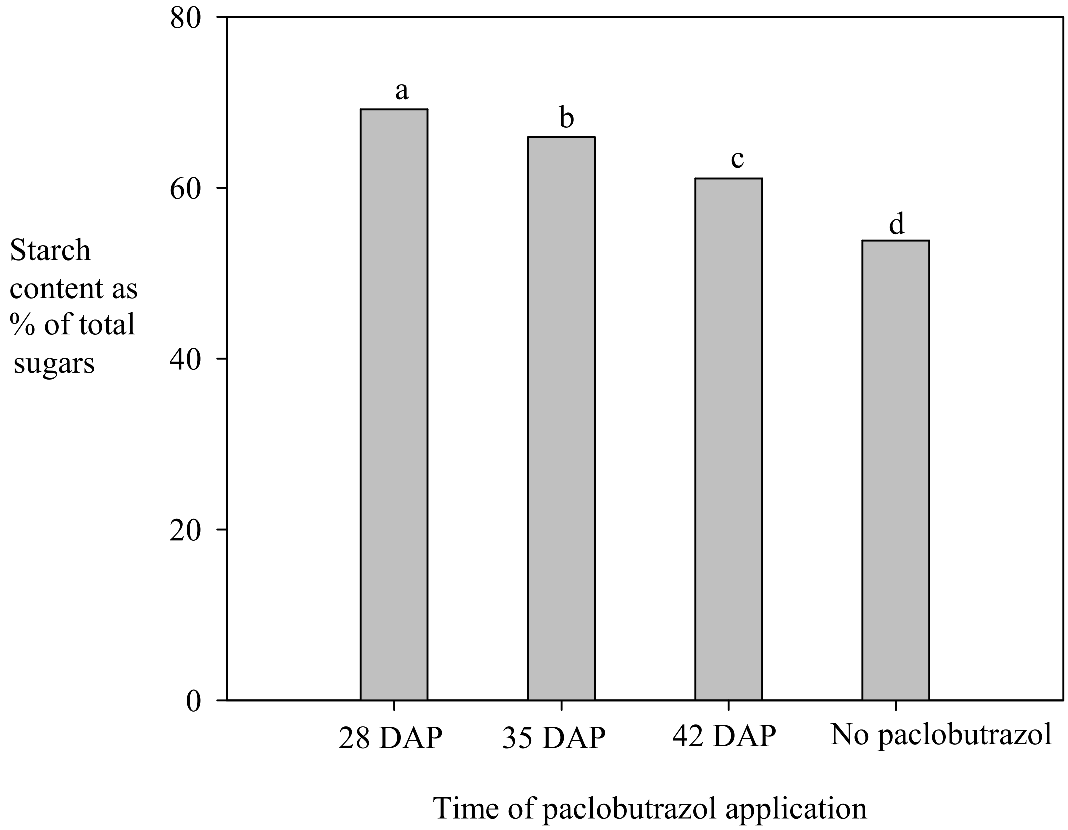

Figure 3.3: Effect of time of paclobutrazol application on potato tuber starch content as a % of sugars

3.7.7 Effect of time of paclobutrazol application on potato tuber reducing sugar content as % glucose

There was no interaction (P>0.05) between variety and time of paclobutrazol application. However, there were significant differences in time of paclobutrazol application with regards to reducing sugar content as shown in Figure 3.4. The control plants where paclobutrazol was not applied had tubers with the highest reducing sugar content. Reducing sugars for treatment where paclobutrazol was applied at 35 and 42 DAP were not significantly different from each other. The lowest tuber reducing sugar content were recorded in treatments where paclobutrazol was applied at 28 DAP and was 40% less than treatments where it was not applied. The tuber reducing sugar for treatments with paclobutrazol applied at 35 and 42 DAP were significantly different which had 28% and 26% less reducing sugars compared to control treatment.

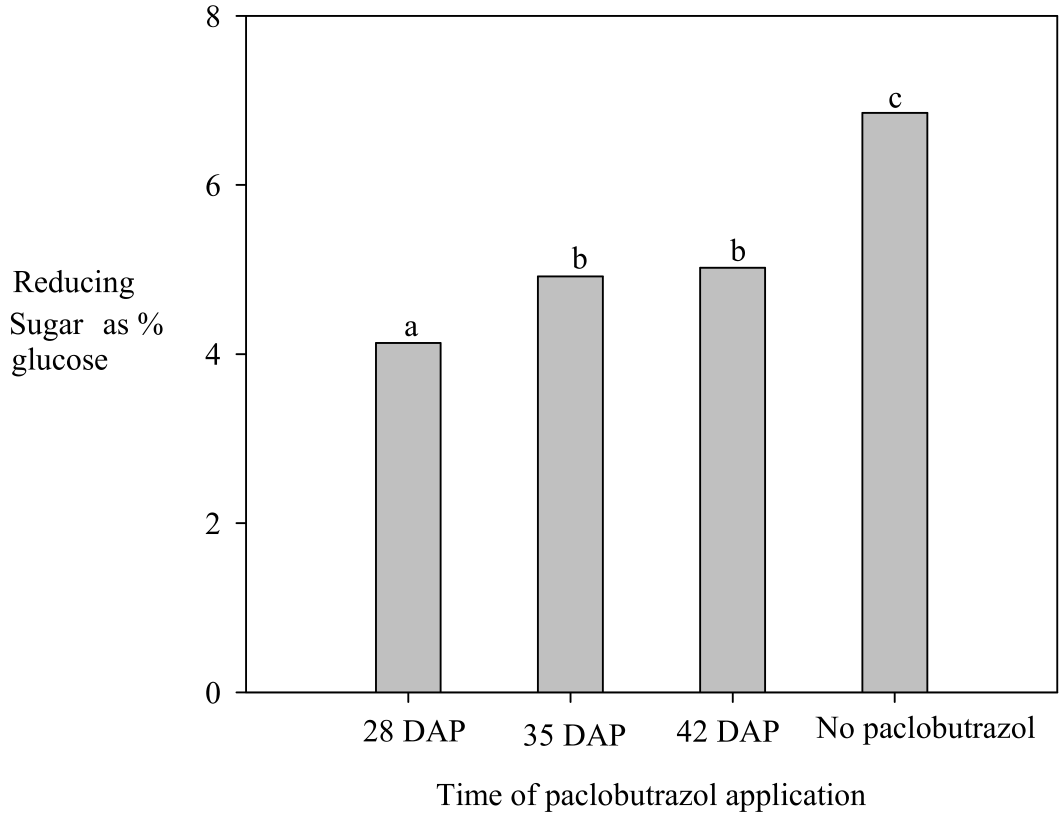

Figure 3.4: Effect of time of paclobutrazol application on potato tuber reducing sugar content as % glucose

3.8 DISCUSSION

Application of paclobutrazol at 28 DAP reduced the stem length by 40% compared with the reduction of 21% when it was applied at 42 DAP. This indicates that early application of paclobutrazol reduced stem length more compared to late application. 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 inter node length (Davis & Curry, 1991). 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 (Hedden *et al*., 1985) Late application of paclobutrazol resulted in longer stem length than when paclobutrazol was applied at 28DAP and this may have been caused by high levels of gibberellic acid in the plants before the application of paclobutrazol and allowed for stem elongation up until when paclobutrazol was applied. This concurs with the findings of Bandara *et al*. (1998) that application of paclobutrazol at early tuber initiation reduces the haulm growth significantly compared to when it is applied at late stolon initiation. The reduction of stem length after paclobutrazol treatment may be explained by the reduction of endogenous gibberellins by paclobutrazol which is the primary hormone responsible for cell elongation (Latimer and Whipker, 2007).

An increase of 74% in stem diameter was recorded in plants where paclobutrazol was applied 28 DAP. This indicated that early application of paclobutrazol increases 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 (Wenzel *et al.*, 2000). 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. The increase in stem length in late applied paclobutrazol may indicate the presence of high levels of gibberellins in the plant before paclobutrazol application and resulted in thinner stem diameter compared to late application. Paclobutrazol treatment increases the thickness of cortex, vascular bundles and pith diameter resulting in thicker stems (Tsegaw & Hammes, 2004).

The least number of tubers per plant was recorded in treatments where paclobutrazol was applied at 28DAP and 35 DAP. This reduction in the number of tubers per plant may be associated with the reduction in the number of stolons due to low levels of gibberellic acid that are responsible for stolon initiation after paclobutrazol application. The fewer number of stolon result in fewer number of tubers formed as tubers are formed after the differentiation of stolons into vegetative storage organs. This concurs with the finding of Tsegaw *et al.* (2005) that application of gibberellic acid reduces number of tubers per plant.

The highest yield was recorded in treatments where paclobutrazol was applied 28 DAP and increased yield by 108% compared to the control treatments. The increase in yield may have been caused by the reduction of stem length that was observed in the experiment. The highest stem reduction was observed in plants treated with paclobutrazol at 28DAP and hence more assimilates were channelled to tuber growth increasing yield. Application of paclobutrazol soon after tuber induction result in decrease in shoot growth and increase in tuber production as more assimilates will be channelled to tuber production (Balamani *et al*., 1985).

The increase in yield may probably have caused by early tuberization due to low levels of gibberellic acid that inhibit or delay tuberization as paclobutrazol is a gibberellic acid biosynthesis inhibitor. Application of paclobutrazol at early tuber initiation for fast maturing determinant varieties result in more yields compared to application at late tuber initiation (Bandara, 1999). Tubers that are formed at the beginning of tuber induction overally attain the greatest weight and hence more yield (Levy *et al.*, 2007). However the tuber yield was considerably high in paclobutrazol treated plants where less number of tubers was recorded as shown in Figure 3.1 and it may have been caused by the increase in size as shown in Table

3.4. This is in agreement with results of Tsegaw *et al*. (2005), where treatment with paclobutrazol increased tuber yield per plant as a result of an increase in tuber size.

Plants treated with paclobutrazol at 28 and 35 DAP had the biggest number of extra large and large tubers. The increase in grades of tubers may be as a result of low competition for assimilates since the early applied paclobutrazol plants had less number of tubers as shown in Table 3.4. The high grades in early applied paclobutrazol may have been caused by the reduction in stem length and hence more assimilates were partitioned to tuber growth compared to haulm growth resulting in increased size of tubers. The increase in grades may also be linked to early tuberization in early applied paclobutrazol plants as tubers formed at the beginning of tuber induction usually attain the greatest size as they will have more time to attract assimilates during tuber bulking stage. Application of paclobutrazol soon after tuber induction result in a decrease in shoot growth and increases tuber growth by increasing the mobilization of assimilates to tuber formation (Balamani *et al*, 1985).

Paclobutrazol treatment resulted in increased tuber starch content and the highest increase of 28% was recorded in plants where it was applied 28 DAP. This might have been caused by increase in sink strength as evident on the increase in tuber size indicated by tuber grades shown in Table 3.4 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 in early applied paclobutrazol plants may have been caused by early tuberization and as the tubers had more time to attract assimilates resulting in increase in starch content compared to the late applications. Treatment of plants with paclobutrazol causes an increase in the number of enzymes that are responsible for starch biosynthesis such as starch synthase and therefore increasing starch content in tubers (Appeldoorn *et al*, 1997). Application of paclobutrazol results in increased starch synthesis and accumulation in tubers

(Tsegaw & Hammes, 2004) 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.

The levels of reducing sugars were lowest in plants treated with paclobutrazol at 28 DAP. 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 (Appeldoorn *et al*, 1997).

3.9 CONCLUSION

- Early application of paclobutrazol at 28 DAP reduced the stem length and increased the stem diameter by 40% and 74% respectively.
- Application of paclobutrazol at 28 DAP reduced the total number of tubers per plant by 20% and increased tuber yield by 108%.
- Late application of paclobutrazol at 42 DAP increased tuber reducing sugar content by 13.5%, reduced the grades of tubers and decreased tuber starch content by 26.7%.

CHAPTER 4

THE EFFECT OF METHOD OF APPLICATION OF PACLOBUTRAZOL AND VARIETY ON GROWTH AND YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.*)*

ABSTRACT

An experiment was set up as a 4 x 2 factorial design in a CRD with 4 replications to investigate the effect of method of paclobutrazol application and variety on growth, quality and yield of potato under greenhouse conditions. The experiment was carried out in a greenhouse with 34 ^{0}C(±3) and 21 ^{0}C(±3) day and night temperatures respectively and average relative humidity of 60%.The first factor was potato variety and the levels were BP1 and Diamond. The second factor was paclobutrazol application method and the levels were drench, foliar and no paclobutrazol applied (control). The two varieties Diamond and BP1 were planted in 20L pockets and paclobutrazol was applied 28DAP at a rate of 250g/ha active ingredient. Drench application increased stem diameter, yield and starch content by 85%, 29% and 126 % respectively. Foliar application increased stem diameter, yield and starch content by 57%, 26% and 120%. The reducing sugar, total number of tubers, grades of tubers and starch content for drench and foliar applied paclobutrazol were not significantly different. Both methods of paclobutrazol reduced the stem length although drench method was more effective and reduced stem length by 40% whilst foliar application reduced stem length by 35%. Drench application of paclobutrazol is recommended in potato as it is effective in reducing excessive top growth resulting in high tuber yield and quality of potato.

4.1 INTRODUCTION

Temperature is the single most uncontrollable factor affecting growth and yield of potato (Levy *et al.*, 2007). Temperature affect the dry matter partitioning to the below ground parts and the net amount of photosynthesis for the whole plant (Ewing, 1985). At high temperatures, the growth of foliage is promoted, net photosynthesis decrease, dark respiration increase and assimilate partitioning to the tubers is reduced (Thornton *et al.*, 1996). Potatoes grown under high temperatures are characterised by taller plants with long internodes, increased leaf and stem growth (Struik *et al.*, 1999). The growth of tubers is completely inhibited at temperatures above 29^0C as carbohydrate consumed by respiration exceeds that which is produced by photosynthesis (Levy, 1992). The inhibitory effect of tuberization at high temperatures is mediated through the production of high levels of gibberellic acids that are known to inhibit tuber formation (Menzel, 1983).

Results obtained previously indicate that reduction in growth and increase in tuberization are accompanied by a reduction in the levels of endogenous gibberellins (Kupidlowska, 1993). As the stolon tips start to develop, the levels of gibberellins in them decreases and accumulation of starch increase together with the levels of glucose and fructose (Tsegaw *et al.*, 2005). This process occurs under inductive conditions for tuberization and under non inductive conditions, the levels of gibberellins will remain high inhibiting tuberization to occur (Levy *et al.*, 2006). Tuberization occurs when there is a balance between endogenous gibberellic acid and tuber forming stimuli is below the threshold (Tsegaw & Hammes, 2004). The balance of gibberellic acid and tuber forming stimulus can be altered by gibberellic acid biosynthesis inhibitor such as paclobutrazol (Balamani *et al.*, 1985).

Paclobutrazol is a member of triazole plant growth regulators that inhibit gibberellin acid synthesis and abscisic acid catabolism through interfering with ent-kaurene oxidase activity in the ent-kaurene oxidation pathway (Rademacher, 1997). Application of paclobutrazol result in shoot growth modification that is helpful in maximising return per unit area by allowing increased populations of the compact plants (Tsegaw *et al.*, 2005). Application of paclobutrazol to plants results in reduction of plant height, internode compression and increased the dry matter content in potato (Bandara *et al.*, 1998).

The method of application of the growth paclobutrazol determines the effectiveness in growth suppression and the ability of the growth regulator to translocate in the xylem and phloem (Keever *et al.*, 1990). Root applied growth regulators are transported acropetally to the leaves and shoot apex through the xylem and transpiration is necessary to move the chemical to the leaves and shoots (Richardson & Quinlan, 1986). Foliar applied growth regulators accumulate in the leaves first, enter into the phloem and eventually translocate into the xylem before it becomes effective (Barrett & Bartuska, 1980). There is a gap in knowledge about the most efficient method of paclobutrazol application to the commonly grown varieties in Zimbabwe. This experiment therefore seeks to establish the most efficient method of paclobutrazol application method using local varieties.

4.2 MATERIALS AND METHODS

4.2.1 Research Site and Characteristics

The research was carried out at Harare Research Station (31^0 03′E and 17^0 48′S). It is located within agro ecological region IIa with an altitude of 1506m above sea level. The research station receives average annual rainfall of 820mm. The experiment was conducted in a greenhouse and the day temperature was 34^0C (±3) and the night temperature was 21^0C (±3). The average relative humidity in the greenhouse was 60%.

4.2.2 Experimental design and treatments

The experiment was set up as a 3 x 2 factorial in a completely randomized design with 4 replications. The first factor was variety and the second factor was method of application as shown in the Table 4.1.

Table 4.1: Treatment structure for the effect of application method of paclobutrazol and variety on the growth, yield and quality of potato

Treatment	Variety	Method of paclobutrazol application
1	BP1	Foliar
2	BP1	Drench
3	BP1	No paclobutrazol
4	Diamond	Foliar
5	Diamond	Drench
6	Diamond	No paclobutrazol

4.3 Plant Culture

Two potato seed varieties namely Diamond and BP1 were were spread on a grass mulch in a dark room and were left to sprout. The tubers were transferred from the dark room into a room with diffuse light when the spouts were 2cm in length and were left to harden for two weeks. Planting soil was gathered from the fields of the research station and the soils were predominantly red clay soils. The soil samples were sent to Department of Research and Specialist Services for pH testing. The pH of the soil was 6.2. Twenty litre black plastic pockets were used for planting and they were half filled with soil. Basal fertilizer was applied at a rate of 2000kg/ha Compound S (7:21:7) and was incorporated into the soil. Seed tubers were placed into the pockets 10cm deep, covered with the soil and irrigated. One seed tuber was placed in each pocket and the pockets were placed inside the greenhouse. Each experimental unit had a total of 5 pots.

Top dressing was done at four weeks after emergence using Ammonium Nitrate (34.5% N) at a rate of 200kg/ha. The pockets filled up with soil that was used at planting just after top dressing. Preventative sprays of blights were done using of copper oxychloride on a weekly basis. Hand weeding was done and irrigation was done twice a week using cans.

4.4 Treatments Application

Paclobutrazol was applied at a rate of 250g/ha active ingredient at 28DAP either using foliar or drench application method. A fine sprayer was used for foliar application of the plant growth regulator. The drench application was done using a 1litre container and the solution was applied to the soil at the base of the plant.

4.5 Measurements

4.5.1 Stem length (cm)

Two plants per experimental unit were chosen randomly for measuring stem length at 49 and 63 DAP and average stem length recorded. A 1m ruler was used for measuring stem length and was measured from the stem base to the apex of the plant.

4.5.2 Diameter of stems (cm)

The diameter of stems was measured using a Vernier calliper. Two plants per plot were sampled for stem diameter and the plants were measured at the base of the stem and the average stem diameter calculated. The measurements for stem diameter were taken twice at 49 and 63DAP.

4.5.3 Number of tubers per plant

Whole plots were harvested and the average number of tubers per plant was calculated by dividing the total number of tubers by the number of plants harvested per experimental plot.

The tubers that were counted had a diameter above 56cm to be recorded as a usable tuber according to the Potato Growers Association Standards 2005.

4.5.4 Yield of potato (kg)

Whole plots were harvested and the tubers were weighed on a digital scale to two decimal places. The average yield per pot was calculated by dividing the total harvested yield for the plot by the total number of pots harvested.

4.5.5 Grades of tubers

The harvested tubers in 2 randomly selected pots per treatment were graded using the standards below. The number of tubers per each grade was recorded and average grade size per pot calculated by dividing the total number of tubers in each grade by 2.

Size	Diameter of tuber
Small	56-63.9mm
Medium	64-75.9mm
Large	76-83.9mm
Extra large	>84mm

Source: Seed Potato Growers Association Standards (2005)

4.5.6 Starch content of tubers

Three tubers from each plot were randomly selected for starch testing. The tubers were chopped and dried in the oven at 105^0C for 24hrs. The chopped tubers were pounded to make flour and placed in the oven at 105^0C for 24hrs to make the flour dry. The starch content of the tubers was determined by Hydrochloric acid dissolution.

4.5.7 Reducing sugar content of tubers

Three tubers were randomly selected for reducing sugar testing from each experimental unit. Tubers were cleaned, chopped and oven dried at 105^0C for 24hrs. The chopped tubers were pounded to make flour and placed in the oven at 105^0C for 24hrs. Reducing sugars were determined by the Gravimetric copper reduction method by Munson and Walker (1906). The quantity of reducing sugars was determined by weighing the cuprous oxide produced by reduction of Fehling's solution.

4.6 Data analysis

The data was subjected to Analysis of Variance using Genstat Version 14. Treatment means were separated using the LSD at 5% level of significance.

4.7 RESULTS

4.7.1 Effect of method of paclobutrazol application on potato stem length (cm) at 49 and 63 DAP

There was no interaction ($P>0.05$) between variety and method of paclobutrazol application with regards to stem length. However, significance differences ($P<0.05$) in method of application of paclobutrazol with regards to stem length were observed. Drench application method recorded the shortest stem length that was 22% and 40% shorter than no paclobutrazol treatments at 49 and 63 DAP, respectively. Foliar application resulted in a reduction of potato stem length by 17% and 35% at 49 and 63 DAP, respectively.

Table 4.2: Effect of method of paclobutrazol application on potato stem length (cm) at 49 and 63 DAP

Method of paclobutrazol application	Stem length (cm) 49 DAP	63 DAP
No paclobutrazol	51.88[a]	71.75[a]
Foliar	42.88[b]	46.12[b]
Drench	40.00[c]	42.62[c]
P value	<0.001	<0.001
LSD0.05	2.828	2.401
CV%	6.0	4.3

4.7.2 Effect of method of paclobutrazol application on potato stem diameter (cm) at 49 and 63 DAP

There was no interaction ($P>0.05$) between variety and method of application with respect to stem diameter at both 49 and 63 DAP. However, method of paclobutrazol application had a significant effect ($P<0.05$) on stem diameter at both 49 and 63 DAP as shown in Table 4.3. The stem diameter increased by 50% and 57% in foliar and drench applied paclobutrazol respectively at 49DAP. Drench application method had the biggest stem diameter at both 49DAP and 63DAP and the diameter was 85% more than that of the control plants where paclobutrazol was no applied at 69 DAP.

Table 4.3: Effect of method of paclobutrazol application on potato stem diameter (cm) at 49 and 63 DAP

Method of paclobutrazol application	Stem length (cm) 49 DAP	63 DAP
No paclobutrazol	0.769[a]	0.910[a]
Foliar	1.194[b]	1.601[b]
Drench	1.255[c]	1.688[c]
P value	<0.001	<0.001
LSD 0.05	0.03630	0.02034
CV%	3.2	1.7

4.7.3 Effect of method of paclobutrazol application on total number of potato tubers per plant

There was no interaction between method of paclobutrazol application and variety with regards to total number of tubers per plant. However, significant difference in the method of paclobutrazol application with respect to the number of tubers per plant was observed. The number of tubers recorded from foliar and drench and drench applied paclobutrazol were not statistically different. Drench and foliar application of paclobutrazol reduced the number of tubers per plant by 15% and 16% respectively. The control treatment where paclobutrazol was not applied had the highest number of tubers produced per plant as shown in Figure 4.1.

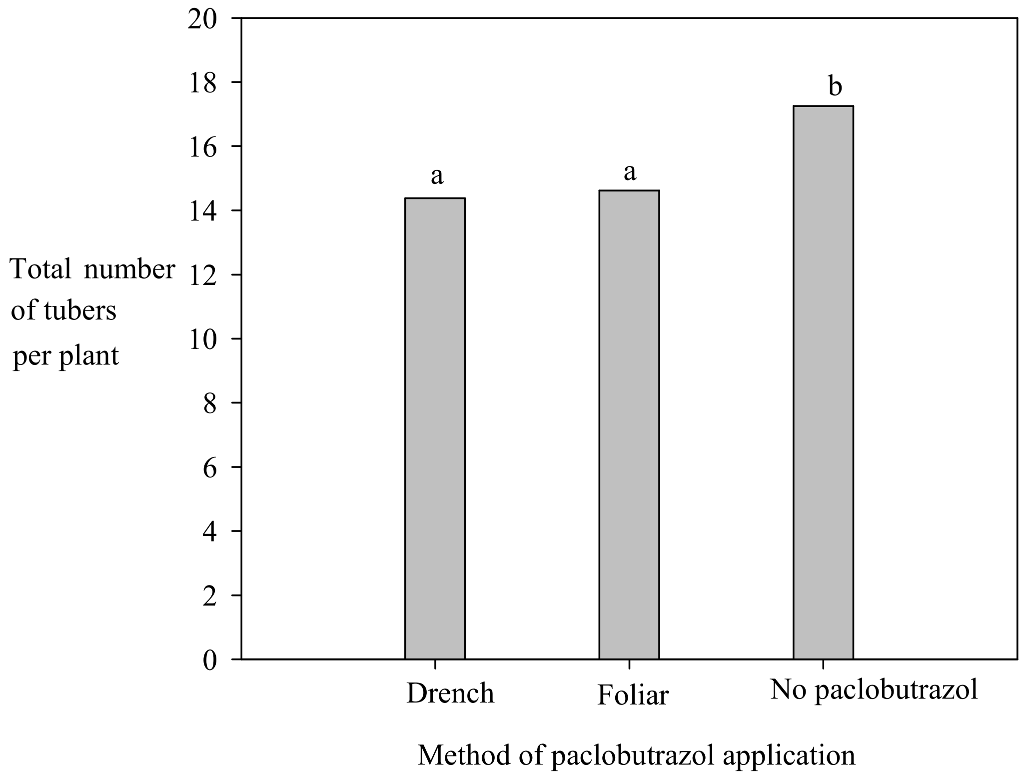

Figure 4.1: Effect of method of paclobutrazol application on total number of potato tubers per plant

4.7.4 Effect of method of paclobutrazol application on potato tuber yield (kg) per plant

There was no interaction between method of application and variety with regards to tuber yield per plant. However, significant differences (P<0.05) in method of paclobutrazol application with respect to yield were observed. The highest yield was recorded in drench applied treatments which increased yield by 126% compared to treatments where paclobutrazol was not applied. The average yield per plant for the foliar applied paclobutrazol plots was 120% more than the yield recorded in treatments where it was no applied.

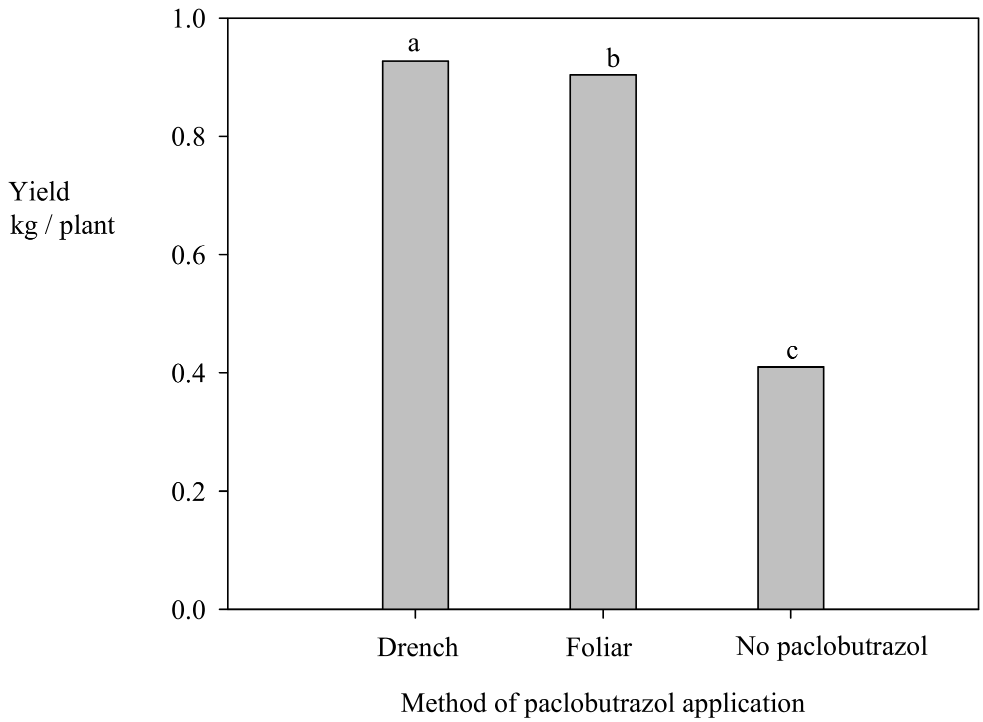

Figure 4.2: Effect of method of paclobutrazol application on potato tuber yield per plant (kg)

4.7.5 Effect of method of paclobutrazol application on potato tuber grades per plant

There was no interaction on the method of paclobutrazol application and variety with regards to the grades of tubers. However, significant differences (P>0.05) in method of paclobutrazol application on grades of tubers were observed. Drench and foliar application method produced the largest number of large and extra large potatoes. The number of extra large, large, medium and small tubers produced in drench applied paclobutrazol was not significantly different from foliar applied paclobutrazol as shown in Table 4.4. The proportion of large and extra large potatoes in foliar and drench applied paclobutrazol was 70% and 73% of the total tubers respectively. The no paclobutrazol treatment had a larger proportion of medium and small tubers that contributed 91% of the total tubers.

Table 4.4: Effect of method of paclobutrazol application on potato tuber grades per plant

Method of paclobutrazol application	Extra large	Large	Medium	Small
Drench	4.375[a]	6.250[a]	2.000[a]	1.750[a]
Foliar	4.250[a]	6.000[a]	2.375[a]	2.000[a]
No paclobutrazol	0.000[b]	1.500[b]	8.625[b]	7.125[b]
P value	<0.001	<0.001	<0.001	<0.001
LSD	0.4464	0.700	1.050	1.013
CV%	14.8	14.5	23.1	26.6

4.7.6 Effect of method of paclobutrazol application method on tuber starch content as a % of total sugars

There were no significant differences between potato varieties on starch content neither was interaction between method of application and variety. However, there was a significant effect ($P<0.05$) on the method of paclobutrazol application with regards to tuber starch content. The starch content for the drench applied paclobutrazol was not significantly different from the foliar applied treatment. Drench application of paclobutrazol increased starch content by 29%. The least starch content was observed in treatments where paclobutrazol was not applied.

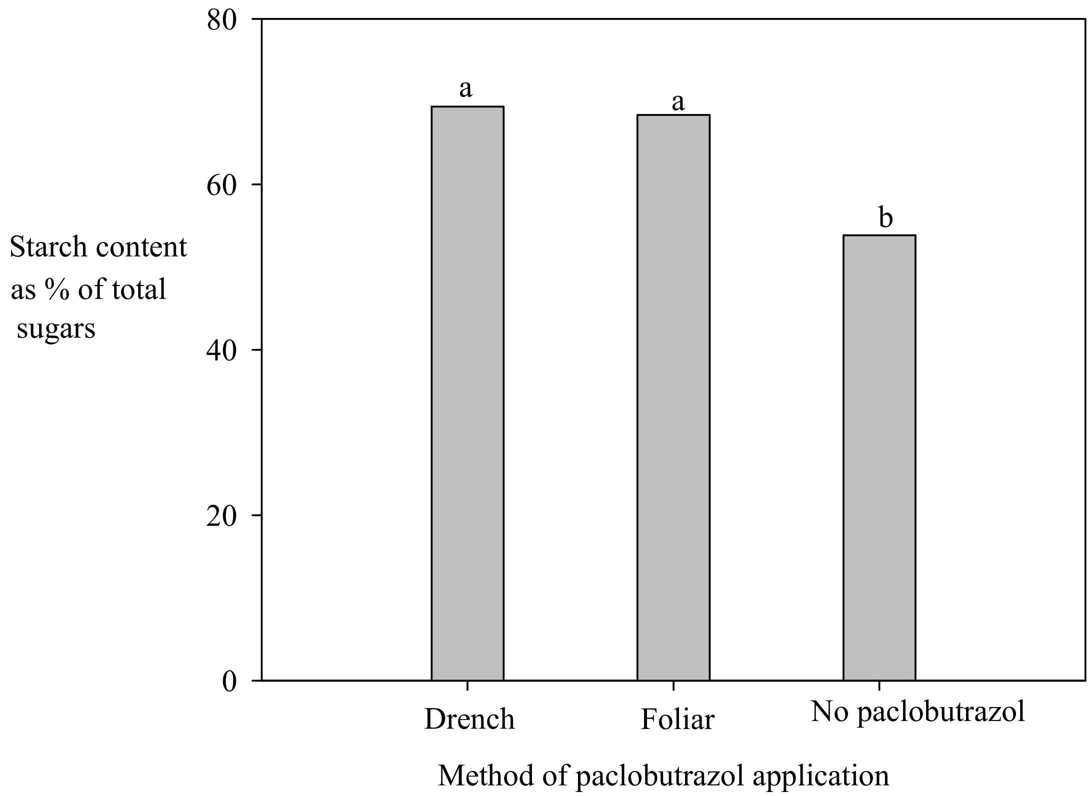

Figure 4.3: Effect of method of paclobutrazol application on potato tuber starch content as a % of total sugars

4.7.5 Effect of method of paclobutrazol application on potato tuber reducing sugar content as % glucose

There was no interaction ($P>0.05$) between variety and method of paclobutrazol application on reducing sugar content of potato, neither varieties were significant. However, method of paclobutrazol application had a significant effect ($P<0.05$) on the tuber reducing sugar content of potato. The no paclobutrazol treatments had the highest reducing sugar content. Drench application method resulted in 41% reduction in reducing sugar content compared to the control treatments. Drench application method was not significantly different from foliar application method with regards to tuber reducing sugar content as shown in Figure 4.4.

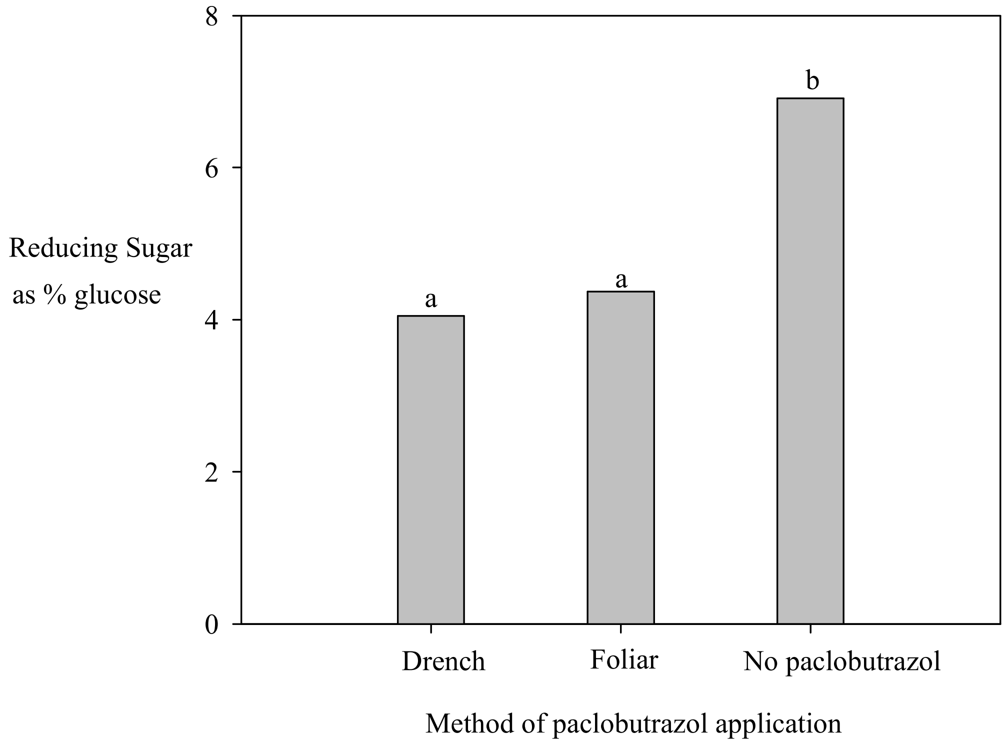

Figure 4.4: Effect of method of paclobutrazol application on potato tuber reducing sugar content as % glucose

4.8 DISCUSSION

Drench application method reduced stem length by 40% at 63 DAP compared to 35% reduction in foliar applied paclobutrazol. The difference in the suppression of growth with the method of application may be due to the difference in uptake of paclobutrazol by either the root or foliage and also the ability of the plant growth regulator to translocate in xylem and phloem (Keever *et al*., 1990). The primary translocation of paclobutrazol occurs through the xylem. Drench application of paclobutrazol was more effective maybe because of the rapid uptake of the plant growth regulator by the roots as the translocation occurs through the xylem quickly reducing the activity of gibberellic acid resulting in reduced stem length. Roots have fewer barriers that prevent entry of plant growth regulators. Foliar applied plant growth regulators first accumulate in the leaves and moves to the phloem and translocate into the xylem and takes more time before they become effective (Barrett & Bartuska, 1980). Previous experiments that were carried out by Tsegaw & Hammes (2004) on method of paclobutrazol application indicated a reduction in height with 46% and 63% on foliar application and soil drenching of paclobutrazol, respectively.

Drench application of paclobutrazol had the highest stem diameter and increased stem diameter by 85% at 63 DAP compared to no paclobutrazol treatment. This perhaps is the result of greater effectiveness of paclobutrazol translocation by the root in drench application as its primary movement occurs through the xylem (Sterret, 1985). Probably drench application was quick to arrest the activity of gibberellic acid in cells resulting in an increase in the stem diameter. Paclobutrazol application increases the size of vascular bundles, cortex and the diameter of the pith resulting in thick stems as it reduces the level of gibberellic acid that limits radial expansion of cells (Tsegaw *et al*., 2005).

There was no significant difference between drench and foliar application with regards to the total number of tubers per plant. This might be because both methods of application were effective in reducing the level of gibberellins that are responsible for stolon initiation by the time of tuber induction and therefore less numbers of stolons were formed resulting in fewer tubers being formed. Paclobutrazol application reduced the total number of tubers regardless of the method of application. These results concur with the findings of Tsegaw *et al*. (2005) who observed that paclobutrazol treatment increased tuber dry matter and promoted early tuberization whilst reducing the number of tubes formed.

Drench application increased yield by 126% whilst foliar application increased yield by 120%. Drench application reduced the stem length more than foliar application and this may imply that more assimilates were partitioned to tuber formation in drench application resulting in high yields. The difference could be attributed to early tuberization in drench applications as paclobutrazol was quickly absorbed by the roots had more absorption time of paclobutrazol when applied to the soil media as compared to foliar applications (Tsegaw & Hammes, 2004). Paclobutrazol is probably more effective when drench applied compared foliar applications where paclobutrazol will first accumulate in leaves and eventually translocated into the xylem (Barret & Bartuska, 1980). Drench applications therefore would quickly reduce the level of gibberellins in the plant resulting in early tuberization increasing yield compared to foliar application.

The grades of tubers in drench and foliar applied paclobutrazol were not significantly different. Paclobutrazol treatment increased the grades of tubers regardless of the method of application. The number of tubers per plant recorded in foliar and drench application was not statistically different and this may have caused the same increase in grades between the two methods of paclobutrazol application. There were fewer tubers and maybe there was less competition for assimilates resulting in higher tuber grades. This may be explained low levels of gibberellins that increases the sink strength to attract more assimilates and increased starch synthesis resulting in increase in grades of tubers. This may also be attributed to the low levels of gibberellic acid in the tubers that influence early tuber initiation, increase tuber growth rate and reduces partitioning of assimilates to above ground parts increasing the size of formed tubers (Jackson, 1999). The paclobutrazol applied plants had short stem length and this may indicates a shift in biomass allocation away from foliage towards tuber growth hence increasing tuber size.

Application of paclobutrazol increased the tuber starch content regardless of the method of application. The starch content for drench applied paclobutrazol was not statistically different from foliar application. Application of paclobutrazol increases enzymes such as ADPG phosphorylase and starch synthase that are responsible for starch biosynthesis hence increasing the starch content in tubers (Visser *et al*., 1994). Paclobutrazol reduces the level of gibberellic acid in tuber tissue that impedes starch accumulation (Vreugdenhil & Sergeeva, 1999) and hence starch accumulation increased in paclobutrazol treated plants as the levels of gibberellins were low.

The reducing sugar content for foliar and drench applied paclobutrazol was not statistically different. Paclobutrazol application reduced reducing sugar content regardless of the method of application. The reduction in reducing sugars in foliar and drench applied paclobutrazol may be explained by the high levels of starch that was observed in the tubers as this may indicate that most of the reducing sugars in the tubers were converted to starch hence low levels of reducing sugars. In control treatments where paclobutrazol was not applied had low levels of starch and hence high levels of reducing sugars. Paclobutrazol application increase the activity of enzymes involved in starch biosynthesis and hence reduction of reducing sugars as they will be converted to starch (Appeldoorn *et al*., 1997). Booth and Lovell (1972) observed that application of gibberellic acid in potato shoots reduce the export of photosynthates to tubers and starch accumulation increasing the levels of reducing sugars in tubers. Therefore reduction of gibberellic acid levels in the plant by paclobutrazol application promoted starch accumulation, reduced the levels of reducing sugars in tubers and increased the weight of tubers.

4.9 CONCLUSION

- Drench application of paclobutrazol reduced the stem length of the crop by 40% and increased stem diameter by 85%.
- Drench application of paclobutrazol increased yield by 126% although it was no different from foliar application on the number of tubers per plant.

- There was no significant difference on the method of paclobutrazol application with regards to grades of tubers, starch content and reducing sugar content.

CHAPTER 5

GENERAL DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

5.1 Discussion

Paclobutrazol treatment resulted in increased stem diameter, yield and starch content of tubers. This showed that the tubers were the dominant sinks as they attracted the highest proportion of assimilates as foliage growth was reduced in paclobutrazol treated plants. This may be linked to the reduction of endogenous levels of gibberellic acid in response to application of paclobutrazol as high levels of gibberellic acid promote vegetative growth and impede starch accumulation. No paclobutrazol treatments had the lowest yield and starch content probably due to the presence of high levels of gibberellins that promote vegetative growth and reduce the amount of assimilates to tubers.

Early application of paclobutrazol at 28DAP recorded the highest tuber yield and starch content. This may be linked to early tuberization as the tubers formed at beginning of tuber development overally attain the greatest size. The tubers had more time for tuber bulking compared with late application of paclobutrazol hence the proportion of large and extra large tubers was high resulting in increased yield. Application of growth retardants soon after tuber induction results in a decrease in shoot growth and increase tuber growth as more assimilates will be channelled to tuber production (Balamani *et al*., 1985).

Paclobutrazol application changed the morphology of the potato plant as treated plants exhibited short and thick stems in Diamond and BP1 under greenhouse conditions. The tuber yield and starch content was significantly increased by paclobutrazol treatment. Paclobutrazol reduced the stem length, number of tubers, reducing sugar content and increased stem diameter, tuber yield and starch content regardless of the method of application. However, drench application method was more effective in reducing stem length and increasing tuber yield than foliar application.

Paclobutrazol treatment significantly reduced the number of tubers per plant and increased the proportion of large and extra large tubers. This may be linked to low levels of gibberellic acid that are responsible for stolon formation. Paclobutrazol treated plants had fewer stolons and hence fewer tubers compared to control plants. Paclobutrazol treatment increased tuber starch content and this may be linked to increase in sink strength enhancing starch synthesis and accumulation due to low levels of gibberellic acid. Both and Lovell (1992) reported reduced sink strength due to gibberellic acid accumulation in tuber tissue. He further observed that application of gibberellic acid to potato shoots reduced export of photosynthates to tubers, decrease starch accumulation and increasing the levels of sugars in tubers.

Drench applications resulted in high yields compared to foliar application and this may be caused by the rapid uptake of paclobutrazol by the roots compared to the leaves. Roots synthesize large amounts of gibberellins and applications of paclobutrazol as drench application directly inhibits synthesis of gibberellins by the roots (Sopher *et al*., 1999). Drench applications gives the plant more absorption time of the plant growth regulator compared to foliar applications and hence more effective (Tsegaw *et al.*, 2005).

5.2 The conclusions derived from this study

- Application of paclobutrazol reduced the stem length, total number of tubers per plant and the reducing sugar content of tubers.
- Application of paclobutrazol resulted in an increase in stem diameter, tuber yield and the starch content of tubers.

- Early application at 4DAP of paclobutrazol was more effective in increasing tuber yield, starch content and reducing the levels of reducing sugar content compared to later applications.
- Foliar application of paclobutrazol was more effective in reducing stem length and increasing stem diameter compared to drench applications.
- There were no significant differences on the method of application with regards to number of tubers per plant, grades of tubers, starch content and reducing sugar content.

5.3 Recommendations

- Early application of paclobutrazol at 28 DAP is recommended in high temperature zones as it increased the quality and yield of potato.
- Further research needs to be carried out to evaluate the effect of paclobutrazol application time on quality and yield of potatoes under field conditions.
- Drench application of paclobutrazol is recommended in potato as it was effective in reducing excessive top growth resulting in high tuber yield and quality of potato.

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APPENDICES

Appendix 1: Effect of time of paclobutrazol application on stem length at 49 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	5.042	5.042	1.44	0.248
Time of PBZ application	3	1315.458	438.486	125.28	<.001
Variety.Time of PBZ application	3	30.458	10.153	2.90	0.067
Residual	16	56.000	3.500		
Total	23	1406.958			

Appendix 2: Effect of time of paclobutrazol application on stem length at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.375	0.375	0.09	0.767
Time of PBZ application	3	2846.458	948.819	230.02	<.001
Variety.Time of PBZ application	3	31.125	10.375	2.52	0.095
Residual	16	66.000	4.125		
Total	23	2943.958			

Appendix 3: Effect of time of paclobutrazol application on stem diameter at 49 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.0002667	0.0002667	0.29	0.600
Time of PBZ application	3	0.2596833	0.0865611	92.74	<.001
Variety.Time of PBZ application	3	0.0005000	0.0001667	0.18	0.909
Residual	16	0.0149333	0.0009333		
Total	23	0.2753833			

Appendix 4: Effect of time of paclobutrazol application on stem diameter at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.002817	0.002817	1.74	0.205
Time of PBZ application	3	1.595417	0.531806	328.95	<.001
Variety.Time of PBZ application	3	0.002283	0.000761	0.47	0.707
Residual	16	0.025867	0.001617		
Total	23	1.626383			

Appendix 5: Effect of time of paclobutrazol application on tuber yield per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.0007594	0.0007594	4.24	0.056
Time of PBZ application	3	0.8558031	0.2852677	1592.19	<.001
Variety.Time of PBZ application	3	0.0001365	0.0000455	0.25	0.857
Residual	16	0.0028667	0.0001792		
Total	23	0.8595656			

Appendix 6: Effect of time of paclobutrazol application on tuber reducing sugar content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.01402	0.01402	0.18	0.675
Time of PBZ application	3	23.85802	7.95267	103.45	<.001
Variety.Time of PBZ application	3	0.00995	0.00332	0.04	0.988
Residual	16	1.23000	0.07688		
Total	23	25.11198			

Appendix 7: Effect of time of paclobutrazol application on tuber starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	2.344	2.344	0.88	0.363
Time of PBZ application	3	799.538	266.513	99.55	<.001
Variety.Time of PBZ application	3	4.175	1.392	0.52	0.675
Residual	16	42.833	2.677		
Total	23	848.890			

Appendix 8: Effect of time of paclobutrazol application on total number of tubers per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	2.6667	2.6667	3.20	0.093
Time of PBZ application	3	39.5000	13.1667	15.80	<.001
Variety.Time of PBZ application	3	1.0000	0.3333	0.40	0.755
Residual	16	13.3333	0.8333		
Total	23	56.5000			

Appendix 9: Effect of time of paclobutrazol application on the number of extra large tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.0417	0.0417	0.14	0.710
Treatment of PBZ application	3	83.4583	27.8194	95.38	<.001
Variety.Time of PBZ application	3	0.7917	0.2639	0.90	0.461
Residual	16	4.6667	0.2917		
Total	23	88.9583			

Appendix 10: Effect of time of paclobutrazol application on the number of large tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Time of PBZ application	3	26.8333	8.9444	21.47	<.001
Variety	1	0.1667	0.1667	0.40	0.536
Variety.Time of PBZ application	3	0.8333	0.2778	0.67	0.585
Residual	16	6.6667	0.4167		
Total	23	34.5000			

Appendix 11: Effect of time of paclobutrazol application on the number of medium tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Time of PBZ application	3	63.0000	21.0000	63.00	<.001
Variety	1	1.5000	1.5000	4.50	0.050
Variety.Time of PBZ application	3	1.5000	0.5000	1.50	0.253
Residual	16	5.3333	0.3333		
Total	23	71.3333			

Appendix 12: Effect of time of paclobutrazol application on the number of small tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Time of PBZ	3	164.1250	54.7083	164.12	<.001
Variety	1	1.0417	1.0417	3.12	0.096
Variety.Time of PBZ application	3	1.4583	0.4861	1.46	0.263
Residual	16	5.3333	0.3333		
Total	23	171.9583			

Appendix 13: Effect of method of paclobutrazol application stem length at 42 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	614.083	307.042	42.35	<.001
Variety	1	2.667	2.667	0.37	0.552
Method_of_application.Variety	2	0.583	0.292	0.04	0.961
Residual	18	130.500	7.250		
Total	23	747.833			

Appendix 14: Effect of method of paclobutrazol application stem length at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method of application	2	4045.750	2022.875	387.36	<.001
Variety	1	1.500	1.500	0.29	0.599
Method_of application.Variety	2	6.750	3.375	0.65	0.536
Residual	18	94.000	5.222		
Total	23	4148.000			

Appendix 15: Effect of method of paclobutrazol application on stem diameter at 42 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	0.992558	0.496279	415.49	<.001
Variety	1	0.001667	0.001667	1.40	0.253
Method_of_application.Variety	2	0.000608	0.000304	0.25	0.778
Residual	18	0.021500	0.001194		
Total	23	1.016333			

Appendix 16: Effect of method of paclobutrazol application on stem diameter at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	2.9060583	1.4530292	2583.16	<.001
Variety	1	0.0002042	0.0002042	0.36	0.554
Method_of_application.Variety	2	0.0003083	0.0001542	0.27	0.763
Residual	18	0.0101250	0.0005625		
Total	23	2.9166958			

Appendix 17: Effect of method of paclobutrazol application on tuber yield per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	1.3639562	0.6819781	1432.60	<.001
Variety	1	0.0010010	0.0010010	2.10	0.164
Method_of_application.Variety	2	0.0005146	0.0002573	0.54	0.592
Residual	18	0.0085687	0.0004760		
Total	23	1.3740406			

Appendix 18: Effect of method of paclobutrazol application on tuber reducing content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	39.3765	19.6882	118.18	<.001
Variety	1	0.1218	0.1218	0.73	0.404
Method_of_application.Variety	2	0.2688	0.1344	0.81	0.462
Residual	18	2.9988	0.1666		
Total	23	42.7659			

Appendix 19: Effect of method of paclobutrazol application on tuber starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	1214.926	607.463	376.92	<.001
Variety	1	0.735	0.735	0.46	0.508
Method_of_application.Variety	2	2.048	1.024	0.64	0.541
Residual	18	29.010	1.612		
Total	23	1246.718			

Appendix 20: Effect of method of paclobutrazol application on total number of tubers per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.000	0.000	0.00	1.000
Method_of_application	2	40.583	20.292	13.53	<.001
Variety.Method_of_application	2	0.250	0.125	0.08	0.920
Residual	18	27.000	1.500		
Total	23	67.833			

Appendix 21: Effect of method of paclobutrazol application on number of extra large tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	99.2500	49.6250	274.85	<.001
Variety	1	0.0417	0.0417	0.23	0.637
Method_of_application.Variety	2	0.0833	0.0417	0.23	0.796
Residual	18	3.2500	0.1806		
Total	23	102.6250			

Appendix 22: Effect of method of paclobutrazol application on the number of large tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	114.3333	57.1667	128.62	<.001
Variety	1	0.1667	0.1667	0.38	0.548
Method_of_application.Variety	2	1.3333	0.6667	1.50	0.250
Residual	18	8.0000	0.4444		
Total	23	123.8333			

Appendix 23: Effect of method of paclobutrazol application on the number of medium tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	221.583	110.792	110.79	<.001
Variety	1	1.500	1.500	1.50	0.236
Method_of_application.Variety	2	0.250	0.125	0.12	0.883
Residual	18	18.000	1.000		
Total	23	241.333			

Appendix 24: Effect of method of paclobutrazol application on the number of small tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Method_of_application	2	147.2500	73.6250	79.12	<.001
Variety	1	0.3750	0.3750	0.40	0.534
Method_of_application.Variety	2	3.2500	1.6250	1.75	0.203
Residual	18	16.7500	0.9306		
Total	23	167.6250			