PERFORMANCE OF WILD BLACKBERRY (*Rubus* spp.) UNDER CONVENTIONAL PRODUCTION IN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted before any institution for a degree or any other award.

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

I dedicate this work to my late parents and my entire family.

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ABSTRACT

Blackberry (*Rubus* L. sub-genus *Rubus* Watson) fruits grow wild in Kenya; though in some parts of the world they have been adopted and are cultivated commercially. However, limited information is available regarding, growth characteristics, fruit yield and quality of wild species growing in Kenya under conventional production. The objective of the study was to contribute towards increased blackberry cultivation, by evaluating the performance of wild blackberry species under conventional production in Kenya. Two seasons involving four wild blackberry species (*Rubus volkensis, Rubus steundneri, Rubus apetalus, and Rubus pinnatus*) growing in Kenya and one cultivated species (*Rubus fruiticosus* variety "Ruben") were carried out to evaluate their performance under conventional production. Season 1 was carried out in January 2016 to December 2016 and season 2 was carried out in June 2016 to July 2017. Both seasons were carried out at the Horticulture Research and demonstration Field 3, Egerton University, Njoro. The seasons were laid out in a Randomized Complete Block Design (RCBD), with three replications. A block consisted of five plots each measuring 4 m by 4 m and separated with a path of 1.5 m wide between blocks and 1 m wide between plots. Data collection was on: plant height, number of laterals, internode length, number of internodes per cane, cane diameter, number of canes per stool, days to first and 50% flowering, duration of blooming and harvesting, number of flower buds and fruits, days to fruit maturity, fruit number per cane, fresh fruit weight (g), fruit dry matter, fruit size and estimated yield per hectare. All the data were subjected to Analysis of Variance (ANOVA) using PROC GLM procedure of SAS program (SAS Institute, Cary Inc, 2001). Significant means were separated using Tukey's Honestly Significant Difference Test (Tukey's HSD) at $p \leq 0.05$. The results indicate that wild blackberry species *Rubus apetalus*, exhibited the most vigorous growth in terms of cane height (154.13 cm), cane diameter (19.90 mm) and fruit number per lateral (56 fruits). Cultivated species *Rubus fruiticosus* was the earliest to flower and fruit at 123 days and had significantly ($p \leq 0.05$) higher fruit yield per plant 373.00 g and fresh weight of 5.60 g per fruit. *Rubus volkensis* was the second in fruit yield per plant 139.00 g and 134.00 g season 1 and 2 respectively. Two (2) wild blackberry species *Rubus pinnatus* and *Rubus steundneri* flowered but did not set fruits. From this study it is recommended that *Rubus volkensis* should be considered for further improvement as it had the higher fruit yield per plant and fresh fruit yield after cultivated species *Rubus fruiticosus* var "Ruben". This study showed that under conventional production, wild blackberry species have different growth characteristics, fruit yield components and fruit quality.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AY	Alternate year
EY	Every year
HSD	Tukey`s Honestly Significant Difference Test
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System

CHAPTER ONE

INTRODUCTION

1.1 Background information

Blackberries (*Rubus* L. sub-genus *Rubus* Watson) are important fruits and are ranked second after Blue berry (*Vaccinium sp.)* among the berry fruit species in the World because it has numerous nutrients such as vitamins, minerals, anti-oxidants and dietary fibres that are essential for health (Ding *et al*., 2006; Tulipani *et al*., 2008). They belong to the genus *Rubus* that comprises a high diversity of species such as (*R. ursinus, R. fruiticosus and R. argutus*) and are among the soft and aggregate fruits considered a healthy and nutritious part of human diet (Tulio, 2008; Hirch, 2013). Blackberries are widely cultivated on over 20,000 Ha worldwide, mainly in Europe and North America (Strik *et al.*, 2007).

Blackberry is a mild climate fruit crop that can easily adapt to different ecological conditions; the plant grows very fast in woodlands, scrubs, hillsides, hedge rows and can be invasive across large areas in a relatively short time. Moreover, blackberry is more tolerant to drought and warm conditions than raspberries, it flowers and produces purple, black or red fruits (Crocker *et al.,* 1998).

The health benefits are attributed to presence of high nutritional content of dietary fiber, vitamin C, vitamin K, folic acid, and the essential mineral, manganese (Sariburun *et al.*, 2010). Blackberries are notable for their phytochemical content that is nutritious and are also ranked highly among fruits for antioxidant strength, which are known to destroy free radicals that harm cells and can lead to cancer. particularly due to their high content of such compounds as ellagic acid, tannins, ellagitannins, quercetin, gallic acid, anthocyanins, and cyanidins (Hager *et al*., 2008, Overall *et al.*, 2017). The phenolic compounds found in blackberries have been linked to a reduced risk of degenerative diseases such as cardiovascular disease and cancer (Reyes-Carmona *et al.,* 2005).

Production of blackberry has increased significantly in the United States of America (USA) (Siriwoharn *et al.*, 2004), in Kenya according to Chittaranjan (2011), there are 84 species of wild blackberries. The number of cultivated species and acreage in Kenya is unknown, however, in U.S.A, 15 species are in cultivation with production of 65,171 tonnes from 7,159 Ha of land. Blackberries have now become a common fruit in marketing outlets, particularly in North America and the European Union and they have enjoyed expansion due to a combination of factors including improved cultivars, expanded marketing efforts and fruit availability (Strik *et al.*, 2007). An overall increase in berry consumption is due to its potential health benefit and functional food market (Ding *et al*., 2006; Tulipani *et al*., 2008; Kaume *et al.*, 2012). However, in Kenya there is little or no information on the performance of the wild blackberry species in comparison to the cultivated types that have been imported. Growth characteristics, fruit yield components and quality of the wild blackberry species is not known as it grows wild in various parts of the country and little is also known about cultivated types since there are few large scale trial if any. The aim of this study was to evaluate the performance of four wild against one cultivated blackberry species, when grown under conventional cultivation.

1.2 Statement of the Problem

Limited blackberry production in Kenya relies on introduced cultivars yet there are numerous wild blackberry germplasm with the potential of being adapted for commercialization under conventional production. Wild blackberry production is unexploited because of a knowledge gap that exists about their growth characteristics, fruit yield potential and quality under conventional production.

1.3 Objectives

1.3.1 Broad Objective

To contribute towards increased blackberry cultivation, by evaluating the performance of wild blackberry species under conventional production in Kenya.

1.3.2 Specific Objectives

i. To determine growth characteristics of wild blackberry species under conventional production in Kenya.
ii. To determine fruit yield components of wild blackberry species under conventional production in Kenya.
iii. To determine fruit quality of wild blackberry species under conventional production in Kenya.

1.4 Hypotheses

i. There are no significant differences in growth characteristics among wild blackberry species in Kenya under conventional production.
ii. There are no significant differences in fruit yield component among wild blackberry species in Kenya under conventional production.

iii. There are no significant differences in fruit quality among wild blackberry species in Kenya under conventional production.

1.5 Justification

Due to increase in demand for fruits that have health benefits in the world, blackberry are gaining importance. Blackberries have numerous plant nutrients such as vitamins, minerals, anti-oxidants and dietary fibre that are essential for good health. The fruits are popular in desserts, jams, and seedless jelly and sometimes wine in the countries where they are grown commercially. Apart from the nutritive aspect, blackberries, can also be a source of income for small holder farmer's thus creating more job opportunities in the country. Conventional horticultural practises affect growth characteristics, fruit yield and quality of crops, hence it is essential to have a good knowledge on how wild blackberries respond to conventional horticultural practises. In order to exploit wild blackberry there is need to understand growth, fruit yield and quality potential by evaluating their performance.

1.6 Scope and Limitation

This study dealt with evaluation of wild blackberry under conventional production in Kenya, the research focused on growth characteristics, fruit yield components and fruit quality of four wild blackberry species and one cultivated species. Although the research achieved its objectives, it was not possible to go all over the country to collect all the wild blackberry species growing for the study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Biology

Rubus berry species are closely related to roses, one of the most diverse genera in the plant kingdom (Thompson, 1995; Daubeny, 1996). The *Rubus* plant forms range from completely self-fertile to completely self-un-fertile and are often referred to as brambles. Bramble fruit are generally separated into two groups: raspberry (*Rubus idaeus* L.) and blackberry (*Rubus fructicosus*) (Industries, 2002). Blackberries are often classified into 3 types according to their cane architecture: erect, semi-erect, and trailing (Strik, 1992). Erect-caned cultivars include the thorny 'Brazos', 'Tupy', 'Cherokee' and the thornless 'Navaho' and 'Arapaho'. Semi-erect types include 'Chester Thornless', 'Thornfree', 'Loch Ness', and 'Cacanska Bestrna'. Trailing types include 'Marion', 'Silvan' and 'Thornless Evergreen' and the blackberry X raspberry hybrids 'Boysen' and 'Logan'. (Strik *et al*., 2007).

In the first year, a new stem, the (primo cane), grows vigorously to its full length of 3-6 m (in some cases, up to 9 m), arching or trailing along the ground and bearing large palmately compound leaves with five or seven leaflets; it does not produce any flowers. In its second year, the cane becomes a floricane and the stem does not grow longer, but the lateral buds break to produce flowering laterals (which have smaller leaves with three or five leaflets (Krewer *et al*., 2004). First and second year shoots usually have numerous short-curved very sharp prickles that are often erroneously called thorns. Primocane fruiting blackberry cultivars began with the first commercial release of 'Prime-Janâ' and 'Prime-Jimâ' in 2004 at the University of Arkansas (Clark *et al.*, 2005). This unique type of blackberry fruits on current-season canes (primocanes) and second-season canes (floricanes) (Clark *et al*., 2005).

2.2 Origin

Blackberry has its centre of origin in Eurasia and Northern America and is widely present as wild types (Clark *et al*., 2007). Though according to Thompson (1997) and Roach (1985) the centre of diversity is considered to be in China, where there are 250-700 species of *Rubus*. Extensive accounts of early domestication of *Rubus* species in the *Rubus* genus are indigenous to six continents and grow from the tops of mountains to the coastal locations at sea level. They grow especially well as cool climate plants, but also produce economic yield crops in the subtropics (Daubeny, 1996).

The formal name of the ancient blackberry was *Rubus eubatus* and it was always considered wild, so in the early days it was not cultivated. Development of the modern blackberry is relatively recent and was mainly done in United States of America. The European blackberry (*Rubus fructicosus* L.) is centred in the Caucasus region and has been introduced into Asia, Europe, North and South America, and Africa. Blackberry grow vigorously and rapidly in woods, scrub, hillsides, and hedgerows, blackberry shrubs tolerate poor soils, readily colonizing wasteland, ditches, and vacant lots (Huxley, 1992).

2.3 Nutrition and Health Benefits of Blackberry

The use of blackberry as a food source and medicinal plant is well documented from prehistory (Early Stone Age, 40,000B.C) to the modern era (21st Century) (Shiow and Lin, 2000). Rubus berries are not true berries but aggregate fruits and have a number of culinary uses in the modern era as: a fresh fruit, processed into jams, as a yogurt flavouring, pie filling (Rao and Snyder, 2010). The species of blackberry (*R. fruticosus*) most common in Britain is naturalized throughout most of the world, including North America. In folk medicinal records, it is not possible to trace the actual species whose roots were used in the past to treat dysentery (Meyer, 1985), and diarrhoea (Cadwallader and Wilson, 1965). The leaves of the blackberry are chewed to treat toothache (Hatfield *et al.*, 1994).

The berry is a powerful source of antioxidants which are known to destroy free radicals that harm cells and can lead to cancer. They also help protect and strengthen the immune system, which lowers the risk of cancer (Wynn and Fougere, 2006). Blackberry also help protect and strengthen the immune system, which lowers the risk of cancer. Blackberry leaves have been traditionally used in herbal medicine as an antimicrobial agent (Wang and Lin, 2000). The plant has triterpenic acid and rubitic acid (Khare, 2007). Blackberries are notable for their high nutritional contents of dietary fiber, vitamin C, vitamin K, and the essential mineral manganese (Ali *et al.*, 2011; Conde, 2013) vitamin E (Van *et al.*, 2009) calcium (Lievre *et al.*, 2011) and non-nutrients such as phenolics (Nigel *et al.*, 2000), ellagic acid (de Ancos *et al.*, 2000), ellagitannins (Clifford and Scalbert, 2000), flavonoids (Kalt *et al.*,1999) ellagitannins and carotenoids (Mertz *et al.*, 2009). The root contains saponins and tannins, whereas leaf acid, flavonoids, and tannins (Pullaiah, 2006).

2.4 Cultivation and Distribution

Blackberry production is rapidly increasing in the world (Strik, 1992; Strik *et al.*, 2007) with an estimated 154,705 tonnes commercially harvested from 20,035 ha in 2005 (Table 1). The world leader in terms of acreage is Europe with 7,692 ha, while North America has the highest production of 65,171 tonnes. Serbia dominates European production with 69 %, however, a number of other countries have significant production. In North America, the US, particularly Oregon State, is the major producer (Clark, 2005). California and Arkansas are the only other states in the US with over 1,000 tonnes productions. Central American production (1620 ha) is predominantly from Costa Rica and Guatemala where in addition to harvest from managed stands, a great deal is harvested from feral stands. South American production (1597 ha) is predominantly from Ecuador and Chile. Mexican production has also been rapidly increasing. Asian production has been rapidly increasing with over 1,550 ha of new plantings, predominantly in China (Strik, 1992).

The production in Oceania according to Strik *et al.* (2007) is mainly in New Zealand although the area planted is small with only about 259 ha. African production is only reported in South Africa at about 100 ha, but has been initiated in Morocco, Algeria and Kenya (Clark, 2005).

The bulk of the fruit is grown for processing applications in the Pacific Northwest U.S, Serbia, and China whereas fresh market sales are the focus of the industry elsewhere. Wild blackberries still make a significant contribution to worldwide production and although accurate data are hard to obtain, survey respondents estimated 8000 ha of wild blackberries harvested in 2005 and had a total reported production of 14,837 tonnes ((Strik, 1992).

Table 1: Worldwide area under production of blackberries

Region	Area (ha)	Production (tonnes)
Europe	7,692	47,398.90
North America	7,159	65,171.28
Central America	1,640	1,752.66
South America	1,597	7,032.67
Asia	1,550	29,045.61
Oceania	297	4,023.40
Africa	100	220.46
World Total	20,032	154,705.37

Source: Strik *et al*. (2007).

2.5 Wild blackberry species Kenya

2.5.1 ***Rubus apetalus*** Poir

Rubus apetalus syn: *Rubus rigidus* Sm. is known locally as Mutare (Kikuyu), Bukarambi (Bukusu), Obukarambi (Tachoni) and Ndaindai (Taita). *Rubus apetalus* is a scrambling shrub that has lateral branches with hairs, armed with hooked prickles, it has leaves with 3-7 leaflets, each ovate, hairy, pale green beneath with serrated margins. Flowers are white to pink fruits are green, turning yellow to purple-black on ripening (Maundu *et al.*, 1999). It is widely distributed in Kenya in Nyambene hills, Mt. Nyiru, Mt kulal, Kandara (Marangua), Chania Falls Ngong hills, Maasai Mara, Meru, Kisii and Marsabit in riverine vegetation, forest edges, humid bushland, hillside springs at an altitude of 1450-2700 m above sea level, Zones II-IV. *Rubus apetalus* is used as food as the fruits are edible with a sweet acid taste and it has the potential for use as a hedge and an ornamental (Maundu *et al.,* 1999).

2.5.2 ***Rubus pinnatus*** Willd.

Rubus pinnatus is known locally as Ndare (Embu), Kitae (Kamba), Mutare, Ndare (Kikuyu), Tangaimamiet (Kipsigis), Bukarambi (Bukusu), Obukarambi (Tachoni) Engaiyagut (Maa) Monmonwo (Pokot), Mtoje, Matoje (Swahili), Ndaindai, ndaendae (Taita) and Momonwo, mowonwo (Tugen) (Maundu *et al*., 1999). *Rubus pinnatus* is a prickly scrambling shrub, the branches are occasionally white, armed with hooked prickles, leaves with up to 9 leaflets, each ovate with serrated margins. Flowers are white to pink and fruits turning from green to reddish black on ripening (Maundu *et al.,* 1999). *Rubus pinnatus* is found in tropical Africa to South Africa, it is also widely distributed in Kenya in Riverine vegetation, near hillside springs, forest edges, and at an altitude of 1500-2700 m above sea level. It is used as food for the fruits are edible and sweet and may be used as hedge plant (Maundu *et al.,* 1999).

2.5.3 ***Rubus volkensis*** Engl.

Rubus volkensis is also known locally as Mutare, kigombe, ndare (Kikuyu), Kipsoeniot, nemingin, degaimamiet, tagaimamiet (Kipsigis**)** and Engaiyaguji, engaiyagut (Maa) (Maundu *et al.,* 1999). It is a prickly shrub that grows up to 4 m, stems are hooked with prickles, covered with brown sticky hairs, the leaves are compound with up to 7 leaflets. The leaflets are hairy, with serrated margins, top leaflets often incompletely divided. The flowers are yellow- white, borne in panicles and fruit which turn orange to red when ripe (Maundu *et al.,* 1999). *Rubus volkensis* are found growing in high altitude forest edges and bushland, bamboo margins, at an altitude of 2150-3550m in zone I-II (Limuru, Lari, Aberdares). It's used as food for its fruits are edible and delicious (Beentje, 1994; Maundu *et al.,* 1999).

2.5.4 *Rubus steundneri*

Rubus steundneri stems is a lined with small, but sharp prickles, the numerous weak stems bend and lean against themselves and other plants, they form an impenetrable thicket that getting to the edible berries can be an ardous task (Michael, 2014).

2.6 Production Systems of Different of Blackberry Types

Blackberry orchards normally have a life of 5–20 years, depending on the production region, type of blackberry grown, level of horticultural management and productivity. Orchards are established using plants propagated by tissue culture or root cuttings, and can also be established with bare root or potted plants (Strik *et al.,* 2007).

2.6.1 Semi Erect Type of Blackberry

The planting density for semi-erect blackberries varies with production region and cultivar. In Serbia plants are generally established at an in-row spacing of 1.0-1.5 m with 2.5-3.0 m between rows. In the United States, plants are typically 1.5-1.8 m apart in rows that are 3.0-3.6 m apart. In most farms in China, the planting density is very high with 0.3-0.4 m between plants and 1.0 m between rows (Strik *et al*., 2007). In almost all regions, primocanes are tipped during the growing season, at 1.5-1.6 m high to encourage branching. Canes are either trained on a multiple wire trellis with a non-divided canopy or are trained to a ''double T'' system. In most regions, plantings are irrigated using drip, overhead, or microjet systems. However, in China fields are commonly flood irrigated. Average yield is 9-50 tonnes/ha with all fruit hand-picked every 3-5 days for fresh market. The fruiting season, in the northern hemisphere, ranges from July to October, depending on cultivar and production region. Excess fruit are processed, usually as a seedless puree (Strik *et al*., 2007).

2.6.2 Erect Type of Blackberry

According Strik *et al.* (2007) most production regions of the erect types, plants are established 0.8-1.2 m apart in rows 3 m apart. During the growing season, primocanes are tipped at a height of 0.9-1.2 m, depending on production region, to encourage branching. After fruit harvest dead floricanes are removed by pruning. In some production regions, like Oregon, dead floricanes are left in the planting to save labour costs; they will eventually break off and fall into the row middles. Erect blackberries are grown without a trellis in some regions; however, the use of a trellis is becoming common as planting area increases. Reasons to trellis include the reduction in cane breakage due to wind along with keeping all fruiting canes upright within the row to limit yield loss at fruit maturation. Usually a simple two- or four-wire trellis is used, but canes are usually not tied to the wire. In Georgia, U.S., hydrogen cyanamide (Dormex; SKW Trostberg AG, Trostberg, Germany) is applied in some years to improve bud break. Drip irrigation systems are most common. Fruit are harvested by hand, primarily for fresh market, every 3-5 day. The fruiting season of erect floricane fruiting cultivars is about 4 weeks long, from May to August, depending on production region. Yields range from 3 tonnes/ha (Texas) to 12 tonnes ha (Ore.). In Mexico, the area planted to blackberry has increased 10-fold since 1995 and growth continues to be strong. Specialized production systems have been developed through on-farm research by growers and private companies to extend the season for 'Brazos', 'Tupy', and other erect cultivars. Primocane-fruiting blackberries can be double-cropped (Strik *et al.,* 2007).

2.6.3 Trailing Type of Blackberry

Trailing types are typically grown in every-year (EY) production systems at in-row spacing of 0.9-1.8 m with 3 m between rows (Bell *et al*., 1995). Most are grown on a trellis with the canes wrapped around two wires (top at 1.7 m second at 1.2 m). Trailing blackberries can be grown in (EY) or alternate year (AY) production systems. In EY production, new primocanes are trained along the ground, under the canopy, while the floricanes are on the wire producing the current season crop. After fruit harvest, the dead floricanes are removed and the primocanes trained onto the trellis wires in August or February. Most growers in Oregon train primocanes in February, leaving canes more protected from cold, potentially injurious temperatures as compared with August-training where canes are more exposed to cold injury on the trellis. In AY production systems, plants fruit every other year. In the ''one year'' floricanes produce a crop and primocanes are not managed. In October, the dead floricanes and the primocanes are pruned off at the crown. The following ''off-year'' primocanes are trained to the trellis as they grow. The yield of an AY field is about 85% of an EY field over a 2-year period (Eleveld *et al.,* 2001). Research has demonstrated that primocanes following an off-year in an AY system is more cold-hardy than primocanes that grew in the presence of floricanes in an EY system (Bell *et al.,* 1995; Cortell and Strik, 1997b). There is also less cane disease in AY production systems than in EY systems. Over 60% of the trailing blackberry acreage in Oregon is grown in AY production systems. In New Zealand, a three-wire trellis is typically used with canes trained in a fan and looped over to the middle wire. Plants are grown in EY production systems. Most plantings are irrigated with overhead systems, but in Chile, furrow irrigation is very common. Trailing types for the processed market are machine-harvested on more than 75% of the area in the United States and New Zealand. Typical yields range from 9 to 16 tonnes/ha (Strik *et al.,* 2007).

2.7 Fruit Quality

Blackberry fruits are sweet, do not have crunchy seeds and are firm enough to ship when ripe. Dual purpose berries can be shipped fresh or processed (Clark and Finn 2011). Fruit quality is now the most important characteristic due to increased consumer demand and quality awareness. Other traits such as a large size and thorn less canes have already been improved and incorporated in more recent cultivar releases.

2.7.1 Fruit Taste

Clark (2005) proposed that enhanced quality particularly sweetness is the key to expansion of fresh market blackberry, flavour is also critical for processed blackberries. Fruit flavour can be divided into other component such as acidity, aromatic content and astringency. Other common quality components include fruit firmness, shape, and strength of skin, texture, seediness, colour and nutraceutical content along with other characters such as ease of fruit removal at harvest (Clark and Finn, 2011). According to Wang and Lin (2005) aromatic flavour component of a given genotype can substantially be influenced by the environment. Generally, a soluble solids content of at least 10% provides “a sweet” eating experience for blackberries. Some of the more common erect cane cultivars such as “Navaho” and Quachita” provide 10-12% soluble solid content. Among the trailing genotypes, cultivars such as “Boysen” can have over 15% soluble solids (Fan Chiang 1999; Siriworharn *et al.,* 2004). Another approach to perceived high soluble solids is by decreased acidity level in berries. However, the problem with this approach can lead to “flat” flavour when acidity falls too low to give a full and balanced flavour profile.

2.7.2 Fruit Colour Development

The impact of fruit ripeness or maturity is very dramatic for blackberries; sweetest berries are those that are dull black (after loss of glossiness), maturity of fruit greatly affects fruit quality, particularly the sugar and acid level. Dull-black fruit were found to be the sweetest compared to mottled or shiny black fruit but were also softer (Perkins *et al*., 2000). Volatiles were much higher in dull-black compared to shiny-black fruit (Perkins *et al.,* 2000; Siriwoharn *et al.,* 2004).

2.7.3 Fruit Firmness

Fruit firmness is usually evaluated subjectively after storage and it's important to note that postharvest firmness retention cannot be judged in the field but is greatly impacted by environment. Perkins and Clark (2002) found that fruits exposed to rainfall with four days of harvest could greatly reduce postharvest storage potential.

2.7.4 Fruit Seediness and shape

Blackberries can have substantial seed content and this trait is unaccepted to some consumers, more specifically the feel of seeds in the mouth is very important. Consumers can perceive that some trailing genotypes are seedless or having low level of seediness (Finn *et al.,* 1997), a perception apparently due to seed shape and endocarp thickness (Takeda, 1993).

Blackberry shape can vary substantially and in general there is no overall consensus on what is the most desired shape. Shape uniformity is imperative, however fruits that irregular druplet size, do not have even shape, or are double fruit are not acceptable. Most individuals agree that a berry with uniform barrel round or conical shape and uniform druplets is most desirable (Clark *et al*., 2007). For fresh market shape impact berry placement in the punnet or clamshell, long berries provide for very attractive placement in the vessel resulting in excellent market appeal (Clark *et al*., 2007). Blackberries that are too large cannot be used in frozen berry mixes as they conceal other berries in the mixes (Clark and Finn 2011).

2.7.5 Fruit Size

The size of fruit has long been a primary objective in all breeding effort and is also important as a yield component in blackberries (Daubeny, 1996). In breeding programs large fruit size is desirable, but excessive fruit size (possibly over 15g) is usually not desired for processed or fresh market use as large fruits can be very difficult to place in punnets. In general, the ideal berry weight for fresh market use is 8-10 g (Clark and Finn, 2011).

2.8 Blackberry Productivity

Productivity or fruit yield of blackberries varies substantially among types, cultivars, horticultural management systems and location of production. An evaluation of fruit yield components has been done for a limited group of cultivars with most attention given to the trailing cultivar “Marion” (Bell *et al.,* 1995a, 1995b; Cortel and Strik, 1997a; Takeda and Peterson, 1999). However, these reports do not address a genetic variability approach to fruit yield. Eyduran *et al*. (2008) found that berry weight was accounted for by cane height, number, diameter and yield for eight cultivars, these cane variables can also affect the overall yield of a plant.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Experimental Site

The study was conducted at the Horticulture Research and Demonstration Field 3, of Egerton University. The farm lies at a longitude 35°35`E and latitude of 0°23`S and an altitude of 2238m. The area receives a total annual rainfall ranging from 1200 to 1400 mm while average maximum and minimum temperatures range from 19 ^oC to 22 ^oC and 5 ^oC to 8 ^oC, respectively. The soils are well drained dark reddish clays classified as *Mollic andosols* (Jaetzold and Schmidt, 2006). Temperature and rainfall data recorded for the site during the study period are presented in (Table 2) (Egerton University Engineering Meteorological Station, 2016- 2017).

3.2 Planting Materials

One blackberry cultivar (*Rubus fruticosus* var. Ruben was sourced from a farm in Nakuru county and three wild blackberries species (*Rubus steundneri, Rubus pinnatus* and *Rubus apetalus* were also collected from the wild in Nakuru (36.0800° E, 0.3031° S) while *Rubus volkensii* was collected from the wild in Baringo County (35.7412° E, 0.4897° N) and planted at Horticulture Research and Demonstration Field 3 between January 2016 and December 2016 for season one and season two was carried out between June 2016 and July 2017.

3.3 Experimental Design and Treatment Application

The study was conducted in a Randomized Complete Block design (RCBD) replicated three times with five treatments (*R. apetalus, R. volkensis, R. pinnatus, R. steundneri* and *R. fruiticosus* var "Ruben". The experiment covered an area of 24 m by 15 m with each block measuring 4m by 24m separated by 1.5m path. Each experimental unit within each block measured 4m by 4m with spacing from each plot measuring 1 m (figure 1). A cage was constructed around the experimental site to protect it from interference. The cage measured 180 cm height 40 m long and 20 m wide. Wire mesh was placed around to prevent interference with the research. A support system was also erected, posts were placed 4 m apart along each block and 1 m along each plot and two trellising wire (galvanised wire) were placed on the post 1 m apart the first wire was 50 cm above the ground and another 1 m above the first wire running across the field.

Table 2: Average monthly air temperature (^oC), precipitation (mm) and Humidity during Blackberry production over the two seasons (Jan. to Dec. 2016 and Aug. 2016 to July 2017).

Year 2016		Season 1												Total
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
	Precip. (mm)	86.6	23.4	42.8	207.9	132.7	100.8	167.0	109.2	101.0	70.2	64.4	3.6	1109.60
	Temp. (^oC)	20.6	22	23.4	20.9	20.5	19.4	18.5	19	20.8	21.2	19.5	20.4	246.2
	Humid. (%)	42	47	46	66	76	75	65	65	59	59	70	66	736
Year 2016-2017		Season 2												Total
		Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	
2016-2017	Precip. (mm)	109.2	101.0	70.2	64.4	3.6	3.7	31.3	37.1	45.4	109.9	29.8	152.5	758.1
	Temp. (^oC)	19	20.8	21.2	19.5	20.4	21.5	21.9	22.8	26.7	24.4	25.3	23.6	267.1
	Humid. (%)	65	59	59	70	66	47	53	46	58	71	65	74	736

Source: Egerton University Engineering Department (2016-2017)

3.4 Crop Establishment and Maintenance

Blackberry planting materials were collected in situ and propagated through split cuttings. The splits were then placed in propagation tanks for them to root and shoot in readiness to be transplanted in the main field. It took four weeks for the splits to be transplanted in the main field after attaining a height of 15 cm. Preceding transplanting, field preparation was done by mechanical ploughing, harrowing and then demarcation of each experimental unit. Planting holes were dug at a spacing of 1m between plants and 1m from row to row. A plot contained 16 plants. Triple Super phosphate (TSP) (0: 46:0) fertilizer was applied at a rate of 50 kgHa^{-1} i.e. 10 g/hole and mixed thoroughly with the soil before transplanting of blackberry seedlings (Hart *et al.*, 2006). Watering was done during the dry season two times a week using hose pipes. Hand pruning was done by tipping using hands at a height of 150 cm, damaged or diseased woods were removed as recommended by Guy and Byers (2006).

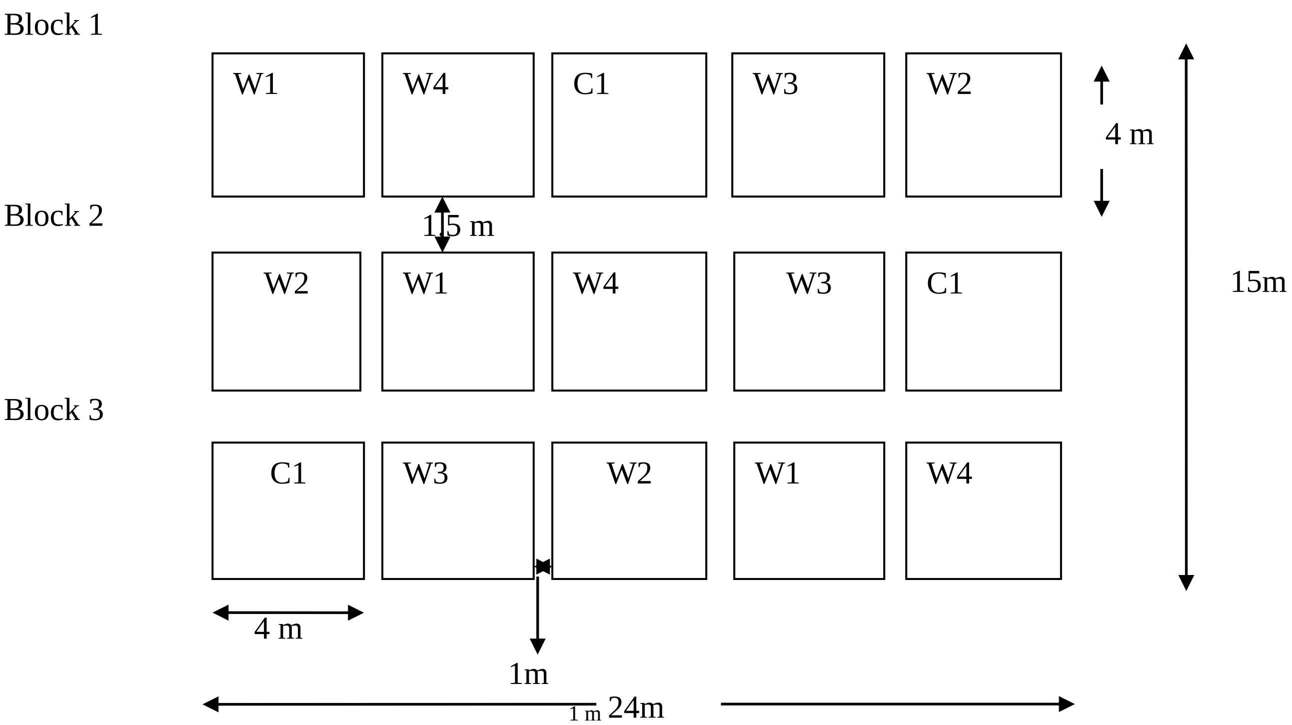

Figure 1: Experimental Field Layout

Key: W1 –*R. steundneri*, W2 -*R. volkensis,* W3-*R.apetalus,* W4-*R.pinnatus,* and C1-*R. fruiticosus* var. "Ruben"

3.5 Data Collection

Data collection commenced four weeks after transplanting on four tagged plants that were randomly selected on the same time in each experimental unit and continued until termination of the study in December 2016 and August 2017 both season 1 and 2 respectively. Data obtained were used to compute the average of each variable for the different treatment. Data were collected as described below:

3.5.1 Growth Variables

i) Cane height

The plant height in centimetres was determined by the use of measuring tape from the ground level to the tip of the longest cane every four weeks on the four tagged plant until it attained a height of 150 cm after which data collection on height was terminated by tipping the cane.

ii) Number of laterals per cane

The number of primary laterals on each tagged cane were counted at three different times: at flowering, mid harvest and at the last harvest date to ensure late developing laterals are counted.

iii) Lateral length

The length from the base of the lateral to the tip of the terminal fruit or terminal leaf bud for vegetative lateral for every counted lateral was measured in centimetres, on the tagged canes at flowering.

iv) Height to the lowest lateral

This was measured from the base of plant to the point of first primary lateral using a measuring tape at first flowering in centimetres.

v) Cane diameter

Cane diameter was measured by the use of Vernier calliper (Model 599-577-1/USA) of the four tagged canes at 5, 15 and 30cm from the soil level every four weeks after planting until flowering stage. The three measurements were averaged to give the cane base diameter in millimetres.

vi) Number of nodes per cane

The total number of nodes per cane were counted from one node to the next node after the canes had bloomed.

vii) Internode length

The distance between nodes at every internode was measured in centimetres on the tagged canes using a ruler at flowering stage.

viii) Number of canes per plant

The total number of canes that emerged from the ground was counted after every four weeks after planting.

ix) Days to first and 50% flowering

The number of days it took from transplanting to first flowering and 50% bloom was taken when the lateral in each tagged plant had at least 5 flowers.

x) Blooming duration

The duration of blooming was determined by counting from the day of first bloom to the last day of blooming.

xi) Number of flowers per lateral and cane

The number of open flowers were counted every three days on each lateral of the tagged cane. After which the flowers on each lateral was summed up to give number of flowers per lateral and cane. Double counting was avoided by subtracting the initial number of flowers counted from the current number of flowers counted.

xii) Percent Fruit set

Percent fruit set was determined by the number of fruit expressed as a percent of the total number of flower per cane.

$$\text{Percent fruit set} = \frac{\text{Number of fruits per cane}}{\text{Total number of flowers per cane}} \times 100$$

xiii) Days to fruit maturity

The number of days it took the fruit to reach maturity was determined by the duration of colour change from red to black or purple on the tagged fruits.

xiv) Harvesting duration

Harvesting duration was determined as the period from first harvest to the last day of harvesting.

3.5.2 Fruit yield

i) Fruit number per cane

The number of ripe harvestable fruits were counted on each lateral of the tagged canes prior to harvesting and then summed up to give fruits per cane.

ii) Fresh fruit Weight

The weight of 20 sampled fruits on each lateral of the tagged cane were weighed in grams using an electric weighing balance (Model: Tanita KD 200-510) from each plot and averaged.

iii) Fruit dry weight

Fruit dry weight was determined by oven drying 20 fresh fruits at 80^oC for 24 hours to indicate fruit dry matter content the weight was in grams.

iv) Fruit yield per plant and estimated fruit yield per hectare

Fruit yield per plant was determined by computing the total yield after every harvest from the four plants then averaged to get yield per plant. Estimated yield per hectare was determined by estimating the total yield per plant.

Estimated yield (Kg/Ha) = Yield/plant (g) × Plant population/Ha

Where plant population = Area (Ha)/Spacing (1.0 m×1.0m)

3.5.2 Fruit Quality

i) Fruit size

The size of the fruit was determined by measuring, two linear dimensions, length (L) and Width (W) in millimetres using a vernier calliper (Model 599-577-1/USA) of 20 fruits at every harvest of sampled fruits.

ii) Total Soluble Solids (TSS)

Harvested fruits were used to determine total soluble solids using a hand-held refractometer (Model 2313 MASTER –M Brand Atago) (0-32 % Brix).

iii) Fruit Titratable Acidity

This was done from the same fruits used to determine TSS, the juice was titrated using the titration method described by AOAC. (2016) by titration to pH 8.1 with 0.1 M Sodium hydroxide (NaOH) solution and calculated as grams of citric acid per 100 g of sample (AOAC, 1984). The percentage of titratable acidity (TA) was calculated using the following formula:

$$TA\left(\frac{g}{l}\right) = T \times A \times 100 \times \frac{10}{V}$$

Where

A= Acid factor of 0.1 M NaOH which is equivalent to 0.0064g citric acid, V= Volume (ml) of Sample, T= Titre (ml) of 0.1 M NaOH

iv) Ratio of Total soluble solids and Titratable acidity

This was obtained by dividing total soluble solids by the titratable acidity that was obtained after each test to obtain the ratio of TSS and Titratable acidity.

Ratio of Total Solubles Solids =TSS/TA

Where: TSS is Total soluble solids and TA is Titratable acidity

3.6 Data Analyses

The data collected were subjected to Analysis of Variance (ANOVA) at $p \leq 0.05$, using SAS (SAS Institute, Cary Inc. 2001**).** Tukey's Honestly Significant Difference (Tukey's HSD) test at $p \leq 0.05$was used to separate means where significant differences were observed. The experimental linear model used for the experiment was:

$Y_{ijk} = \mu + S_i + B_j + T_k + ST_{ik} + \varepsilon_{ijk}$

i=1, 2, j = 1, 2, 3; k = 1, 2, 3, 4,5

Where; Y_{ijk} – blackberry performance, μ – Overall mean, S_i – effect of the i^{th} Season, B_j – effect of the j^{th} Block, T_k – effect of Species, ST_{ik}–interactive effect of Season and Species, ε_{ijk}– Random error component

The results obtained were used to determine whether different blackberry species differ in performance in terms of growth, fruit yield and fruit quality. The overall assumption for normality of data was made and it was further assumed that standard deviations will not be equal to zero.

CHAPTER FOUR

RESULTS

In this chapter, results obtained are presented following the order: Crop growth variables, fruit yield and fruit quality variables.

4.1 Growth variables

4.1.1 Cane height

Blackberry cane height of *R. apetalus,* (35.07 cm) *R. volkensis,* (31.73 cm) *R. steundneri* (29.87 cm), and *R. fruiticosus* (27.7 cm) showed no significant variation in week 4 in season 1 (Figure 2). Significant ($p \leq 0.05$) variation in height in week 4 between *R. apetalus* (35.07 cm) and *R. pinnatus* (26.3 cm) in season 1 was observed. There was significant ($p \leq 0.05$) variation in cane height in week 16 among *R. apetalus* (74.53 cm), *R. steundneri* (63.53 cm), *R. pinnatus* (62.00 cm) and *R. fruiticosus* (61.20 cm) in season 1 and no significant variation in cane height between *R. apetalus* (74.53 cm), and *R. volkensis* (67.36 cm) in season 1. In week 20 for season 1 there was a significant ($p \leq 0.05$) variation in cane height among *R. apetalus* (97.96 cm), *R. pinnatus* (79.53 cm) and *R. fruiticosus* (77.06 cm) but no significant differences were observed among *R. Apetalus* (97.96 cm), *R. volkensis* (88.23 cm) and *R. steundneri* (85.06 cm) there was also no significant difference in cane height among *R. volkensis,* (88.23) *R. steundneri* (85.06 cm), *R. pinnatus* (79.53 cm) and *R. fruiticosus* (77.06 cm) in week 20. In week 24 and 28 significant variation was observed between *R. apetalus* and all the other species, *R. apetalus* had a cane height of 130.10 cm and 154.13 cm respectively in season 1. *R. apetalus* was the first to attain the height of 150 cm and above after which it was tipped to encourage lateral growth. It took 36 weeks *R. volkensis, R. steundneri, R. pinnatus* and *R. fruiticosus* to attain a height of 145 cm and above (Figure 2).

There was no significant variation in cane height from week 4 to week 20 in season 2, significant ($p \leq 0.05$) variation was observed in week 24 between *R. apetalus* (91.10 cm) and *R. volkensis* (79.33 cm). There was no significant variation in cane height among *R. Steundneri* (84.87), *R. pinnatus* (83.13 cm), *R. volkensis* (79.33 cm) and *R. fruiticosus* (81.76 cm) in week 24. Significant ($p \leq 0.05$) variation in height in week 28 was observed in *R. apetalus* (107.03 cm), *R. volkensis* (91.10 cm), *R. pinnatus* (94.33 cm) and *R. fruiticosus* (94.20 cm). There was no variation between *R. apetalus* (107.03 cm), *and R. steundneri* (97 cm in week 28 and no variation in cane height of *R. volkensis* (91.10 cm) *R. steundneri* (97.10 cm), *R. pinnatus* (94.33 cm) and *R. fruiticosus* (94.20 cm). In week 32 after planting there was a significant variation in cane height between *R. apetalus* and all the other species grown (*R. volkensis*, *R. steundneri*, *R. pinnatus* and *R. fruiticosus).* Significant variation was also observed in week 36 among *R. apetalus*, *R. volkensis* and *R. fruiticosus* (Figure 2).

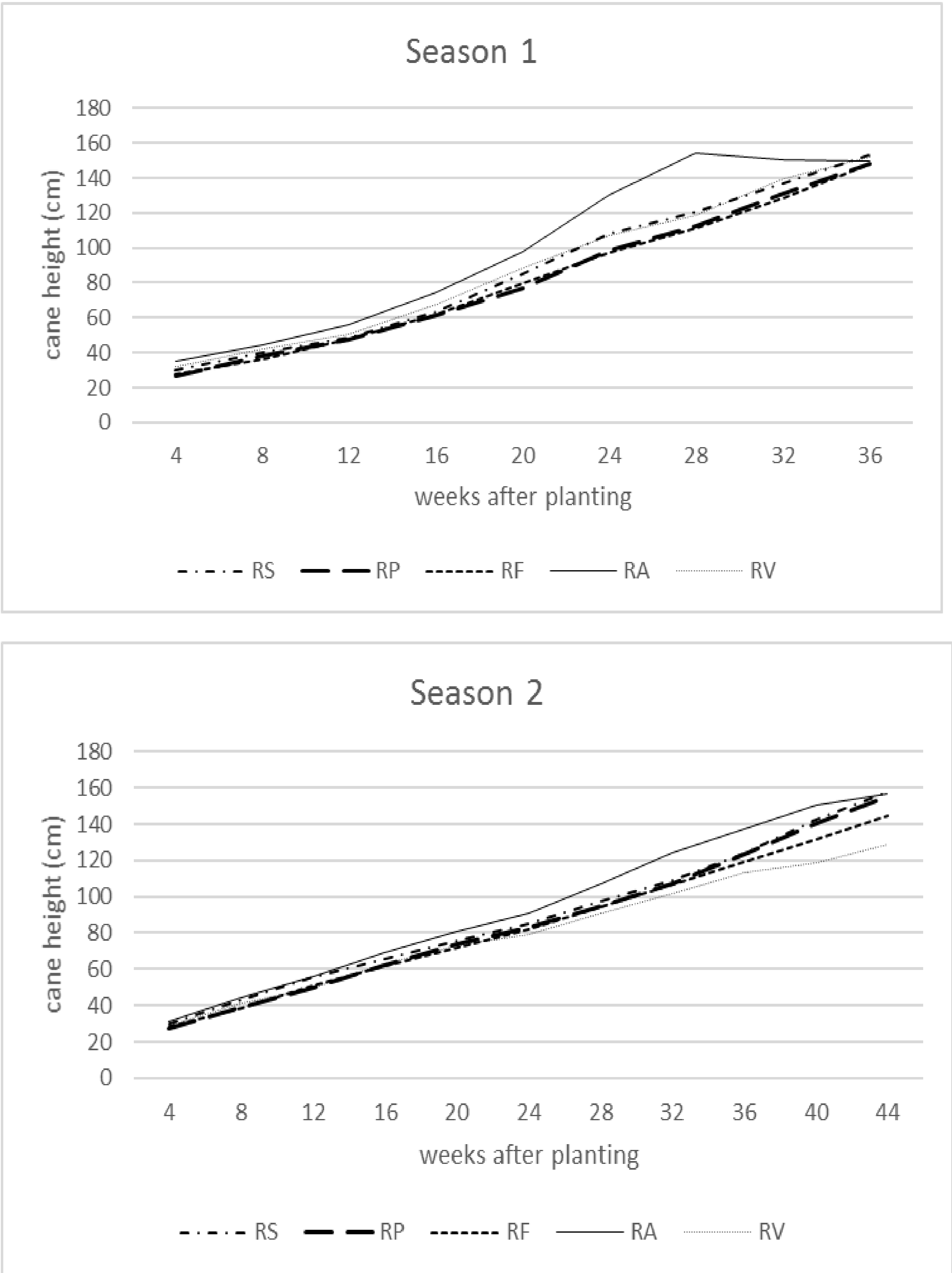

Figure 2: Cane height of different blackberry species (cm) in season 1 and season 2.

4.1.2 Cane diameter

Cane diameter for all the blackberry species in season 1 were not significantly different from each other during the duration of the experiment. However, cane diameter differed significantly ($p \leq 0.05$), in season 2 from week 8 to the end of the season at week 36. *Rubus apetalus* had significantly thicker cane diameter ranging from 7.06 mm to 19.90 mm while *R. fruiticosus* had a thinner cane diameter ranging from 5.93 mm to 14.40 (Figure 3).

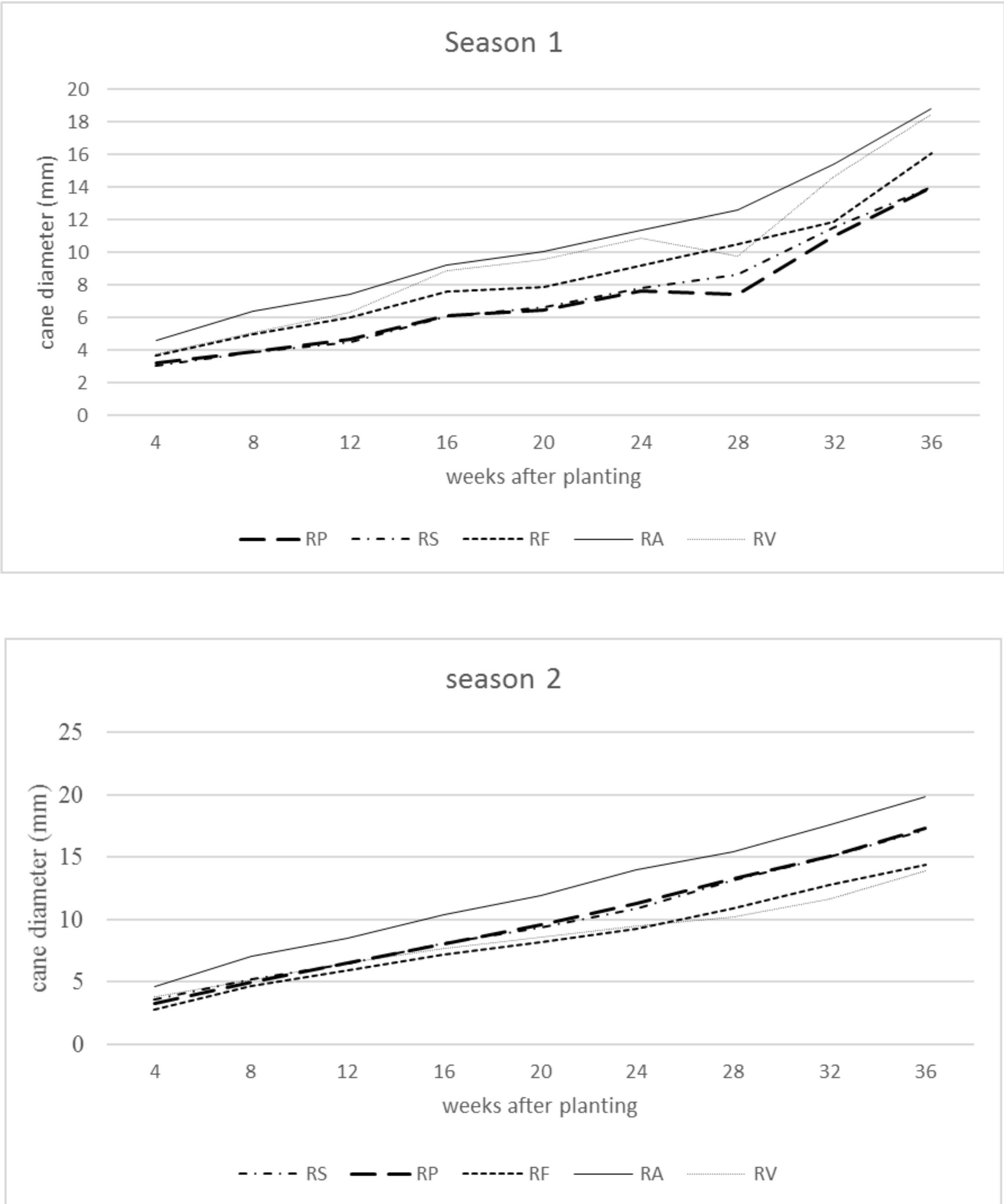

Figure 3: Cane diameter of different blackberry species (mm) in season 1 and season 2.

4.1.3 Number of laterals at first flowering, mid flowering and harvesting

The number of laterals in seasons 1 and 2 at first flowering did not show significant variation among the tested blackberry species (Table 3), while at mid flowering there was a significant variation in season 1 between *R. apetalus* (22.53) and *R. pinnatus* (16.33). The number of lateral at mid flowering among *R. volkensis. R. steundneri, R. pinnatus* and *R. fruiticosus* was not significant. Similarly, no significant variations were observed for *R. apetalus, R. volkensis, R. steundneri* and *R. fruiticosus* in season 1. In season 2 number of laterals did not vary significantly at mid flowering. At harvest there was no statistical differences between *R. apetalus, R. volkensis,* and *R. steundneri*. However, there was a statistical difference in the number of laterals at harvest between *R. pinnatus* and *R. fruiticosus.* In season 2 there was no significant difference in the number laterals at first flowering, mid flowering and harvest (Table 3).

4.1.4 Internode length and lateral length

The length of internodes for the different blackberry species in season 1 varied significantly, among *R. apetalus* (6.06 cm), *R. volkensis*, (6.50 cm), *R. pinnatus* (8.57 cm), which had the longest internodes. However, there were no significant differences in internode length in season 2 though *R. pinnatus* had the longest internode length (Figure 3). In season 1 length of lateral for *R. apetalus, R. volkensis* and *R. steundneri* did not vary significantly but there was a significant variation between *R. pinnatus* and *R. fruiticosus*. In season 2 *R. apetalus,* and *R. pinnatus* did not differ from each other in the length of lateral, while *R. fruiticosus, R. pinnatus* and *R. volkensis* differed significantly ($p \leq 0.05$) (Figure 3).

4.1.5 Height to the lowest lateral

The height to the lowest lateral at flowering was not significant for season 1 between *R. apetalus* (5.10 cm) and *R. pinnatus* (5.30) cm respectively, at the same time a significant difference was observed between *R. volkensis* (8.13 cm) and *R. fruiticosus* (10.27 cm) respectively. In season 2 there was a significant difference between *R. apetalus* and all the other species, *R. fruiticosus* and *R. volkensis* did not show significant difference in height to the lowest lateral as the two species had the shortest height from the ground to the first lateral. A significant difference in the height to the lowest lateral was observed between *R. steundneri* and *R. pinnatus* in season 2 (Figure 3).

Table 3: Number of laterals at first flowering, mid flowering, at harvesting stage, internodes length (cm) laterals length (cm), and height to the lowest laterals (cm) of different blackberry species

Blackberry species	First flowering	Mid flowering	At harvest	Internode length (cm)	Lateral length (cm)	Height to the lowest lateral (cm)
			SEASON 1			
R. apetalus	17.03	22.53[a]	25.03[ab]	6.06[b]	63.90[b]	50.10[a]
R. volkensis	16.93	22.10[ab]	23.67[ab]	6.50[b]	56.57[b]	8.13[c]
R.steundneri	14.00	17.27[ab]	20.47[bc]	7.67[ab]	59.97[b]	28.23[b]
R. pinnatus	13.50	16.33[b]	17.94[c]	8.57[a]	77.27[a]	51.30[a]
R.fruiticosus	10.10	17.10[ab]	25.93[a]	5.80[b]	28.40[c]	10.27[c]
			SEASON 2			
R. apetalus	13.85	16.27	20.70	7.33	74.87[a]	50.27[a]
R. volkensis	12.00	16.67	19.33	6.73	52.53[b]	9.33[d]
R.steundneri	13.53	14.97	18.77	8.10	59.93[b]	31.33[c]
R. pinnatus	13.36	15.70	18.93	8.37	82.77[a]	40.77[b]
R.fruiticosus	10.10	14.93	23.10	7.13	25.57[c]	9.70[d]

Means followed by the same or no letters within a season and column are not significantly different according to Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

4.1.6 Number of canes per plant and number of nodes

The number of canes emerging from the ground (Table 4) was significantly ($p \leq 0.05$) higher in *R. apetalus* (9.93 and 9.77 in seasons 1 and 2 respectively). In season 1 *R. volkensis, R. pinnatus* and *R. fruiticosus* did not show significant differences in the number of canes emerging from the ground. However, there was a significant variation in the number of canes emerging from the ground between *R. pinnatus* and *R. apetalus* in season 1. Though in season 2 a significant difference was observed between *R. volkensis* and *R, steundneri* but not between *R. volkensis* and *R. fruiticosus* and between *R. steundneri* and *R. fruiticosus.*

Number of nodes per cane for the different blackberry species also showed significant ($p \leq 0.05$) differences between *R. pinnatus* and *R. fruiticosus* and between *R. apetalus* and *R. pinnatus* in season 1, but there was no significant variation in the number of nodes among *R. apetalus, R. volkensis* and *R. steundneri.* Significant variation in the number of nodes was not recorded among all the species in season 2 (Table 4).

4.1.7 Days to first flowering, 50% flowering and flowering duration

The number of days to the first flowering varied significantly ($p \leq 0.05$) among the blackberry species. The earliest to flower was *R. fruiticosus* at day 123 and 130 in season 1 and season 2 respectively after planting, *R. apetalus* was the second earliest to flower at 211 and 243 days after planting in both season 1 and 2 respectively. However, there were no significant differences in the days to first flowering among *R. volkensis, R. steundneri* and *R. pinnatus* in both season 1 and 2 respectively (Table 4).

Number of days to 50% flowering also varied significantly ($p \leq 0.05$) (Table 4) among the different blackberry species with *R. fruiticosus* taking the fewest days to reach 50% flowering at 141 and 160 days in season 1 and 2 respectively, followed by *R. apetalus* 238 and 306 days in both season 1 and 2 respectively. The other three species *R. volkensis, R. steundneri* and *R. pinnatus* did not show any significant differences in both season 1 and 2 in days to 50 % flowering.

Duration of flowering also differed significantly ($p \leq 0.05$) from one species to another with *R. fruiticosus* had the longest flowering duration (283 days) followed by *R. apetalus* 162 day in season 1 while in season 2 *R. fruiticosus* flowered for a period of 286 days and *R. apetalus* flowered up to 164 days. In both seasons *R. steundneri* and *R. pinnatus* recorded the shortest flowering duration which was significantly ($p \leq 0.05$) different from *R. volkensis* which had a slightly longer flowering duration (Table 4)

Table 4: Number of canes emerging from the ground, number of nodes, days to first flowering, 50% flowering and flowering duration of different blackberry species

Blackberry species	Number of canes	Number of nodes	First flowering (Days)	50% flowering (Days)	Flowering duration (Days)
			SEASON 1		
R. apetalus	9.93[a]	24.27[ab]	211.00[b]	238.00[b]	162.27[b]
R. volkensis	4.33[c]	22.63[abc]	310.33[a]	337.33[a]	85.60[c]
R.steundneri	4.83[c]	20.17[bc]	320.33[a]	342.00[a]	36.97[d]
R. pinnatus	5.97[b]	17.60[c]	321.33[a]	342.67[a]	40.50[d]
R.fruiticosus	4.03[c]	26.03[a]	123.67[c]	141.33[c]	283.10[a]
			SEASON 2		
R. apetalus	9.77[a]	20.53	243.33[b]	306.00[b]	164.53[b]
R. volkensis	3.00[d]	22.33	355.00[a]	388.67[a]	86.63[c]
R.steundneri	4.77[c]	18.53	347.00[a]	376.67[a]	37.70[d]
R. pinnatus	6.03[b]	18.27	361.00[a]	392.67[a]	40.10[d]
R.fruiticosus	3.97[cd]	23.97	130.00[c]	160.00[c]	286.77[a]

Means followed by the same or no letters within a column and season are not significantly different according to Tukey's Honestly Significant Difference Test at ($p \leq 0.05$).

4.1.8 Number of flowers per lateral and number of flowers per cane and % fruit set

The number of flowers per lateral differed significantly ($p \leq 0.05$) in both season 1 and 2 (Table 5), *R. apetalus* had the highest number of flowers (58.43 and 57.87) per lateral respectively in both seasons. However, the number of flowers per lateral did not differ significantly between *R. volkensis* and *R. pinnatus* and between *R. steundneri* and *R. pinnatus* in season 1 but in season 2 there was a significant ($p \leq 0.05$) difference between *R. volkensis* and *R. pinnatus* and also between *R. steundneri* and *R. fruiticosus*.

The number of flowers per cane varied significantly ($p \leq 0.05$) in both season 1 and season 2 with *R apetalus* (583 and 566) having the highest number of flowers per cane respectively (Table 5). However, there was no significant difference in the number of flowers per cane among *R. fruiticosus, R. volkensis, R. pinnatus* and *R. steundneri.*

Fruit set was significantly ($p \leq 0.05$) higher in *R. apetalus* in both season 1 and 2 at 84.7 and 84.3 % respectively (Table 5) the second highest in fruit set was *R. fruiticosus* at 53 and 58.7 % in both season 1 and 2 respectively, followed by *R. volkensis* at 36.7 and 42.3 % respectively in both season 1 and 2, while *R. pinnatus* and *R. steundneri* had 0.00% fruit set in both seasons.

4.1.9 Days to fruit maturity and harvesting duration

The number of days to fruit maturity did not vary significantly among the different blackberry species grown in both season 1 and 2 (Table 5). All the three blackberry species that set fruits, *R. fruiticosus, R. apetalus* and *R. volkensis* matured within 35, 33 and 36 days respectively for season 1 and 34, 35 and 34 days respectively for season 2. The other two blackberry species, *R. pinnatus* and *R. steundneri* did not set fruits therefore days to fruit maturity was not recorded.

Harvest duration was significantly ($p \leq 0.05$) longer in *R. fruiticosus* in both season 1 and 2 at 266 and 273 days respectively, *R. apetalus* had 178 and 173 harvesting days in both season 1 and 2 respectively. *Rubus volkensis* had the shortest harvesting duration 90 and 84 days of in both season 1 and 2 respectively. *R. steudneri* and *R. pinnatus* however did not have a harvesting duration as they did not set any fruit (Table 5).

Table 5: Number of flowers per lateral, number of flowers per cane, fruit set per lateral, harvesting duration, days to fruit maturity and harvesting duration of different blackberry species

Blackberry species	Number of flowers per lateral	Number of flowers per cane	%Fruit set per lateral	Days to fruit maturity	Harvest duration (Days)
			SEASON 1		
R. apetalus	58.43^{a}	583.50^{a}	84.70^{a}	33.30^{a}	178.33^{b}
R. volkensis	17.27^{c}	76.50^{b}	36.70^{c}	35.97^{a}	90.00^{c}
R.steundneri	29.93^{b}	102.10^{b}	0.00^{d}	0.00^{b}	0.00^{d}
R. pinnatus	23.83^{bc}	89.43^{b}	0.00^{d}	0.00^{b}	0.00^{d}
R.fruiticosus	25.50^{b}	103.67^{b}	53.00^{b}	35.43^{a}	266.33^{a}
			SEASON 2		
R. apetalus	57.87^{a}	566.10^{a}	84.30^{a}	33.53^{a}	173.33^{b}
R. volkensis	19.50^{c}	50.17^{b}	42.30^{c}	34.60^{a}	84.33^{c}
R.steundneri	31.10^{b}	98.83^{b}	0.00^{d}	0.00^{b}	0.00^{d}
R. pinnatus	28.33^{b}	89.43^{b}	0.00^{d}	0.00^{b}	0.00^{d}
R.fruiticosus	26.43^{bc}	97.33^{b}	58.70^{b}	33.73^{a}	273.33^{a}

Means followed by the same within a column and a season are not significantly different according to Tukey's Honestly Significant Difference Test at ($p \leq 0.05$

4.2 Fruit Yield of blackberry

Blackberry fruit yield variables measured in this study were; fruit number per lateral, fresh fruit weight, fruit size, fruit dry weight and estimated yield per hectare.

4.2.1 Fruit number per lateral, fresh fruit weight, fruit dry weight

The number of fruits per lateral was significantly ($p \leq 0.05$) higher in *R. apetalus,* 56 and 56 in both season 1 and 2 respectively. *Rubus fruiticosus* had 18 and 17 fruits per lateral in both seasons 1 and 2 respectively, fewer fruits than *R. apetalus* in both season 1 and 2, *R. volkensis* had lowest number of fruits 14.42 and 14.42 in both season 1 and 2 respectively (Table 6).

Rubus fruiticosus had a significantly ($p \leq 0.05$) higher fresh fruit weight (5.17 and 5.6) g than all the blackberry species grown in both season 1 and 2 respectively. Wild blackberry species *R. volkensis* was the second highest in fruit weight at 3.6 gm and 3.66 g in both season 1 and 2 respectively. *Rubus apetalus* had the least fresh fruit weight 1.2 and 1.28 g respectively. While two wild species *R. steundneri* and *R. pinnatus* did not set fruit (Table 6).

The dry weight of blackberry fruits after oven drying showed significant ($p \leq 0.05$) weight differences with *R. fruiticosus* recording the highest dry weight of 2.57 g and 2.25 g for seasons 1 and 2 respectively and *R. volkensis* had 1.66 g and 1.45 g dry weight in both season 1 and 2 respectively, while *R. apetalus* had the least dry weight of 0.80 g and 0.72 g for seasons 1 and 2 respectively (Table 6).

Table 6: Fruit number per laterals, fresh fruit weight and fruit dry weight of different blackberry species

Blackberry species	Fruit number per lateral	Fresh fruit weight (g)	Fruit dry weight (g)
	SEASON 1		
R. apetalus	56.42[a]	1.20[c]	0.80[c]
R. volkensis	14.42[c]	3.60[b]	1.66[b]
R.steundneri	0.00[d]	0.00[d]	0.00[d]
R. pinnatus	0.00[d]	0.00[d]	0.00[d]
R.fruiticosus	18.92[b]	5.17[a]	2.57[a]
	SEASON 2		
R. apetalus	56.08[a]	1.28[c]	0.72[c]
R. volkensis	14.42[c]	3.66[b]	1.45[b]
R.steundneri	0.00[d]	0.00[d]	0.00[d]
R. pinnatus	0.00[d]	0.00[d]	0.00[d]
R.fruiticosus	17.92[b]	5.60[a]	2.25[a]

Means followed by the same letter within a column and season are not significantly different according to Tukey's Honestly Significant
Difference Test at $p \leq 0.05$

4.2.3 Fruit yield per plant and estimated fruit yield per hectare

Estimated fruit yield per plant was significantly different ($p \leq 0.05$) among the different species in both seasons 1 and 2 (Table 7). *Rubus fruiticosus* had the highest estimated yield per plant in both seasons at 363 g and 373 g respectively, the second highest estimated yield per plant was *R. volkensis* (139 g and 134 g) respectively. The least in estimated fruit yield per plant was recorded in *R. apetalus* at 59 g and 57 g respectively (Table 7).

Growing different wild blackberry species under conventional production showed a significant ($p \leq 0.05$) variation in estimated fruit yield per hectare (Table 7) with *R. fruiticosus* having an estimated yield of 3687 and 3664 kgha^{-1}for both season 1 and 2 respectively. *Rubus volkensis* had an estimated yield of 1338 and 1350 kgha^{-1}in both seasons, *R. apetalus* had the lowest estimated yield at 565 and 560 kgha^{-1}in season 1 and 2 respectively.

Table 7: Yield per plant and estimated yield per Hectare of different blackberry species

Blackberry species	Fruit yield per plant (g)	Estimated fruit yield per hectare (kgha^{-1})
	SEASON 1	
R. apetalus	59.00^{c}	565.00^{c}
R. volkensis	139.00^{0b}	1338.00^{b}
R. steundneri	0.00^{d}	0.00^{d}
R. pinnatus	0.00^{0d}	0.00^{d}
R. fruiticosus	363.00^{a}	3687.00^{a}
	SEASON 2	
R. apetalus	57.00^{c}	560.00^{c}
R. volkensis	134.00^{b}	1350.00^{b}
R. steundneri	0.00^{d}	0.00^{d}
R. pinnatus	0.00^{d}	0.00^{d}
R. fruiticosus	373.00^{a}	3664.00^{a}

Means followed by the same letter within a column and season are not significantly different according to Tukey's Honestly Significant Difference Test at $p \leq 0.05$

4.3 Fruit quality

Blackberry fruit quality variables measured in this study were; total soluble solids, fruit titratable acidity and ratio of total soluble solids to titratable acidity.

4.3.1. Fruit size, total soluble solid, fruit titratable acidity, ratio of soluble solids and titratable acidity

Fruit size of different blackberry species grown varied significantly ($p \leq 0.05$) in both seasons in terms of fruit diameter and fruit length (Table 8). *Rubus fruiticosus* had the largest fruit diameter of 20.09 mm and 22.09 mm, while *R. volkensis* had a fruit diameter of 16.00 mm and 15.73 mm in season 1and 2 respectively. *Rubus apetalus* had the least fruit diameter of 11.19 mm and 10.96 mm for both seasons. Fruit height was also significant ($p \leq 0.05$) in both seasons with *R. fruiticosus* having the largest fruit diameter in both seasons at 22.93 mm and 22.75 mm respectively, while *R. apetalus* had the smallest fruit length of 11.37 mm and 11.68 mm in season 1 and 2 respectively.

Total soluble solids of different blackberry species *R. apetalus* and *R. volkensis* did not show any significant variation in both season 1 and 2. Similar results were also observed in fruit titratable acidity in two blackberry species *R. apetalus* and *R. volkensis. Rubus fruiticosus*, however, varied significantly from *R. apetalus* and *R. pinnatus* in total soluble solids and fruit titratable acidity. The ratio of soluble solids to titratable acidity also did not show significant variation between *R. apetalus* and *R. volkensis* in both seasons (Table 8).

Table 8: Fruit size (diameter and length), total soluble solids, fruit titratable acidity and ratio of soluble solids to titratable acidity of different blackberry species

Blackberry species	Fruit diameter (mm)	Fruit length (mm)	Total soluble solids (%)	Fruit titratable acidity (%)	Ratio of soluble solids and titratable acidity
			SEASON 1		
R. apetalus	11.19[c]	11.37[c]	10.85[a]	1.54[a]	7.06[a]
R. volkensis	16.00[b]	16.37[b]	10.55[ab]	1.52[a]	6.96[a]
R.steundneri	0.00[d]	0.00[d]	0.00[c]	0.00[c]	0.00[b]
R. pinnatus	0.00[d]	0.00[d]	0.00[c]	0.00[c]	0.00[b]
R.fruiticosus	20.09[a]	22.93[a]	9.91[b]	1.34[b]	7.39a
			SEASON 2		
R. apetalus	10.96[c]	11.68[c]	10.41[a]	1.53[a]	6.82[b]
R. volkensis	15.73[b]	16.09[b]	10.39[a]	1.51[a]	6.88[b]
R.steundneri	0.00[d]	0.00[d]	0.00[c]	0.00[c]	0.00[c]
R. pinnatus	0.00[d]	0.00[d]	0.00[c]	0.00[c]	0.00[c]
R.fruiticosus	22.09[a]	22.75[a]	9.90[b]	1.36[b]	7.30[s]

Means followed by the same letter within a column are not significantly different according to Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

CHAPTER FIVE

DISCUSSION

In this chapter, the results presented in chapter four are discussed. The same order of presentation of results has been adopted in the discussion.

5.1 Growth of different blackberry species

5.1.1 Cane height

Results of the present study showed that cane height varied from species to species, with wild species having the longest canes. Cane height of black berry is significant because it affects blooming (Eyduran *et al.,* 2008). The difference in height could have been attributed to environmental effects and species adaptation (Facteau *et al*., 1986; Eyduran *et al*., 2006). Wild blackberry *R. apetalus* had the most vigorous growth, compared to other wild black berries and the cultivated blackberry, most probably due to better adaptation of *R. apetalus* to the environmental conditions around Njoro. This species was collected from the wild in Njoro implying that *R. apetalus* had an added advantage compared to the other species. Canes were taller in season 1 than season 2, this is probably because of the higher amount of rainfall recorded in season 1 (Table 2) compared to season 1 than season 2 at 1109.60 mm and 758.10 mm respectively.

5.1.2 Cane diameter

Blackberry cane diameter varied from one species to the other with the wild species *R. apetalus* having the greatest cane thickness compared to other wild species and *R. fruiticosus* var. "Ruben". Cane diameters is mostly affected by environmental factors early in the growing season (Prive *et al.,* 1993). Stem diameter in plants is also related to the level of carbohydrate and water uptake which is directly related to the genetics of species and the interaction between genotype and the environment. Blackberry cane diameter is an important character for plants against wind lodging and other unfavourable environmental conditions that affect fruit yield ultimately (Eyduran *et al.,* 2008). In a previous study by Cangi and Islam (2003), cane diameter range was 3.49 - 7.99 mm among different cultivars of blackberry with the lowest performance being *R. fruiticosus* cv "Jumbo". In another study carried by Eyduran *et al.* (2008), cane diameter for eight American cultivars ranged from 10.00 to 18.20 mm. In the present study, cane diameter varied from 4.63 mm to 19.90 mm, a range that is consistent and comparable to cane diameter of other studies reported by Eyduran *et al.* (2008).

5.1.3 Number of laterals at first flowering, mid flowering and harvesting

The number of laterals at different stages in this study varied from one species to another, at first flowering, mid flowering and at harvest. Number of laterals of a plant varies at different stages of plant growth, this variation is due to how well a plant species is adapted to certain environmental conditions and the genotype of that particular plant (Eyduran *et al.,* 2008). On a study by Strik (2012) on two cultivars, "Prime jam" and "Prime jim" total branches per cane was reported as 3.9 and 4.1 respectively, which varied from the present study at 17.94 to 25.93 and 18.93 to 23 10 in both seasons 1 and 2 respectively. *Rubus apetalus, R. fruiticosus* and *R. volkensis* had higher number of laterals that can translate to higher fruit yield According to Jennings (1988), the number and extend of laterals development in blackberry is a key yield component. When a plant develops more laterals at the varying stage of its growth it is an indication that the plant is well adapted to that particular location and it has a genetic makeup suitable for that particular location therefore the prolific number of laterals it has.

5.1.4 Lateral length and height to the lowest lateral

Lateral length differed from one species to another, difference in the pattern of lateral length growth on the cane is also attributed to genotype and environment (Eyduran *et al.,* 2006), as it is among the many pomological trait of different blackberry species. In the current study *R. apetalus* had the longest lateral length than cultivated species, therefore the higher fruit number per lateral observed in this species than cultivated species *R. fruiticosus* var "Ruben" which had shorter lateral length and few fruit number per lateral. Dale (1990) associated long lateral length with high fruit number per lateral in some raspberry, this is because long laterals have the ability to intercept light better than shorter ones (Waistser *et al.,* 1980).

The height to the lowest lateral were different from one species to the other, *R. apetalus* had the highest height to the lowest lateral, while *R. volkensis* and *R. fruiticosus* had shortest height to the lowest lateral. As with other pomological traits such as fruit weight, cane diameter, length of cane, height of cane per plant in blackberry variability in the height to the lowest lateral is due to the effect of yearly environmental variation and genotype (cultivar/species) (Atila *et al.,* 2006; Agaoglu and Eyduran, 2006; Eyduran *et al.,*2007). *Rubus apetalus* therefore has genotype that is attributed to longer height to the lowest lateral or it is more adapted to the yearly environmental variation. While the other species has different genotype and have different yearly environmental adaptation.

5.1.5 Number of canes per plant, number of nodes and internode length

Number of canes emerging from the ground varied in this study, variation in the number of canes is largely due to the effect of phenotype (Eyduran *et.al.,* 2008; Dale, 1990). Gundershein and Pritts (1991), also demonstrated that optimum cane number varies with cultivar due to cultivar difference and many interacting factors. Work by Eyduran *et al.* (2008) showed that among eight cultivars the average number of canes varied from 6.70 to 10.00 in a 2002 study period which was slightly higher than the current study. The highest number of canes recorded was 10.00 on cultivar “Nahavo” and “Chester” thornless respectively and a minimum number of canes recorded was 6.70 for Dirksen thornless. *Rubus apetalus* had the highest number of canes emerging from the ground in both seasons, this is an indication of the difference in the phenotypic and genotypic growth vigour of the different blackberry grown during this current study. Comparing wild species to cultivated blackberry *R. fruiticosus,* wild blackberry species exhibited vigorous growth in terms of number of canes per plant in this study.

The number of nodes per cane on the different black berry species varied from one species to another. As other pomological traits, number of nodes is also attributed to environment and genotype (Eyduran *et. al.,* 2008). In a study by Salvador *et al.* (2015) the number of nodes range was 73.6 to 129.0 nodes on six blackberry cultivar, which was higher than the present study. The number of nodes was higher in cultivated species *R. fruiticosus* and the two wild species *R. apetalus* and *R. volkensis,* the number of nodes was related to fruit yield which was significantly higher in this species. The number of nodes also related to the number of fruiting laterals that was observed in *R. apetalus.* Number of nodes is important as it has been shown to have a positive correlation with fruit yield. Gundershein and Pritts (1991) reported that the number of nodes per cane have the greatest single influence on fruit yield on purple raspberry cultivar “Royalty”. Hoover *et al.* (1988) also reported that of the four genotypes that were studied, number of nodes per cane occupied the third place in contributing to fruit yield. High node number per cane is important (Jennings and Dale, 1982; Jennings and McCregor, 1989) and can be used for selection in breeding programs, because it is closely related to the number of fruiting laterals.

The length of internode was different among blackberry species; length of internode is associated with the height of canes of the different species that were studied in the current research. However, in the current study, the length of internode did not show any relationship with cane height. In a similar study involving six genotype, Salvador *et al.* (2015) reported that cultivar "Obsidian" had the shortest internodes of 4.45 cm, while cultivar "Onyx had the longest internodes of 7.31 cm. These result did not differ from that reported in this current study by the former author did have a significant difference from this current study. Two wild species *R. pinnatus* and *R. steundneri* had the highest length of internode and the difference is attributed to the different genotype of each species that respond differently in a given environmental condition, therefore the two wild blackberry species having genes responsible for longer internode length or are more adapted to this environmental conditions.

5.1.6 Days to first, 50% and flowering duration

In this study there was a significant difference in the number of days to first and 50% flowering of the blackberry species grown. Duration to first and 50 % flowering in fruit crop is important because it determines when fruit will be ready for harvesting. The transition from vegetative growth to flowering in plants is regulated by environmental factors such as temperature and light (Guo *et al.*, 1998; Mouradov *et al.*, 2002). The time to flowering in plants can also be due to its genetics make up (Mouradoy *et al*., 2002; Simpson *et al.*, 2002; Putterill *et al*., 2004) as there are specific genes responsible for early or late flowering in plants. This variation in the number of days to flowering is because different blackberry cultivars have different chilling requirement, (Dale *et al*., 2003). Chilling requirement has been described as a basic climatic factor for flowering and fruit set (Elloumi *et al*., 2013) that has a strong effect on phenological stages (Javanshah, 2010). Under warm winter conditions, temperate fruit cultivars with set chilling requirements, show immense variability in the flowering period from year to year (Petri *et al.*, 2008). Cultivated species *R fruiticosus* might have responded better to its set chilling requirements thus the shorter number of days taken to first and 50% flowering.

There is evidence that carbohydrates accumulation may influence flower bud induction in blackberries (Crandall *et al.*, 1974), however there has been no systematic study to establish a causal relationship (Takeda *et al.*, 2003) or to examine the interacting effects of irradiance and cane carbohydrates reserves on blackberry flower bud differentiation. Flowering time is also affected by many other environmental factors such as mineral nutrition and different biotic stresses. This could be the reason in the present study, for the difference in time of flowering of the grown blackberry as all species were grown under the same environmental conditions. The difference in flowering time could be due to the genetic make-up of the different blackberry species.

According to Takeda *et al.* (2002) in biennial blackberry cultivars flower bud initiation is generally thought to be a short day response and the rate of flower bud varies with the type of cultivar and prevailing winter temperature. Flowering time can also be manipulated by exogenous application of GAs as it has been shown to positively regulate the expression of flowering signal integrator genes such as *SOC1* and *LFY* (Blazquez and Weigel, 2000; Moon *et al*., 2003). This study shows that cultivated blackberries that were planted together with the wild species have shorter chilling requirement thus the reason for shorter duration to first and 50 % flowering.

5.1.7 Number of flowers per lateral, number of flowers per cane and % fruit set

Flower number per lateral was higher in *R apetalus* than all other species grown, the significant difference in the number of flowers shown by different blackberry species is due the genetic makeup of the different blackberry species and environmental adaptability of a specific blackberry species (Eyduran *et al.,* 2008).

Fruit set variation was observed in different blackberry species that were grown, wild blackberry *R. apetalus* had the highest percent fruit set. While cultivated *R. fruiticosus* and wild species *R. volkensis* had lower percent fruit set. MacDaniels (1922) proposed that all bramble buds have the potential to develop into fruit buds and others (Carew *et al.,* 2000) have observed that full flowering potential is often inhibited by cultural conditions. Some buds may be suppressed by the more advanced buds that have completed differentiation (Takeda *et al*., 2003), or arrested by the effects of internal shading on early leaf senescence and abscission (Wright and Waister, 1984). Fruit set is determined by the adaptability of a species to given location; it is affected by moisture content of the soil and nutrient availability. The rate of reproductive bud development and differentiation in blackberries are dependent on climate, and the time of floral bud differentiation and blooming (Moore and Caldwell, 1985). Blackberry plants that look normal and healthy may sometimes flower profusely but fail to set fruit (Mohammad, 1996). This failure may be complete, with no fruit set at all, but more often it may be partial, with the production of misshapen berries. The appearance of such berries may range from nearly normal to some with only a single drupelet. The condition may be the result of an infection by a virus or fungus, insect damage, hereditary abnormalities, or a combination of these causes (Mohammad, 1996).

5.1.8 Days to fruit maturity and harvesting duration

The number of days from flower opening to fruit maturity did not show any significant difference apart from the two species which did not set fruit. The difference in the number of days from first flowering to fruit maturity depends on cultivar and climatic conditions (Salgado and Clark, 2015). A similar result was also reported by Ibrar *et al.* (2016) where the time between flower bud and ripe berry stages of blackberry cultivars 'Tupy' and 'Xavante' was quite similar, 29.6 and 31 days, respectively. Strik *et al.* (2012) also observed out that the number of days from first flowering to first fruit maturity was unaffected by cultivar or treatment and average was 36 and 43 days in 2004 and 2005, respectively. This is an indication that the days from first bloom to fruit maturity is not influenced by cultivar/species for this study, therefore wild species *R. apetalus* and *R. volkensis* that were studied performed the same as cultivated species *R. fruiticosus* var "Ruben" in terms of days from flower opening to fruit maturity.

Harvesting duration for the different blackberry species were significant with *R. fruiticosus* having the longest harvesting duration, while the shortest in harvesting duration was *R. volkensis*. The longer harvesting duration is due to the ability of a plant species to utilize its carbohydrates or photosynthates efficiently therefore the longer duration of flowering. In some species the harvesting duration was shorter and is due lack of continuous flowering, fruit set, diseases and environmental condition. Phenological characteristics especially flowering period, varied due to cultivars and ecological conditions (Rosati *et al.*, 1993). In another study by Campagnolo and Pio (2012) involving eleven blackberry cultivars, the longest harvesting duration of cultivar "Amora vermelha" was 161 and 245 days, in 2009/11 and 2010/2011 respectively, which was shorter than the results of the current study of the different blackberry species while the shortest harvest duration was for cultivar "Chactow" at 42 and 38 days in 2009/11 and 2010/2011 respectively. In these study it was found out that *R. fruiticosus* had the longest harvesting duration followed by *R, apetalus* and *R. volkensis* in that order an indication that they are adaptable to this environmental conditions. Duration of harvest varies from one species to the other due the adaptability of that species to a given environmental conditions. In other studies, carried out it was observed that phenological characteristics including days to fruit maturity harvesting period vary because of cultivars and ecological conditions (Rosati *et al.*, 1993).

5.2 Yield of different blackberry species

5.2.1 Fruit number per lateral

The number of fruits per lateral varied significantly in the current study, with wild blackberry *R. apetalus* having the highest fruit number per lateral. Fruit number is an important component in fruit crops as the number of fruits per laterals will determine the total yield of a given fruit crop and it is determined by genotype and the environment (Rosati *et al.,* 1993). Salgado and Clark (2015) reported that fruit laterals for early cultivars could have 5 to 10 fruits while late cultivars have more than 50 fruits per laterals which was observed in *R. fruiticosus* and *R. apetalus* in the present study with 18 and 56 fruits per lateral respectively. *Rubus apetalus* can be categorized as late species while *R. fruiticosus* an early cultivar due to the number of fruits per lateral.

5.2.2 Fresh fruit weight and fruit dry weight

Fresh fruit weight per fruit showed a significant variation among the different blackberry species grown. The variation in fruit weight could be because of the different species/cultivar grown, environmental conditions and nutritional status of the plantation (Yilmaz *et al.,* 2009) *Rubus fruiticosus* had the largest fruit weight compared to all the wild blackberry species that were planted, however, *R. volkensis* had a closer fresh fruit to the cultivated species. This shows that *R. volkensis* is adapted to the environment and is a genotype that produces heavier fruits. *Rubus apetalus* had the least fruit weight however it had many fruit per lateral. According to Clark and Finn (2011) berry weight has a direct effect on the marketability and acceptance of blackberries in both fresh and processing. This results are in agreement with a study carried out by Eyduran *et al.* (2008) where the weight of eight American blackberry cultivars was found to range from 1.00 to 5.50 g. Fruit weight of blackberry cultivars grown in a different regions of Turkey were previously reported between as 2.0-6.6 g per fruit (Cangi and Islam, 2003, Gercekcioglu *et al.,* 2003; Agaoglu *et al*., 2007) while fruit weight of wild growing blackberries in Turkey were between 1.5-2.1 g (Celik *et al.,* 2003). In the current study the berry weight from the different species were less than the weight for fresh market which is recommended to have a berry weight that ranges from 8-10 g and should also not be more than 15 g (Clark and Finn, 2011).

Fruit dry weight showed that cultivated species *R. fruiticosus* had the highest dry matter an indication that fruit dry weight is associated with increased fresh weight matter, since cultivated species was also the largest in fruit size compared to the wild species that were grown during this study. A similar result by Wolukau (1992) indicated that the largest raspberry fruits had the greatest percent fruit dry weight. Differences in berry dry weight could also be due to cultivars, management techniques, weather, and soil conditions, often referred to as the genotype environmental interaction.

5.2.3 Fruit yield per plant and estimated fruit yield per Hectare

Fruit yield per plant showed significant variation among the wild blackberry species with *R. fruiticosus* exhibiting the highest yield. A similar study on the average estimated yield per plant by (Campagnolo and Pio, 2012) the range was 9.4 to 1128.1 g per plant, which was slightly higher than what was observed in the current study. The reason for higher yield of *R. fruiticosus* could be because it's a cultivated species that may have been bred for higher yields compared to the wild species that had lower yield. Higher yield can also be attributed to how well a plant adapted to a given locality or environmental conditions and genotype of a given plant thus the ability of a plant to yield more.

Estimated fruit yield per hectare varied significantly, the difference in estimated yield per plant is attributed to different genotype of each blackberry species that was planted. In a study of different trailing blackberry genotypes in an organic production system by Salvador *et al.* (2015), total and marketable yield were affected by genotype. *Rubus fruiticosus* had an estimated higher fruit yield, followed by *R volkensis* and the least in estimated fruit was *R apetalus*. In another study by Campagnolo and Pio (2012) for 11 berry cultivar the average estimated yield per hectare ranged from 62.2 to 7523.8 $kgha^{-1}$. The lowest and the highest yield in that study was higher than the current study for different wild species. According to Eyduran *et al.* (2008), it is assumed that the difference among pomological traits are due to genotype and environmental variation. The difference in yield is also related to the thermal requirement of each cultivar (Campagnolo and Pio, 2012).

5.3 Quality of different blackberry species

5.3.1 Fruit size (diameter and length), total soluble solid, fruit titratable acidity and ratio of soluble solids and titratable acidity

Fruit size varied significantly from one species to the other with cultivated species having the largest fruit size (diameter and length). In a similar study by Campagnolo and Pio

(2012) on 11 berry cultivars, the average berry size range was length 16.6 mm to 27.3 mm and diameter was 17.3mm to 25.1 mm. This results were not consisted with the current study and this is due to genetic and genotypic expression of different cultivars/species.

Total soluble solids varied between wild and cultivated species in this study, with the wild having higher total soluble solids than cultivated species. As in other fresh horticultural produce quality is an important aspect of fruit as it determines the acceptability of the fruits to the consumer. Total soluble solid is a good indicator of blackberry maturity and also very important in the food industry and critical in comparative studies where variations by cultivar and environment are high (Clark and Finn, 2011). Different blackberry species/cultivars/varie ty have varying quality attributes that are determined by the species/genotype and the environmental conditions. Based on work carried out on the fruit quality of blackberry in Turkey, total soluble solids of fruits of wild growing blackberries were between 11.3-13.1 %. (Celik *et al.*, 2003). This result is consisted to the findings of the present study in which total soluble solids ranged between 9.91 to 10.85 %, this range was within the limit of blackberry total soluble solid range that recommends total soluble solids of at least 10% as it provides for a 'sweet' eating experience for fresh blackberries (Clark and Finn 2011).

Titratable acidity of the wild blackberry varied from cultivated species with the wild having higher titratable acidity. The differences or similarities in titratable acidity can be attributed to environment variation of a given area during blackberry production and genetic makeup of a given blackberry plant (Eyduran *et al.*, 2008). Titratable acidity is an important fruit quality as it is attributed to notably influencing berry taste (Vrhovsek *et al.*, 2008). According to Threlfall *et al*. (2016) on consumer sensory studies, fresh market blackberry should have a titratrable acidity between 0.9% and 1.0 %. This recommended titratable acidity varied from this current study, however, this results don't vary from fruits of wild growing blackberries in Turkey which were between 0.7-1 % (Gercekcioglu *et al.*, 2003). In the same study in Turkey cultivated cultivar titratable acidity of blackberry fruit grown in a different region, previously reported 1.0-3.1% (Cangi and Islam, 2003; Gercekcioglu *et al.*, 2003; Agaoglu *et al*., 2007), while the cultivated species *R. fruiticosus* had a titratable acidity of 1.34 and 1.36 % respectively.

The ratio of soluble solids and titratable acidity showed variation between wild and cultivated blackberry that were grown. This variation can occur in the chemical composition due to the differences in the intensity of the solar radiation rather than the differences in the site where the plants are grown. Temperature variation has been shown to affect the organoleptic characteristics of blackberry fruits (Siriwoharn *et al.,* 2004; Ali *et al.,* 2011). A study by Campagnolo and pio (2012) on 11 berry cultivar the ratio of total soluble solid and titratable acidity range was 3.1 to 5.8 compared to the current study which had a higher ratio.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings of this study, the following conclusions can be made:

i. Under conventional production, wild blackberry species have different growth characteristics.

ii. Under conventional production wild blackberry species have different fruit yield components with *Rubus volkensis* having the highest fruit yield per plant after cultivated species *Rubus fruiticosus*.

iii. Under conventional production fruit quality of wild blackberry species grown did not vary, however there was observed difference in quality between cultivated species and the wild species.

6.2 Recommendations

From the above conclusions, the following recommendations can be made:

i. Wild species *Rubus volkensis* can be domesticated and improved because it had higher fruits yield after *R. fruiticosus*.

ii. More study should be carried out in different location to determine their growth characteristics, fruit yield components and quality attributes.

iii. Breeding work should be carried to come up with new blackberry variety that are thorn less as managing thorny blackberries is a challenges.

iv. Nutritional studies of different wild blackberry species should be carried out to find out exactly the nutritional aspect each species.

v. More research work should be carried out on how to increase fruit size of *Rubus apetalus.*

vi. Further research should also be carried out on why *Rubus pinnatus* and *Rubus steundneri* did not set fruit even after flowering.

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APPENDICES

Appendix: Samples of ANOVA Tables

Source of variation	DF	Mid flowering	Last flowering	Lateral length	Height to the lowest lateral	Internode length	First flowering	Fifty % flowering	blooming duration
Block	2	13.13	9.53	31.83	14.99*	1.47	114.70	330.30	88.06
Season	1	84.67***	44.90**	47.38	9.86	1.37	6720.03***	8366.70***	15.99
Species	4	20.11*	35.64***	2382.56***	2312.42***	6.12***	53025.28***	53199.47***	65086.97***
Season*Species	4	8.52	7.30	57.01*	34.38***	0.43	331.95**	358.53	3.63
R^2		0.69	0.74	0.97	0.99	0.70	1.00	0.98	1.00
CV		13.56	10.06	6.75	6.20	12.04	2.77	5.62	3.53

Source of variation	DF	number of nodes	no. of flowers/lateral	no of flowers/cane	no. of canes	fruit set	fruit weight	dry weight	Cane diameter
Block	2	7.26	3.20	85.56	524.36	13.46	0.09	0.00	0.25
Season	1	14.98	4879.43***	188163.36***	228516.4963***	36.08	0.10	0.12	0.67
Species	4	47.02***	512.06***	82097.18***	71838.00***	8020.11***	34.01***	6.55	536.74
Season*Species	4	4.28	276.74***	63313.63***	68844.49***	15.27	0.05	0.03	1.39
R^2		0.72	0.99	1.00	0.99	0.99	0.99	1.00	1.00
CV		10.62	9.39	7.22	21.01	9.68	13.36	7.30	3.99

Source of variation	DF	height	fruit number	Est. yield/plant	Est. yield/ha	TSS	TA	TA/TSS
Block	2	0.11	1.20	5.33	687.57	0.11	0.01	4910.38
Season	1	0.01	0.53	3.71	9276070.59***	217.35**	82.77	9252686.35***
Species	4	608.93***	3185.86***	141446.20***	3562928.02***	63.98*	32.27	3518366.93***
Season*Species	4	0.08	0.28	50.18*	3529960.25***	36.34*	13.90	3493514.68***
R^2		1.00	1.00	1.00	1.00	1.00	1.00	1.00
CV		4.16	3.46	2.67	5.51	5.98	3.29	10.93