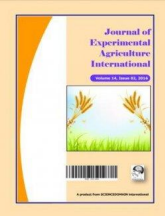

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Growth and Yield Potential of Wild Blackberry (*Rubus* spp.) under Conventional Production Practices in Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author OKO performed the experiment, data collection and statistical data analysis, interpretation of results and preparation of first draft of the manuscript. Authors GRM and WJN conceived the idea, designed the experiment and edited the manuscript. They also provided for experimental materials. All authors read and approved the final manuscript.

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ABSTRACT

Wild Blackberry (*Rubus* L. sub-genus *Rubus* Watson) species were evaluated for their growth and yield potential under conventional production practices at the Horticulture Research and Teaching Farm, Egerton University, Njoro, Kenya between January 2016 and July 2017. A randomized complete block design (RCBD) with three replications and five treatments (species) were used. The treatments included four wild blackberry species *Rubus volkensis, Rubus steundneri*, *Rubus apetalus, Rubus pinnatus* and one cultivar *"*Ruben*"* (*Rubus fruiticosus*). Growth and yield potential were determined by their respective components i.e. cane height, cane diameter, number of canes per plant emerging from ground, number of laterals per cane, lateral length, internode length, number of flowers per lateral and cane, fruit number per lateral, fruit size (length and width), fresh and dry fruit weight. Analysis of the data showed that wild species *Rubus apetalus* had the highest growth in terms of cane height (143.53 cm), cane diameter (19.37 mm), number of canes emerging

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from the ground (9 canes), number of flowers per lateral (58) and cane (581) and number of fruits per lateral (56), while *Rubus pinnatus* had the longest internodes of 8.47 cm and lateral length of 80.02 cm, however, *R. volkensis* was second to the cultivar "Ruben" (*Rubus fruiticosus*) in terms of, fruit size (length 22.84 mm and width 21.10 mm) and fruit fresh and dry weights of 3.7 vs 5.4 and 1.6 vs 2.4 g respectively. It is concluded that wild blackberry had growth and yield potential under conventional production practices. Adoption of *Rubus volkensis* under conventional production and the incorporation of growth vigour characteristics of wild species in breeding programs of the already cultivated species is recommended.

Keywords: Wild blackberry; growth; yield potential; conventional production.

1. INTRODUCTION

Blackberry belongs to the genus *Rubus* that has a large number of diverse species which are among the soft and aggregate fruits that are highly nutritious and therefore can form part of the human diet [1]. Blackberries are rich sources of carbohydrates, dietary fiber, vitamins, minerals and other bioactive compounds [2]. Blackberry fruits have also a high concentration of phenolics, carotenoids and flavonoids compounds, which can help protect against degenerative diseases. These compounds are anti-carcinogens and have anti-neuro-degenerative and anti-inflammatory effects [2]. Natural pigments, mainly anthocyanin used in dairy products, jams and preserves are also found in blackberry [4]. According to Ferreira et al. [3], blackberry cultivation has increased in recent years because of increased demand. Blackberry is cultivated on over 20,000 ha, mainly in Europe and North America [5]. Blackberry is now a common fruit in marketing outlets, particularly in North America and the European Union and it has enjoyed expansion due to a combination of factors including a few improved cultivars, expanded marketing efforts and fruit availability [5]. Up to 84 wild blackberries species have been reported in Kenya [6]. Growth characteristics and yield potential of these species are not known when cultivated conventionally.

Blackberry production in Kenya relies on introduced cultivars yet numerous wild blackberry germplasm with the potential of being adapted grow in the wild. Production is unexploited because of a knowledge gap regarding their growth and yield potential under conventional production. Conventional horticultural practices affect growth characteristics, fruit yield potential of crops, hence it is essential to have a good knowledge on how wild blackberries respond to conventional horticultural practices. In order to exploit wild blackberry there is need to understand growth and fruit yield potential by evaluating their performance under conventional production.

The aim of this study was to evaluate the growth and fruit yield potential of some of the wild blackberry species, in order to identify species that have comparative advantage over presently commercialized cultivars and may provide diverse options for further improvement through plant breeding and cultivation.

2. MATERIALS AND METHODS

The study was conducted at the Horticulture Research and Demonstration Farm of Egerton University, Njoro, Kenya. The farm lies at a latitude of 0°23`S longitude 35°35`E and an altitude of ≈2238 m above sea level. The area receives a total annual rainfall 1200 to 1400 mm while average maximum and minimum temperatures range from 19°C to 22°C and 5°C to 8°C, respectively. The soils are well-drained dark-red clays classified as *Mollic andosols* [7].

Plant materials (rooted splits) of the wild blackberry species *Rubus steundneri, Rubus apetalus, Rubus volkensis, Rubus pinnatus Rubus fruiticosus* were collected from the wild, the different species were identified and confirmed by a botanist. The planting materials were then planted out in December of 2015 at a spacing of 1.0 m×1.0 m (a stand of 10,000 plants per hectare). The experiment was conducted in randomized complete blocks containing 5 treatments (species) with three blocks and 16 plants per experimental unit. Triple Super phosphate (TSP) fertilizer was applied at a rate of 50 kg/ha i.e. 10 g/hole and mixed thoroughly with the soil before transplanting. The plants were maintained according to the recom-mendation of Campagnolo and Pio [8]. Watering was done during the dry season two times a week using hose pipes, pruning was done by tipping using hands at a height of 150 cm using

hands, damaged or diseased woods were removed by us of secateurs. Weeding was carried out manually and top dressing fertilizer of N.P.K. 17: 17:17 was used at a rate of 50 kg/ha i.e. 10 g per plant.

Four plants from each experimental unit were selected randomly and tagged for data collection for plant growth and fruit yield potential variables. In this study, the plant growth variables measured were cane height, cane diameter, number of laterals per cane lateral length, number of canes and internode length. Plant growth data, was collected after every four weeks, beginning 28 days after planting. Cane diameter, number of laterals per cane and lateral length were measured until the first day of flower set. During each data collection date, cane diameter of the four tagged blackberry species plants was measured at ≈ 15 cm from the ground level using a digital Vernier calliper (model 599-577-USA) and data obtained used to compute the average cane diameter of plants for the different species in millimeters.

Cane heights of tagged plants were determined using a tape measure until the plants attained a height of 150 cm after which they were tipped to encourage lateral growth.

Number and length of laterals were counted and measured in centimeters respectively at the beginning of flowering. Number of primary laterals on each tagged cane was counted at three different times: at flowering, mid harvest and at the last harvest date to ensure late developing laterals were counted.

Lateral length was measured from the base of the lateral to the tip of the terminal fruit or terminal leaf bud for vegetative laterals.

Total number of canes that emerged from the ground were counted every four weeks after planting.

Fruit yield potential variables were number of flowers per lateral and cane, number of fruits per lateral, fruit weight and fruit size. Number of open flowers was counted every three days on each lateral of tagged canes. Subsequently, the flowers on each lateral were summed up to give number of flowers per cane per plant. Double counting was avoided by subtracting the initial number of flowers counted from the current number of flowers counted.

Number of ripe harvestable fruits was determined on each lateral of the tagged canes prior to harvesting. Harvesting was done by picking berries that had reached maturity changed colour from green, yellow red to black colour. Weight of 20 sampled fruits on each lateral of the tagged cane was determined using an electric weighing balance (Model: Tanita KD 200-510) from each plot and averaged. The fruit dry matter content was determined by oven drying 20 sampled fruits from each plot at 80°C for 24 hours. The dried fruit were weighed using an electric weighing balance (Model: Tanita KD 200-510). Fruit size was determined by measuring two linear dimensions, length (L) and width (W) using a vernier caliper (Model 599-577-1/USA) at every harvest of sampled fruits.

The Proc univariate procedure of SAS (Version 9.1; SAS Institute, Cary, NC) was used to check for normality of the data before statistical analysis. Data were then subjected to analysis of variance (ANOVA) using the GLM procedure of SAS at P=0.05. Data were analyzed using the model: $Y_{ij} = \mu + \alpha i + \beta_j + \varepsilon ij$

$i=1,2,3,4,5, j=1,2,3$

Where; Y_{ij} is the Blackberry species response, μ is the overall mean, i^{th} is the effect due to the ith treatment, βj is the effect due to the j^{th} block, ε_{ij} the random error term. Means for significant treatments at the F test were separated using Tukey's honestly significant difference (THSD) test at P=0.05.

Monthly mean temperatures, relative humidity and total precipitation under Egerton ecological conditions during the experimental year 2016 January to 2017 July, is shown (Table 1).

3. RESULTS AND DISCUSSION

3.1 Cane Height and Diameter of Different Blackberry Species

Canes of *R. apetalus* were significantly longer (34.07 cm), while *R. volkensis,* (29.91 cm) *R. steundneri* (30.15 cm)*, R. pinnatus* (26.93 cm) and *R. fruiticosus* (28.17 cm) showed no significant variation in cane length at week 4 (Table 2). At week 8, significant variation was observed among *R. apetalus R. pinnatus* and *R. fruiticosus,* however, there was no significant variation between *R. pinnatus* and *R. fruiticosus*. At week 12 after planting no significant variation

Table 1. Average monthly air temperature (°C), precipitation (mm) and humidity during blackberry production over the two trials (Jan. to Dec. 2016 and Aug. 2016 to July 2017)

Year		Month												Total
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
2016	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	1109.6
	Temp. (^{o}C)	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
2017	Precip.(mm)	3.7	31.3	37.1	45.4	109.9	29.8	152.5						
	Temp (^{o}C)	21.5	21.9	22.8	26.7	24.4	25.3	23.6						
	Humid.(%)	47	53	46	58	71	65	74						

Source: Egerton University Engineering Department (2016-2017)

Table 2. Cane height and cane diameter of different blackberry species

	Weeks after planting								
Treatment	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**
					Cane height (cm)				
R. apetalus	34.07a	44.50a	55.90a	71.75a	89.40a	109.10a	130.58a	137.23a	143.53a
R. volkensis	29.91b	41.53ab	50.38a	65.35b	80.53b	93.38bc	104.96b	120.56b	132.57b
R.steundneri	30.15b	41.55ab	51.90a	64.43b	80.53b	96.65b	108.73b	122.93b	138.38ab
R. pinnatus	26.93b	38.37b	48.75a	61.85b	75.43b	90.83c	103.41b	119.00b	136.00ab
R.fruiticosus	28.17b	37.43b	49.18a	61.93b	75.73b	89.52c	102.81b	117.52b	133.42b
					Cane diameter (mm)				
R. apetalus	4.62a	6.72a	7.94a	9.80a	10.98a	12.67a	14.22a	16.53a	19.37a
R. volkensis	3.78a	5.12a	6.42a	8.28a	8.90a	10.18a	9.98b	13.20ab	16.18b
R.steundneri	3.33a	4.57a	5.53a	7.08a	8.00a	9.35a	10.92ab	13.32ab	15.58b
R. pinnatus	3.25a	4.45a	5.62a	7.08a	8.06a	9.05a	10.37b	13.06b	15.67b
R.fruiticosus	3.23a	4.82a	5.98a	7.43a	8.05a	9.23a	10.70b	12.32b	15.35b

Means followed by the same letter(s) within a column are not significantly different at P= 0.05 according to HSD Turkey's test

was observed among all the blackberry species grown but at week 16 to week 32 a significant variation was observed with *R. apetalus* having the longest canes (71.75 to 137.58 cm). At week 36, significant variation was observed among *R. apetalus R. volkensis* and *R. fruiticosus* and significant variation among *R. volkensis R. steundneri, R. pinnatus* and *R. fruiticosus.* Significant differences were also not observed among *R. apetalus, R. steundneri* and *R. pinnatus* at week 36 after planting. The growth of different blackberry species showed differences in vigour with wild species *R. apetalus* being the most vigorous in terms of cane height. These observations maybe attributed to the fact that *R. apetalus* is highly adapted to the Njoro environment since it was originally collected from that environment. Adaptation has been shown to positively affect performance of germplasm if other factors are held constant [9]. It is also assumed that difference among pomological traits is due to the effect of genotype and environmental interactions [10]. Plant height in blackberries is very important, as it affects flowering [11]. The height of the different blackberry grown varied from one species to the other indicating varied genetic backgrounds.

Cane diameter for all blackberry species did not vary significantly from week 4 to week 24 after planting though *R. apetalus* had a numerically larger cane diameter compared to all other blackberry species. At week 28, significant variation was observed among *R. apetalus, R. volkensis, R. pinnatus* and *R. fruiticosus*, however, there was no significant variation between *R. apetalus* and *R. steundneri* and also no significant differences among *R. volkensis, R. steundneri R. pinnatus* and *R. fruiticosus.* At week 36, significant variation was observed with *R. apetalus* having the thickest diameter of cane (19.37 mm), while all the other blackberry species did not show any significant difference in in cane diameter at week 36 (Table 2). Cane diameter is an important indicator of the plants ability to withstand unfavourable environmental conditions that affect yield such as wind [11]. In a previous study [12], cane diameter for blackberries ranged from 3.49 to 7.99 mm among different cultivars of blackberry with the lowest performance being *R. fruiticosus* cv, "Jumbo" [11]. A cane diameter of 6.60 to 15.20 mm for eight cultivars, similar to findings of the present study were reported [11].

3.2 Lateral Length, Number of Laterals, Number of Canes Emerging from the Ground and Number of Flowers per Lateral of Different Blackberry Species

R. pinnatus had significantly longer laterals (80.02 cm) than all the other blackberry species; *R. fruiticosus* had the shortest lateral length (26.98 cm). There were no significant differences in lateral length between *R. steundneri* and *R. volkensis*. Differences in the pattern of lateral length growth on the cane is attributed to genotype and environment [10]. Lateral length is among the many pomological trait of different blackberry species/cultivar that were grown in this present and other studies. Long laterals are associated with high fruit number per lateral in some raspberry [13] since long laterals have the ability to intercept light better than shorter ones [14].

The number of laterals showed a significant variation among the different blackberries, with *R. fruiticosus* (24.52) recording the highest and *R. pinnatus* (18.38) the lowest (Table 3). 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 [11]. A study [15] with two cultivars "Prime jam" and "Prime jim" total branches per cane was reported as (3.9 and 4.1) respectively, which varied significantly from the present study. According to Jennings [16] the number and extend of laterals development in blackberry is a major yield component. When a plant shows more number of 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.

The number of canes emerging from ground was significantly higher in *R. apetalus* (9.85)., compared to the rest (Table3). Number of canes emerging from the ground varied in this study; this variation in the number of canes is largely due to the effect of phenotype and genotype [11,13,17]. The authors also demonstrated that optimum cane number varies with cultivar due to cultivar difference and many interacting factors. In a study by among eight cultivars the average number of canes varied 6.70 to 10.00 [11]; which observation was slightly higher than the current study. The highest number of canes recorded

was 10.00 on cultivar "Nahavo" and "Chester" thornless and a minimum number of canes recorded was 6.70 for Dirksen thornless. The difference in the number of canes that emerged from the ground in this study is also attributed to the genotypic differences in vigour and stature, with the wild type being the most vigorous in number of canes per plant.

The number of flowers per lateral (Table 3) was significant with *R apetalus* having the highest number of flowers (58.15) per lateral, however the number of flowers per lateral was not significant between *R. steundneri* and *R. pinnatus* and between *R. apetalus* and *R. fruiticosus. R. volkensis* had the lowest number of flowers per lateral. 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 [11].

The length of internodes differed significantly from one species to another. *R. pinnatus* had the longest internodes (8.47 cm) while cultivated cultivar had the shortest internodes (6.00 cm). Length of internode is associated with the height of the plant, however, in the present study the length did not show any relationship with cane height (data not shown). In a similar study on six genotypes by Salvador et al. [18] cultivar "Obsidian" had the shortest internode of (4.45 cm), while cultivar "Onyx had the longest internode length of 7.31 cm. Those result by the former author differed from this current study. The difference in the length of internode is attributed to the different genotype of each species that respond differently in a given environmental condition.

3.3 Number of Flowers per Cane, Number of Fruits per Lateral, Fruit Weight, Fruit Size (Length and Width) of Different Blackberry Species

The number of flowers per cane (Table 3) was significant with *R apetalus* having the highest number of flowers (58) per lateral. A significant difference was also observed in the number of flowers per cane with *R. apetalus* having the highest number flowers per cane (581) (Table 3). The number of fruits per lateral was significantly higher in *R. apetalus* (56), while the lowest number was recorded in. *R. fruiticosus* with 18 fruits per lateral. *R. fruiticosus* had a significantly higher fresh fruit weight (5.38 g). Wild blackberry species *R. volkensis* was the second highest in fresh fruit weight (3.68 g) and. *R. apetalus* had the least fresh fruit weight (1.24 g), while two wild species *R. steundneri* and *R. pinnatus* did not set fruit (Table 4). The dry weight of blackberry fruits after oven drying recorded a significant difference with *R. fruiticosus* recording the highest dry weight (2.42 g), *R. volkensis* had (1.56 g) and *R. apetalus* had the least dry weight (0.76 g). While the other two wild species *R. steundneri* and *R. pinnatus,* however, could not have dry and fresh weight as they did not set fruits (Table 4). A similar result by Wolukau [19] indicated that the largest raspberry fruits had the greatest percent fruit dry weight. The variation in fruit weight could be because of the different species/cultivar grown, environmental conditions and nutritional status of the plantation [20]. According to Clark and Finn [21] 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. [11] 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 2.0-6.6 g per fruit [12,22,23], while fruit weight of wild growing blackberries in Turkey were between [24]. In the current study the berry weight from the different species were less than the ideal 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 [21]. Blackberry plants that look normal and healthy may sometimes flower profusely but fail to set fruit [25]. 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 [25]. This could be the reason why *R pinnatus* and *R steundneri* did not have any yield during the production period though the two species flowered.

Fruit size of different blackberry species grown were significantly different in terms of fruit width and fruit length (Table 4). *R. fruiticosus* recorded the largest fruit width of (21.10 mm), while *R. volkensis* had a fruit width of 15.87 mm. *R apetalus* had the least fruit width of 11.08 mm. Fruit length was also significant with *R. fruiticosus* having the longest fruit length

Table 3. Lateral length, number of laterals, number of canes, internode length and number of flowers per lateral of different blackberry species

Treatment	Lateral length (cm)	Number of laterals	Number of canes	Internode length (mm)	Flowers per lateral
R. apetalus	69.73b	22.87ab	9.85a	6.70bc	58.15a
R. volkensis	54.55c	21.50abc	3.67d	6.12bc	18.38c
R. steundneri	58.45c	19.62bc	4.75c	7.88ab	26.08b
R. pinnatus	80.02a	18.38c	6.00b	8.47a	25.97b
R. fruiticosus	26.98d	24.52a	4.00cd	6.00c	30.52a

Means followed by the same letter(s) within a column are not significantly different at P= 0.05 according to HSD Turkey's test

Table 4. Number of flowers per cane, number of fruits per lateral, fruit weight (g) and fruit size (length and width) of different black berry species

Treatment	Flowers per cane	Fruits per lateral	Fruit fresh weight (g)	Fruit dry weight (g)	Fruit length (mm)	Fruit width (mm)
R. apetalus	581.60a	56.25	1.24c	0.76c	11.53c	11.87b
R. volkensis	63.33c	14.42c	3.68b	1.56b	16.23b	15.87b
R. steundneri	100.47b	0.00d	0.00d	0.00d	0.00d	0.00d
R. pinnatus	89.43bc	0.00d	0.00d	0.00d	0.00d	0.00d
R. fruiticosus	100.50b	18.42a	5.38a	2.42a	22.84a	21.10a

Means followed by the same letter(s) within a column are not significantly different at P= 0.05 according to HSD Turkey's test

(22.84 mm), *R. volkensis* had a fruit length (15.87 mm) and *R. apetalus* had the shortest fruit length (11.08 mm) (Table 4). In a similar study by Campagnolo and Pio [8] on 11 berry cultivars, the average berry size range was length (16.6 to 27.3 mm) and diameter was (17.3 mm to 25.1 mm). These results did not vary from the current study and the variation in fruit size is due to genetic and genotypic expression of different cultivars/species.

4. CONCLUSION

In the present study blackberry germplasm exhibited varying growth and fruit yield potential. The wild species *Rubus apetalus* was observed to be the most vigorous in terms of cane height, cane diameter, length of laterals and number of canes. In terms of fruit yield potential e.g. number of flowers per lateral, number of fruits per lateral, fruit size and fresh fruit weight, *Rubus apetalus* recorded the highest number of flowers per lateral while *Rubus volkensis* had larger fruit size and fresh fruit weight after cultivar "Ruben" *Rubus fruiticosus.*

Wild blackberry can be adopted for cultivation and or introgressed in commercial cultivars with low vigour. A wider study to explore potential in the vast wild blackberry germplasm in the country is recommended.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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