Performance of Micropropagated and Conventional Passion Fruit (*Passiflora edulis* Sims.) Varieties in Three Contrasting Agroecological Zones

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Abstract

Diseased propagules prevent adequate production of passion fruits (*Passiflora edulis* Sims.) in Kenya. Commercial micropropagation of *P. edulis* is not practiced in Kenya, and its implications are not known. The objective of the current study was to determine the effect of site and planting material on growth and yield of passion fruits. The experimental layout used was split plots in randomised complete block design. Contrasting sites assigned to main plots were Lare, Njoro and Molo. Tested planting materials assigned to subplots were yellow conventional, yellow tissue-cultured, yellow conventional grafted, yellow tissue-cultured grafted, purple conventional, purple tissue-cultured. Each treatment had 10 plants, replicated four times in each site. Plant growth and yield were assessed for over one year. Generally, plant performance depended on the site and planting material that significantly ($P \leq 0.05$) interacted. Growth of planting materials was more vigorous in Lare followed by Njoro and lastly Molo. Yellow passion fruits were severely stunted in Molo followed by Njoro, but grew vigorously in Lare. Non-grafted yellow passion fruits failed to set flowers and fruits during the first year. Highest yielding plants varied with site. Interaction of planting material and site significantly ($P \leq 0.05$) affected total soluble solids only. Most micropropagated plants were slightly more vigourous than corresponding conventional materials in each site. Thus variety, soils, climate and pests also influenced performance. Micropropagation proved effective for rapid multiplication of passion fruit plants, but the type of material to plant successfully will vary depending on agroecological zones. Pilot tests ought to be conducted in each site before implementing large scale planting. Organizations with tissue culture laboratories are recommended to adopt this method to multiply passion fruit varieties for growers.

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Key words: Aphids, micropropagation, passion fruit, *Passiflora*, Fusarium wilt, woodiness virus

Introduction

Passion fruit (*Passiflora edulis* Sims.) is an important fruit crop in many tropical countries, including Kenya. Owen (1971) reported the emergence of passion fruit growing as a viable new industry in Kenya in the early 1970's. Potential for this crop exists in Western, Nyanza and Rift Valley provinces of Kenya. Passion fruit growing is rapidly expanding to replace disease-ravaged and low value crops (MoALDM, 1997). Exported passion fruits generated Kenya Shillings 161 millions in 2002, representing a 36% increase over the previous year, but a decrease over the 1990's earnings (HCDA, 2003).

Among the cultivated varieties, purple passion fruit (*P. edulis* var. *edulis*) is the most important in the juice industry (Nakasone and Paull, 1998). Passion fruits are also processed into jam, jelly, pudding, flavours for yoghurt, ice cream and other food products, or exported. Resistant yellow passion fruit *(P. edulis* var. *flavicarpa*) rootstocks protect purple passion fruits against soil-borne diseases such as *Fusarium* wilt (*F. oxysporum* f. *passiflorae*). However, it is not yet widespread in Kenya (Amugune *et al.*, 1993).

The major constraints preventing adequate production and supply of passion fruits in Kenya include poor quality seeds, diseased planting materials, *Fusarium* wilt, woodiness virus, brown spot disease, high costs of pesticides, transport, orchard establishment and maintenance (MoALDM, 1997). Past research priorities in Kenya focused on cultivar adaptation, trellising, pruning, fertilizer regimes, intercropping, pest control, spacing, water needs and development of brown spot-resistant varieties (MoALDM, 1997).

Most commercial passion fruit producers establish plantations using seedlings, which do not spread the woodiness virus, but generate undesirable genetic variability (Nakasone and Paull, 1998). Both yellow and purple passion fruits have been micropropagated in many countries, but not in Kenya; micropropagation confers many advantages such as rapid production of uniform, disease-free and vigorous plants (Kantharajah and Dodd, 1990; Drew, 1991; Amugune et al., 1993; Dornelas and Vieria, 1994; Kawata *et al.*, 1995; Faria and Segura, 1997).

Field-testing of tissue-cultured (TC) passion fruit plantlets has been reported in several countries. Faria and Segura (1997) reported that micropropagated yellow passion fruits performed normally in the field, but they did not compare them to seedlings. Performance of TC passion fruit plants under Kenyan field conditions is not known. Guidelines that growers may follow to successfully establish and maintain TC passion fruit plants in Kenya have not been developed. This research aimed at evaluating field performance of TC passion fruits in comparison to conventional seedlings. The research question investigated whether field performance of TC passion fruits is better than of seedlings, because of high vigour in the field.

Materials and Methods

Planting Materials

Seeds were extracted from disease-free yellow and purple passion fruits, obtained from the Kakuzi (Kenya) limited and the National Horticultural Research Centre at Thika-Kenya. Seeds of each variety were germinated in sterilized sand on a laboratory bench maintained at 25 ± 1°C and 16 hours of 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Kantharajah and Dodd, 1990). Shoot apices, measuring 0.5 cm long were excised from seedlings and established on modified Murashige and Skoog (1962) basal salts medium, as described by Isutsa (2004). Shoot tip and internodal segments, measuring 1 cm long were proliferated according to previously established protocols (Faria and Segura, 1997; Isutsa, 2004). Resulting stage II microshoots rooted best ex vitro (Isutsa, 2004). Subsequently, plantlets were transplanted to the same sand: soil mixture as that used for ex vitro rooting and acclimatized in a greenhouse. Conventional seedlings were grown in a greenhouse. Half of the yellow passion fruit plants were grafted using conventional purple scion shoots.

Field Trials

Planting was done at Lare, Njoro and Molo to test stability of performance across agro-ecological zones (AEZ). Lare is 20 km from the TC laboratory, 2160 m above sea level (asl) and in AEZ lower highland 3, receiving 832 to 931 mm rain annually and 8 to 24°C; Njoro is 0.5 km from the laboratory, 2238 m asl and in AEZ lower highland 2 to 3, receiving 908 to 1012 mm rain annually and 8 to 22°C; and Molo is 60 km from the laboratory, 2408 m asl and in AEZ upper highland 2, receiving 1100 to 1227 mm rain annually and 9 to 25°C (Jaetzold and Schmidt, 1983). According to Jaetzold and Schmidt (1983) all the three sites have high soil fertility. Kenya is divided into six AEZ’s, with most regions in the uppermost and in the three lowermost AEZ's being unsuitable for passion fruit growing (Jaetzold and Schmidt, 1983). It is expected that performance in the three test sites could be reproduced in regions with the same or similar environmental conditions.

Soil samples were taken from the three sites and analysed at the soil science laboratories using standard methods for nutrient content determination.

The experiment was arranged as split plots in randomised complete block design. Site was assigned to main plots and planting material was assigned to subplots. Variation in agro-ecological conditions most likely influenced plant performance, justifying assignment of site to main plots. Each treatment was assigned 10 plants and replicated four times in each site. Plants were established and maintained according to the recommendations of Nakasone and Paull (1998). Plants measuring 30-cm in height were transplanted in November 2002 into 60 cm x 60 cm x 60 cm holes, spaced at 2 m x 3 m. Farmyard manure (5 kg) and 100 g diammonium phosphate were placed into each hole, mixed with top soil and followed by planting.

Plants were irrigated by pouring 20 litres of water per plant immediately after planting. A trellis was established soon after planting to support passion fruit vines. Two main shoots were trained on a string up to a wire in opposite directions (Nakasone and Paull, 1998). All other shoots were pruned off to avoid their competitive and stunting effects to the main shoot. Fruit-bearing laterals on the main shoots were left to grow hanging down. Weeding was done regularly through shallow cultivation. Top-dressing fertilizer (calcium ammonium nitrate) was applied at a rate of 70 g/plant at the beginning and middle of the growing season. Irrigation with 15 litres of water per plant per week was performed when rains failed.

Variables were measured and counted bi-weekly to determine plant performance in height, number of leaves and laterals, reproductive growth (number of flowers), yield components (number and weight of fruits) and quality (fruit fresh weight, diameter and total soluble solids). Height was measured using a tape measure; number of leaves, laterals, flowers and fruits was counted; fruit weight was weighed on a balance; fruit diameter was measured with a vernier calliper; and total soluble solids were measured with a hand-held refractometer. Data were subjected to analysis of variance using the MSTAT-C programme and Duncan's Multiple Range Test was used for separation of different means.

Results

There was variation in agro-ecological conditions of the three sites (Table 1; Figure 1). Molo soil was strongly acidic, whereas pH for Njoro and Lare soils was within the range recommended for passion fruits (Nakasone and Paull, 1998). Lare and Njoro soils are vintric mollic andosols (well-drained sandy loams), whereas Molo soil is poorly drained clay loam. The difference in nitrogen and carbon content for the three sites appeared small. Phosphorous, calcium and magnesium contents were highest in Lare, followed by Njoro and lastly by Molo. The reverse was observed for potassium content.

The near freezing point temperature experienced in Molo inhibited plant growth (Figure 1). Average temperature at Njoro was 20°C. Rainfall was highest at Molo during the peak-growing season (June to August 2003), thereby water-logging the clay soils at the site for long periods. Rainfall was lowest at Lare, but the deficiency was overcome through irrigation.

Table 1: Soil characteristics at Lare, Njoro and Molo sites [z]

Site	pH	%N	%C	P (ppm)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Lare	7.2	0.29	1.5	88	250	846	55
Njoro	5.7	0.25	1.7	70	275	455	57
Molo	4.8	0.25	1.5	63	325	257	43
Recommended pH for passion fruits 5.5 to 6.8 (Nakasone and Paull, 1998)							

[z] Soil samples were analysed by the soil science laboratory using standard methods

Plant Height

All plants (conventional and tissue-cultured) grew normally and without any apparent aberration. Height of plants differed significantly until 24 weeks after planting (WAP), when tallest plants started coiling along the trellis wire (Table 2). Variation in height was attributed to strong interaction between site and planting material. In Lare and Molo, yellow conventional and yellow TC plants were significantly taller than all the other planting materials. In Molo, height of purple passion fruit plants was greater than that of all yellow passion fruit plants, which also remained stunted indefinitely and did not improve with time (Table 2).

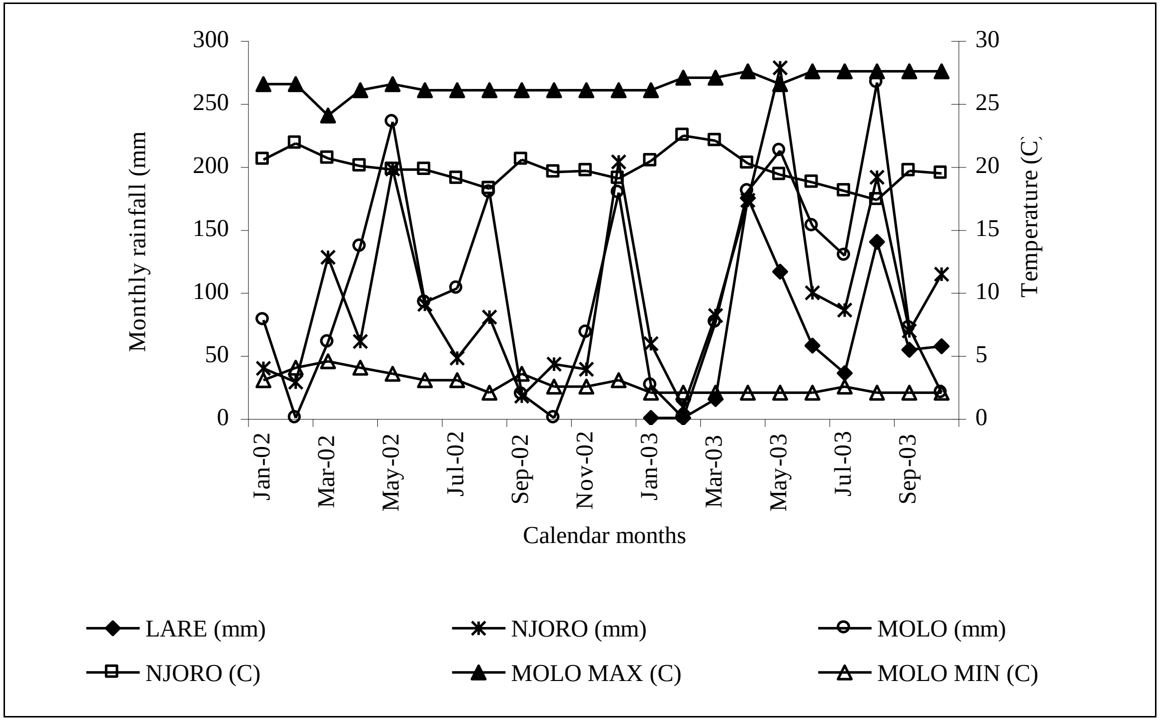

Figure 1: Weather data during the study period. Lare temperature was not available

Table 2: Effect of site and planting material on height (cm) of passion fruit plants grown in three Kenyan high altitude agro-ecological zones

		Time (weeks after planting) ^{z}					
Site	Planting material	14	16	18	20	22	24
Lare	Yellow conventional	136.3^{a}	174.3^{a}	219.0^{a}	266.0^{a}	310.7^{a}	318.3^{a}
Lare	Yellow tissue-cultured	140.0^{a}	176.0^{a}	221.3^{a}	268.7^{a}	314.7^{a}	324.0^{a}
Lare	Yellow conventional grafted	84.3^{c}	92.7^{cde}	105.3^{de}	120.7^{de}	155.0^{d}	194.3^{cd}
Lare	Yellow tissue-cultured grafted	79.3^{cd}	97.0^{cd}	102.3^{de}	101.0^{efg}	166.7^{cd}	201.3^{cd}
Lare	Purple conventional	73.0^{cde}	81.3^{de}	81.0^{efg}	97.3^{efg}	123.7^{de}	178.3^{d}
Lare	Purple tissue-cultured	91.3^{bc}	101.3^{cd}	109.3^{cde}	122.7^{de}	155.0^{d}	198.0^{cd}
Njoro	Yellow conventional	141.3^{a}	181.3^{a}	206.3^{a}	257.3^{a}	284.7^{a}	299.0^{a}
Njoro	Yellow tissue-cultured	139.7^{a}	184.7^{a}	222.0^{a}	250.0^{a}	277.3^{a}	304.7^{a}
Njoro	Yellow conventional grafted	84.7^{c}	112.0^{bc}	141.0^{b}	166.0^{bc}	205.7^{bc}	228.0^{bcd}
Njoro	Yellow tissue-cultured grafted	76.3^{cde}	110.3^{bc}	135.3^{bc}	146.3^{cd}	164.8^{cd}	220.3^{bcd}
Njoro	Purple conventional	104.7^{b}	130.3^{b}	154.0^{b}	189.3^{b}	221.3^{b}	253.7^{b}
Njoro	Purple tissue-cultured	72.7^{cde}	100.3^{cd}	129.3^{bcd}	168.3^{bc}	205.3^{bc}	235.3^{bc}
Molo	Yellow conventional	32.3^{h}	41.1^{f}	52.7^{g}	69.0^{g}	85.1^{e}	91.1^{e}
Molo	Yellow tissue-cultured	35.5^{h}	46.2^{f}	62.3^{fg}	77.9^{fg}	94.7^{e}	107.9^{e}
Molo	Yellow conventional grafted	43.0^{fgh}	49.4^{f}	59.2^{g}	72.6^{g}	89.1^{e}	106.3^{e}
Molo	Yellow tissue-cultured grafted	39.4^{gh}	47.6^{f}	57.2^{g}	72.4^{g}	92.1^{e}	117.0^{e}
Molo	Purple conventional	61.7^{def}	73.3^{e}	89.4^{ef}	111.7^{def}	151.3^{d}	178.6^{d}
Molo	Purple tissue-cultured	56.7^{efg}	83.4^{de}	104.5^{de}	137.1^{cd}	162.1^{cd}	180.9^{d}
CV(%)		12.93	12.03	12.95	12.89	14.20	12.74
$LSD_{0.05}$		17.87	20.99	27.00	32.17	42.88	44.10

^{z}Means followed by the same letter within columns are not significantly different at $P \leq 0.05$, according to the DMRT.

At the beginning of assessment in Lare and Molo, purple TC plants were slightly more vigorous than the purple conventional plants (Table 2). However in the end, there was no significant difference in vegetative growth, suggesting that conventional plants caught up with TC plants. Moreover, the effect of tissue culture and grafting on height of corresponding plants (yellow conventional versus yellow TC, purple conventional versus purple TC, yellow conventional-grafted versus yellow TC-grafted) within each site was minimal (Tables 2). Thus, tissue culture and grafting alone did not significantly ($P \leq 0.05$) alter the height of plants at the three sites.

Number of Leaves and Lateral Shoots

The effects of site and planting material significantly ($P \leq 0.05$) affected leaf and lateral shoot growth (Tables 3 and 4). At 20 WAP, most plants in Molo had fewer leaves and laterals than materials in the other two sites. At 20 WAP the number of leaves ranged from 12 to 34 per plant (Table 3). At 34 WAP, the number of laterals ranged from 1 to 36 per plant, with the lowest developing on Molo plants (Table 4).

Table 3: Effect of site and planting material on number of leaves of passion fruit plants grown in three Kenyan high altitude agro-ecological zones

		Time (weeks after planting) ^{z}			
Site	Planting material	14	16	18	20
Lare	Yellow conventional	15^{abcde}	19^{abcd}	25^{ab}	30^{abc}
Lare	Yellow tissue-cultured	16^{abc}	19^{abcd}	25^{ab}	26^{bcde}
Lare	Yellow conventional grafted	12^{def}	15^{def}	18^{cdef}	20^{def}
Lare	Yellow tissue-cultured grafted	15^{abcde}	17^{cde}	17^{def}	22^{cde}
Lare	Purple conventional	12^{ef}	14^{ef}	16^{efg}	19^{efg}
Lare	Purple tissue-cultured	16^{abcd}	19^{bcde}	20^{bcde}	24^{cde}
Njoro	Yellow conventional	17^{ab}	20^{abc}	23^{abc}	34^{a}
Njoro	Yellow tissue-cultured	18^{a}	23^{ab}	26^{ab}	33^{ab}
Njoro	Yellow conventional grafted	14^{bcde}	17^{cde}	24^{ab}	29^{abcd}
Njoro	Yellow tissue-cultured grafted	12^{def}	20^{abc}	25^{ab}	26^{bcde}
Njoro	Purple conventional	17.7^{a}	24^{a}	29^{a}	36^{a}
Njoro	Purple tissue-cultured	16^{abc}	20^{abc}	25^{ab}	30^{abc}
Molo	Yellow conventional	7^{gh}	8^{g}	9^{h}	12^{g}
Molo	Yellow tissue-cultured	9^{fgh}	9^{g}	10^{gh}	14^{fg}
Molo	Yellow conventional grafted	6^{h}	7^{g}	10^{h}	12^{fg}
Molo	Yellow tissue-cultured grafted	8^{gh}	8^{g}	10^{gh}	13^{fg}
Molo	Purple conventional	10^{fg}	12^{fg}	14^{fgh}	19^{efg}
Molo	Purple tissue-cultured	13^{cde}	18^{cde}	23^{abcd}	30^{abc}
CV(%)		14.12	15.76	16.16	18.88
$LSD_{0.05}$		3	4	5	7

^{Z} Means followed by the same letter within columns are not significantly different at $P \leq 0.05$, according to the DMRT.

Table 4: Effect of site and planting material on number of lateral shoots of passion fruit plants grown in three Kenyan high altitude agro-ecological zones

		Time (weeks after planting) [z]			
Site	Planting material	28	30	32	34
Lare	Yellow conventional	16[a]	16[a]	20[ab]	18[bc]
Lare	Yellow tissue-cultured	16[a]	18[a]	18[abc]	18[bc]
Lare	Yellow conventional grafted	10[a]	11[a]	15[abc]	20[abc]
Lare	Yellow tissue-cultured grafted	12[a]	15[a]	16[abc]	22[ab]
Lare	Purple conventional	7[a]	12[a]	10[bcd]	13[bc]
Lare	Purple tissue-cultured	12[a]	13[a]	15[abc]	20[ab]
Njoro	Yellow conventional	15[a]	15[a]	18[ab]	18[bc]
Njoro	Yellow tissue-cultured	12[a]	15[a]	18[ab]	17[bc]
Njoro	Yellow conventional grafted	9[a]	11[a]	18[ab]	19[bc]
Njoro	Yellow tissue-cultured grafted	12[a]	15[a]	18[abc]	18[bc]
Njoro	Purple conventional	13[a]	18[a]	22[ab]	23[ab]
Njoro	Purple tissue-cultured	15[a]	20[a]	25[ab]	27[ab]
Molo	Yellow conventional	0[bc]	0[c]	1[e]	1[f]
Molo	Yellow tissue-cultured	0[bc]	1[bc]	1[e]	2[e]
Molo	Yellow conventional grafted	1[bc]	3[b]	4[d]	6[d]
Molo	Yellow tissue-cultured grafted	2[b]	3[b]	6[cd]	9[cd]
Molo	Purple conventional	5[a]	9[a]	13[abc]	13[bc]
Molo	Purple tissue-cultured	10[a]	18[a]	9[a]	36[a]
CV(%)		20.8	19.4	18.1	13.0
$LSD_{0.05}$		6	10	5	8

[4Z]Means followed by the same letter within columns are not significantly different at $P \leq 0.05$, according to the DMRT. Data were transformed to natural logarithm before analysis.

Flowering

The interaction between site and planting material significantly ($P \leq 0.05$) affected flower growth (Table 5). Both yellow passion fruit plants (non-grafted conventional and TC) in all sites set no flowers during the first year. Yellow TC-grafted plants in Lare developed the highest number of flowers throughout the first year, whereas purple TC plants in Njoro and Molo set a greater number of flowers than other plants (Table 5). Generally, plants in Molo developed fewest flowers, while those in Njoro set the highest at the end of 34 WAP (Table 5). The number of flowers per plant ranged from 0 to 330 at 34 WAP.

Table 5: Effect of site and planting material on number of flowers of passion fruit plants grown in three Kenyan high altitude agro-ecological zones

		Time (weeks after planting) ^{z}			
Site	Planting material	28	30	32	34
Lare	Yellow conventional	0^{f}	0^{d}	0^{d}	0^{e}
Lare	Yellow tissue-cultured	0^{f}	0^{d}	0^{d}	0^{e}
Lare	Yellow conventional grafted	4^{cde}	19^{bc}	66^{ab}	121^{ab}
Lare	Yellow tissue-cultured grafted	24^{abc}	66^{a}	73^{ab}	180^{ab}
Lare	Purple conventional	1^{def}	19^{bc}	26^{b}	29^{c}
Lare	Purple tissue-cultured	21^{abc}	36^{abc}	73^{ab}	147^{ab}
Njoro	Yellow conventional	0^{f}	0^{d}	0^{d}	0^{e}
Njoro	Yellow tissue-cultured	0^{f}	0^{d}	0^{d}	0^{e}
Njoro	Yellow conventional grafted	19^{abc}	36^{abc}	79^{ab}	175^{ab}
Njoro	Yellow tissue-cultured grafted	26^{ab}	54^{ab}	93^{ab}	126^{ab}
Njoro	Purple conventional	54^{a}	89^{a}	194^{a}	289^{a}
Njoro	Purple tissue-cultured	48^{a}	96^{a}	200^{a}	330^{a}
Molo	Yellow conventional	0^{f}	0^{d}	0^{d}	0^{e}
Molo	Yellow tissue-cultured	0^{f}	0^{d}	0^{d}	0^{e}
Molo	Yellow conventional grafted	0^{f}	1^{d}	2^{cd}	6^{d}
Molo	Yellow tissue-cultured grafted	0^{ef}	2^{d}	4^{c}	6^{d}
Molo	Purple conventional	3^{def}	13^{c}	27^{b}	54^{bc}
Molo	Purple tissue-cultured	6^{bcd}	13^{c}	37^{b}	64^{bc}
CV(%)		55.7	29.8	25.6	22.9
$LSD_{0.05}$		30	56	120	210

^{Z} Means followed by the same letter within columns are not significantly different at $P \leq 0.05$, according to the DMRT. Data were transformed to natural logarithm before analysis.

Yield

The effect of site and planting material on yield was significant (Table 6). Non-grafted yellow conventional and yellow TC plants set no fruits during the first year of growth in the field. The type of plants bearing higher yields varied from site to site. Generally, plants in Molo produced the lowest yields. First-year yields for the three sites ranged from 0 to 894 fruits/plant, corresponding to 0 to 33 kg/plant, or 0 to 54,678 kg/ha (Table 6). Planting material bearing the highest number of fruits in the first year were yellow TC-grafted in Lare, purple conventional in Njoro, and purple TC in Molo. Within each site, the difference in fruits on purple conventional and purple TC plants was not significant ($P \geq 0.05$) (Table 6).

Table 6: Effect of site and planting material on first-year yield of passion fruit plants grown in three Kenyan high altitude agro-ecological zones

Site	Planting material	First-year yield attribute ^{z}		
		Fruits/plant	Kg/plant	Kg/ha
Lare	Yellow conventional	0^{g}	0^{g}	0^{g}
Lare	Yellow tissue-cultured	0^{g}	0^{g}	0^{g}
Lare	Yellow conventional grafted	469^{e}	18^{e}	$30{,}673^{e}$
Lare	Yellow tissue-cultured grafted	794^{ab}	32^{ab}	$53{,}344^{ab}$
Lare	Purple conventional	542^{de}	22^{de}	$36{,}007^{de}$
Lare	Purple tissue-cultured	655^{bcd}	26^{bcd}	$44{,}009^{bcde}$
Njoro	Yellow conventional	0^{g}	0^{g}	0^{g}
Njoro	Yellow tissue-cultured	0^{g}	0^{g}	0^{g}
Njoro	Yellow conventional grafted	624^{cde}	25^{cde}	$41{,}342^{cde}$
Njoro	Yellow tissue-cultured grafted	577^{cde}	23^{cde}	$38{,}674^{cde}$
Njoro	Purple conventional	824^{a}	33^{a}	$54{,}678^{a}$
Njoro	Purple tissue-cultured	734^{abc}	30^{abc}	$49{,}343^{abc}$
Molo	Yellow conventional	0^{g}	0^{g}	0^{g}
Molo	Yellow tissue-cultured	0^{g}	0^{g}	0^{g}
Molo	Yellow conventional grafted	196^{f}	8^{f}	$13{,}336^{f}$
Molo	Yellow tissue-cultured grafted	214^{f}	9^{f}	$14{,}670^{f}$
Molo	Purple conventional	509^{de}	20^{de}	$33{,}340^{de}$
Molo	Purple tissue-cultured	596^{cde}	24^{cde}	$40{,}008^{bcde}$
CV(%)		23.8	40.0	39.9
$LSD_{0.05}$		149	9	9,839

^{Z} Means followed by the same letter within columns are not significantly different at $P \leq 0.05$, according to the DMRT.

Flowering of Yellow Passion Fruits at Lare

Non-grafted yellow passion fruit planting materials at Lare only set flowers during the second year in the field. Flowers were borne on secondary and tertiary shoots, which were extremely long and intertwined. Consequently, flowers were recorded per square metre for standardization purposes. Non-grafted yellow conventional plants produced more (4 m^{-2}) flowers than non-grafted yellow tissue-cultured plants (3 m^{-2}), although the difference was not significant ($P \geq 0.05$). Flowers developed and set fruits of variable sizes. The variation in seedling (conventional) material was greater than in tissue-cultured material.

Purple Passion Fruit Quality

Purple passion fruit ripening period varied from site to site. Fruits ripened first in Lare (11 months after planting), followed by Njoro (12 months after planting) and lastly by Molo (14 months after planting). There somewhat was no significant difference ($P \geq 0.05$) in timing by the various planting materials within each site. Two quality attributes (fresh weight, diameter) of fruits in all sites were similar (Table 7). Total soluble solids varied within and among the sites. Quality attributes were measured on ripe fruits that had turned dark-purple. Fresh weight, diameter and total soluble solids per fruit ranged from 38 to 46 g, 4.3 to 5.3 cm, and 13% to 16.2%, respectively (Table 7).

Table 7: Effect of site and planting material on quality attributes of purple passion fruits produced in the three Kenyan high altitude agro-ecological zones

		Quality attribute ^{z}		
Site	Planting material	Fresh weight (g/fruit)	Fruit diameter (cm)	Total soluble solids (% sugar)
Lare	Yellow conventional grafted	46	5.1	15.1^{abc}
Lare	Yellow tissue-cultured grafted	42	4.9	15.2^{abc}
Lare	Purple conventional	40	4.9	13.0^{d}
Lare	Purple tissue-cultured	42	5.3	15.0^{abc}
Njoro	Yellow conventional grafted	43	4.4	16.2^{a}
Njoro	Yellow tissue-cultured grafted	39	4.3	15.9^{ab}
Njoro	Purple conventional	40	4.3	15.6^{abc}
Njoro	Purple tissue-cultured	43	4.4	14.8^{bc}
Molo	Yellow conventional grafted	40	4.6	15.2^{abc}
Molo	Yellow tissue-cultured grafted	42	4.6	15.5^{abc}
Molo	Purple conventional	40	4.7	15.1^{abc}
Molo	Purple tissue-cultured	38	4.7	14.5^{c}
	Reported (Nakasone and Paull, 1998)	36	3.5 to 7.0	15.0
CV(%)		7.34	3.41	4.19
$LSD_{0.05}$		NS	NS	1.09

^{Z} Means followed by the same letter, or no letter, within columns are not significantly (NS) different at $P \leq 0.05$, according to the DMRT.

Discussion

This research concerned field performance of tissue-cultured passion fruits in comparison to conventional passion fruits. Vigour was assessed on height, leaves and laterals (Tables 2, 3 and 4). Vigour of plants was modified more by the effect of site (environment) than of genotype (Table 1; Figure 1).

According to Nakasone and Paull (1998), passion fruit plants thrive best at pH ranging from 5.5 to 6.8. Molo site had extremely acidic (pH 4.8) soil, which probably adversely affected passion fruit plants (Table 1).

Passion fruits perform well under 1000 to 1500 mm of rainfall per annum plus supplementary irrigation during dry periods (Nakasone and Paull, 1998). Rainfall in Molo was heavier than in the other two sites during the main growing season, which span from March 2003 to August 2003 (Figure

1). The high rainfall caused waterlogging, which adversely affected passion fruit plants through suffocation, excessive stem thickening, and general growth stunting. According to Nakasone and Paull (1998) temperatures of 15^{o}C day and 10^{o}C night decrease vegetative growth, whereas 30^{o}C day and 25^{o}C night can prevent flower production. Lowest temperatures of 2^{o}C at Molo were below the tolerable lower limit.

In Lare, tissue-cultured (TC) plants were slightly bigger than their corresponding counterparts, whereas in Njoro and Molo this trend was true for the yellow variety only (Table 2). Huang et al. (1997), reported that TC own-rooted and TC-grafted plants were longer and larger than other plants of *P. edulis* x *P. flavicarpa* hybrids, although they did not state whether the difference was significant. The increase in vigour of TC plants is often attributed to the optimal conditions (both nutritional and environmental) provided *in vitro* (Faria and Segura, 1997). Enhanced vigour (plant height, leaves and laterals) could translate into higher and profitable yields, which can offset costs of tissue-culturing plants (Huang et al., 1997). Profitability is desirable to sustain a tissue culture enterprise. The current research proved that *ex vitro*-rooted TC passion fruit plants, when grafted or not grafted, are as good as corresponding seedling plants, although the ultimate performance depended on agro-ecological conditions prevailing in each site.

The number of flowers and fruits set varied depending on the planting material and site. All purple variety plants set flowers and fruits during the first year, but all non-grafted yellow variety plants did not set flowers in the first year (Table 5). In Spain, Faria and Segura (1997) reported that micropropagated yellow passion fruits (*P. edulis* var. *flavicarpa*) exhibited normal development and blossomed abundantly in the field, although they did not mention conventional plants, prevailing environmental conditions, and duration to flowering.

The difference in flowering and fruiting can be attributed to environmental conditions, which are usually below optimal in high altitudes for yellow passion fruit varieties (Figure 1). This result agrees with the fact that yellow passion fruit thrives best in low altitudes, with ample warmth that drives rapid growth. Our three sites were located in high altitudes, which experience cool temperatures at some point during the year.

Furthermore, non-grafted yellow passion fruit plants failed to set flowers and fruits in the first year probably because of juvenility (Nakasone and Paull, 1998). Moreover, Watson and Bowers (1965) proposed that flowering of yellow passion fruits responds to photoperiodism, a condition often mild in the tropics. This result means that the yellow variety could only be used as a rootstock in regions where it grows well vegetatively, but without setting fruits.

Yields realised corresponded to flowers set (Tables 5 and 6). Plants that set many flowers yielded more fruits than the others, suggesting that flowers set indicate potential yields to be expected (Nakasone and Paull, 1998). Thus, planting materials selected for each site should possess the potential to set many flowers and hence many fruits.

Lack of a significant difference in physical fruit quality attributes (fresh weight and diameter) suggests that environmental conditions (sites) and type of planting materials exerted more impact on growth and yields than on physical fruit quality attributes. The physical and chemical quality attributes observed in the current study (Table 7) agreed with standard ones reported elsewhere (Nakasone and Paull, 1998).

The current study showed no significant difference in performance of corresponding conventional and TC plants (yellow conventional versus yellow TC, purple conventional versus purple TC), as well as grafted and non-grafted plants (yellow conventional-grafted versus yellow TC-grafted) in each site (Tables 2 to 8). This result implied that tissue culture and grafting alone did not significantly alter performance of passion fruits in the three sites, agreeing with other researchers (Faria and Segura, 1997; Nakasone and Paull, 1998). The result also underscores the significance of field-testing to generate information on performance (growth, pests, yields, somaclonal variants, and farmers' perception, among other variables), before adopting planting materials on a large-scale. Field trials indicate strength, safety, and reliability of micropropagation relative to conventional techniques (Faria and Segura, 1997). The currrent study revealed that performance of tissue-cultured passion fruit plants is at par with that of conventional plants (seedlings) of the same genotype.

The current study proved that passion fruit planting materials could be produced rapidly, locally for farmers through ex vitro rooting. This method needs to be adopted, starting with organizations that have tissue culture laboratories. Such an action could sustain production and arrest the short supply of passion fruits in the region. Planting more passion fruits would boost acreage, production and income (HCDA, 2003), which in turn would improve food security, nutrition and living standards of growers, particularly those unable to produce other cash crops due to recalcitrant constraints. The increase would also enhance foreign exchange earnings (HCDA, 2003), thereby boosting socio-economic development.

These developments notwithstanding, sustainable passion fruit production will result only if other constraints such as drought, diseases and insect pests are concurrently managed to augment the ready availability of planting materials. Pests remain a big threat and a hindrance to realization of the full potential of passion fruits in Kenya. The current study, however, was unable to quantify contribution of pests to performance of the passion fruits, due to great variation in the three sites. Concerted efforts were made to manage aphids and diseases (brown spot, woodiness), but complete control proved impossible.

Conclusions and Recommendations

The current study proved that TC slightly enhances vigour and field performance of passion fruits compared to conventional plants. At Lare and Molo TC plants produced more fruits than conventional plants, although the difference for corresponding materials was not significant. Due to variation, recommended materials are as follows: yellow TC-grafted plants for Lare, purple conventional or TC plants for Njoro, and purple tissue-cultured plants for Molo. Micropropagation is, thus, recommended for rapid regeneration of own-rooted or grafted plants of both the yellow and purple passion fruit varieties in Kenya.

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