Original research papers

Mechanical strengths, Hydraulic Conductance and Growth of *Passiflora edulis f. edulis* grafted on five different rootstocks at three different cleft lengths in Nakuru Kenya.

Abstract

Vertical rupture, horizontal tensile strength, hydraulic conductance and growth of Passiflora edulis f edulis grafted on P. edulis f. flavicarpa, P. ligularis, P. mollisima, P. subpeltata and P. caerulea rootstalks with 1, 1.5 and 2 cm cleft lengths were determined 13 weeks after grafting and compared with self-grafts. Vertical rupture force was highest in P. edulis f. flavicarpa self grafts in all the three cleft lengths. Grafts with 1 and 1.5 cm cleft lengths had no significant difference in horizontal tensile strength except for P. ligularis self grafts which were the weakest. Self grafts with 1.5 cm clefts had higher hydraulic conductance than cross grafts. P. edulis f. flavicarpa rootstocks self-grafted or cross-grafted with P. edulis f. edulis scions resulted in the longest vines. The strength of wind needed to break the weakest unions (P. edulis f. flavicarpa by P. edulis f edulis, and P. ligularis by P. edulis f. edulis (cleft length 2 cm) was higher than the maximum recorded in Nakuru district implying that cross grafts of P. edulis f. flavicarpa by P. edulis f. edulis with 1.5 cm cleft lengths are not prone to wind breakages in Nakuru, Kenya.

Key words: *Mechanical tensile strength, grafting, growth, Passiflora, wind.*

1. INTRODUCTION

For several years, passion fruit growing has been declining in many parts of the world due to *Fusarium* wilt infection [2]. In many places, the yellow passion fruit (*P. edulis f. flavicarpa*) seedlings are used as rootstocks because they offer short term resistance to *Fusarium* wilt. However, recently there have been many reports from Kenyan growers that *P. edulis f. flavicarpa* is no longer resistant to *Fusarium* wilt [2]. An alternative compatible rootstock with *P. edulis f edulis* and resistant to *Fusarium* wilt would be useful. This alternative rootstalk can be found if more species in the family *Passifloraceae* are screened. The family *Passifloraceae* has more than 500 species [6].

The *Fusarium* wilt pathogen gains entry into the plant directly or though wounds. The wounds on the plant can be caused by nematodes, weeding, slashing or wind [1] [4]. The deleterious effects of wind have also been reported by [9] and [8]. According to [9], the extent of wind damage in apples is mainly determined by the speed of wind, the vertical rapture and horizontal tensile strengths of the plants. These strengths depend on cleft lengths [3]. According to [3] [7], hydraulic conductance is variable amongst different graft cleft lengths. Hydraulic conductance is directly related to nutrient uptake and growth [7]. The objective of this experiment was to study the strength of graft unions between different graft combinations with respect to cleft lengths, wind damage and growth.

2. MATERIALS AND METHODS

Seedlings of *P. mollisima, P. subpeltata, P. caerulea, P. edulis* f. *flavicarp, P. edulis f. edulis* and *P. ligularis* were raised from open pollinated seeds were sown in flats in Egerton University, Njoro Kenya. Eight weeks after sowing, 12 seedlings from each seed source were transplanted into 17 cm tall and 15 cm diameter round containers. Eight weeks later the seedlings were grafted with purple passion fruit scions. These grafted plants were used in a series of three experiments described below. The plants were grown in containers placed on benches under 50% lath shade in a randomized complete block design in two blocks.

The rootstock species were chosen to represented poor (*P. ligularis*), moderately poor (*P. mollisima*), and good (*P. mollisima*) compatible rootstocks (with respect to *P. edulis f. edulis* scions). Also, two new compatible rootstock accessions, *P. subpeltata* and *P. caerulea* were included. The effect of three lengths of cut (1.0 cm, 1.5 cm and 2 cm) was tested. For each rootstock species and cleft length graft combination, two single plant replications were used. Also, self-graft controls i.e. *P. mollisima* on *P. mollisima*, *P. ligularis* on *P. ligularis* and *P. edulis* f. *flavicarpa* on *P. edulis* f. *flavicarpa* were included. There were 192 total grafted plants included in the experiment; the missing treatment was due to the limited number of seeds (and thus rootstocks) from the two new species (*P. subpeltata* and *P. caerulea*). Thirteen weeks after grafting, the following data was collected: hydraulic conductance, scion vine length, vertical and horizontal mechanical strength.

Hydraulic conductance (the speed of water movement across the graft union) was measured by collecting condensed transpired water vapor in polyethene bags. Before 0800 hours, 50 x 20 cm polythene bags were weighed and placed over two randomly selected grafted plants from each rootstock-scion graft combination (24 in total). The plastic bags were secured at the graft union using rubber bands. Five un-grafted seedlings of *P. mollisima*, *P. ligularis* and *P. edulis* f. *flavicarpa* covered with plastic bags as described above were also included as controls. The grafted plants were moved out doors between 0800 and 1600 hours on a cloudless day. At 1600 hours, the plants were gently shaken to collect all the moisture on the leaves into the polythene bags. Then the bags were weighed using an analytical balance (JA 2003, Hangping, China). The transpired water was calculated by subtracting the weight of empty bags from the weight of the bags with water. The hydraulic conductance in mm of water per centimeter of stem length per minute (ml/cm/min) was calculated. Scion vine length was measured as previously described.

Vertical rupture strength was determined using a method similar to Rehkuger [9] but modified to measure upward force. One grafted plant from each of the fifteen graft combinations and nine self grafts were tied with a thread immediately above the graft union. The thread was tied to a spring balance mounted on an adjustable arm which was attached to a firm tripod stand. The base of the plant was also held with a clamp attached to a tripod stand. The arm holding the balance was slowly raised. The force (N) needed to break the graft union was calculated as the maximum Kgs of upward force needed to break the graft union multiplied by 9.8 m/s, the conversion factor.

Horizontal rupture force was determined by a method used by Rehkuger [9]. All the 48 remaining plants were removed from pots and their roots washed and trimmed back to the trunk axis. Loading to failure was done and the depth and width of each sample's cross-section was measured at the point at which it failed. A graft failed when it split, shattered or snapped or when the failure occurred at or above the graft union.

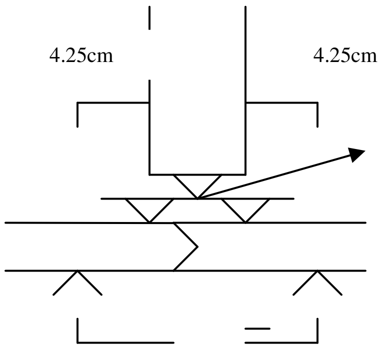

Figure 1: The arrangement of the stem to determine graft rupture force.

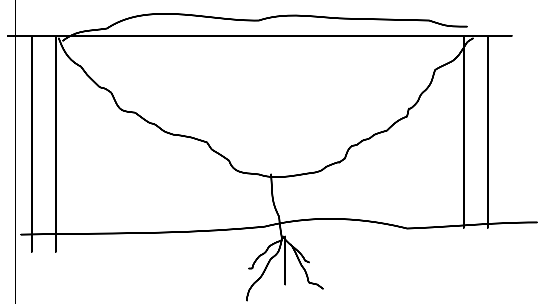
Figure 2: The geometry and wind velocity profile for calculating stress on the graft union

The maximum bending stress (expressed as Pascals, Pa) in the test section was calculated as: $S_{max} = MC/I$; where S_{max} was the maximum stress in material at the outer fiber (Pa), M was the bending moment ([illegible]n), C was the ½ the depth of the section in the direction of loading (m), I was the area moment of inertia of the graft cross-section (m^2), The section shape was elliptical, so the value of I/c became: $I/C = \pi bd^2/32$ where b was the graft section width (m), d the graft section depth (m), Defining P as the force (N) applied by the crosshead of the testing machine and R as the horizontal distance (m) at the loading point, then: $M = PR/2$ and substituting equation 2 and 3 into 1 gave : $S_{max} = 16PR/ \pi bd^2$. This was the expression defining the maximum stress in the test specimen as a function of loading and geometry. The specimens were loaded to failure by gradually increasing the load applied at the center of the graft union. The calculated maximum stress at failure was the tensile modulus of rupture of the graft union material.

Trellising wire displacement force was determined at three points (1, 1.25 and 1.5 m along the wire) using a digital cable tension meter (Quantrol GTX, Avery Weigh-Tronix, Fairmont, MN). A trellising wire 16 gauge was mounted with fencing nails top of two posts 3 m apart and 2.5 m posts high (after installation). The displacement force (Pa) was determined by pulling the wire down using the tension meter to the furthest point. The displacement distance (m) was the vertical distance the wire moved way from the original point of loading.

Maximum wind velocity at the graft union was determined using a method similar to the one used by Rehkuger [9]. It was assumed that the plant's canopy had an inverted semi elliptical shape. The wind velocity profile was calculated relative to distance from the ground. i.e. $V = V_{max}((y+a+b)/9.144)^{1/7}$; where

V = velocity of wind at any position y, Vmax = velocity (m/sec) at 9.133 m, y= position on the three as defined by coordinate, a = distance from the ground surface to the point of the graft union (m) and b = the distance from the graft union to the top of the plant (m).

The bending moment (horizontal wind force) at the graft union was determined by integrating the moment produced by the wind.

$$M = (\rho C V_{max}^2 W)/2 \int ((y+a+b)/9.144)^{2/7}(y+b)(y^2/H^2)^{1/2}$$

C = drag coefficient (1.5)

ρ = air density (Kg/m^3)

W = plant width (m)

H = tree height minus (a+b) (m)

2.1 Data Analysis

Data was subjected to multivariate analysis of variance test (MANOVA) using the GLM procedure within the SPSS the version for personal computers (SPSS 15.0, SPSS Inc, University of Chicago). Means were separated using Waller-Duncan test at $p = 0.05$ level of significance. Pearson's correlation analysis for growth factors was carried out using the SPSS program. Pair wise comparisons were done at $p = 0.05$ level of significance.

3. RESULTS

There was a significant graft union length by rootstock type interaction regarding vertical force needed to break the graft union ($p < 0.001$) (Table 1). Regardless of the union length, *P. flavicarpa* and *P. ligularis* self grafts had significantly greater graft union strength compared to *P mollisima* self grafts and all the other graft combinations with *P. edulis f. edulis* scions. In all cases, the stems severed abruptly above the graft union indicating that the difference in vertical force strength was related to scion properties and not caused by weakness of the graft union. In contrast, there was no significant difference between *P. flavicarpa* self grafts and the other graft combination in the horizontal force needed to break the 1 cm and 1.5 cm graft unions except for *P. caerulea* by *P. edulis* and *P. ligularis* by *P. edulis* 1.5 cm combinations which were significantly weaker. When the graft union length was 2 cm, *P. flavicarpa* by *P. edulis* and *P. ligularis* by *P. edulis* had significantly higher mechanical strength with regard to horizontal force than all of the three self-grafts.

Hydraulic conductance was significantly reduced by grafting ($p < 0.001$). All the graft combinations and self-grafts had significantly lower hydraulic conductance than the un-grafted controls (Table 1). When the graft union was 1 cm and 1.5 cm long, all the graft combinations except *P. flavicarpa* by *P. edulis* had significantly lower hydraulic conductance than *P. flavicarpa* and *P. ligularis* self-grafts. When the union length was 2 cm, hydraulic conductance was significantly higher in only *P. ligularis* self-grafts. Grafting significantly reduced scion vine length ($p < 0.001$) except in *P. flavicarpa* by *P. edulis* 1 and 1.5 cm long union length graft combinations. However, when the union length was 2 cm, there was no significant difference between any of the graft combinations and self-grafts.

Generally, when all graft combinations and self grafts except *P. mollisima* had 1.5 and 2 cm union lengths, the vertical force needed to break the unions was significantly higher than when the unions were 1 cm long (Table 3). Maximum tensile strength was not significantly different in the graft combinations when the union length was 1 cm and 1.5 cm long except in *P. ligularis* by *P. edulis* and *P. caerulea* by *P. edulis* and *P. mollisima* and *P. ligularis* self-grafts. Hydraulic conductance was significantly higher when the graft unions were 1.5 cm in the *P. ligularis* by *P. edulis* and *P. flavicarpa* by *P. edulis* graft combinations. Scion length on the other hand was significantly high when the union length was 1.5 and 2 cm in *P. ligularis* by *P. edulis* and *P. flavicarpa* by *P. edulis* graft combinations while in the other graft combinations, there was no significant difference.

Vertical force generated by wire displacement showed that enough force was generated that could damage the vines (Table 3). An analysis of the strength of wind on the graft union revealed that the minimum wind speed strong enough to break the weakest unions (*P. flavicarpa* by *P. edulis*, and *P. ligularis* by *P. edulis* (both graft union length 2cm) was 150 km /hr (2.46 km/h at the union) (Table 4). The maximum maximum wind speed (9.1 m) recorded in Nakuru district i.e. 102.15 km/hr (2.32Km/hr at the union) (Table 4).

Table 1: The effect of the length of the cleft graft on mechanical strength, hydraulic conductance and scion growth thirteen weeks after grafting for grafted *Passiflora* plants

Graft combination	Vertical rupture force [V] (Pa) Union length			Maximum tensile strength [W] (Pa) Union length			Hydraulic conductance [X] (g/cm/day) Union length			Scion length [Y] (cm) Union length		
	1 cm	1.5 cm	2 cm	1 cm	1.5 cm	2 cm	1 cm	1.5 cm	2 cm	1 cm	1.5 cm	2 cm
Scion *P. edulis*												
P. flavicarpa	16.5c	36.4cd	37.4cd	5.7a	22.5ab	8.9a	3.0bc	3.4bc	1.9c	**23.7a**	**35.7b**	15.0a
P. ligularis	19.1c	32.8de	33.7cd	27.3a	15.6bc	7.6a	1.5c	2.8c	1.7c	11.7b	16.0cd	12.0a
P. molisima	19.6c	31.6de	33.4cd	22.6ab	23.1ab	5.8ab	1.5c	2.7c	1.7c	13.1b	15.1cd	12.2a
P. subpeltata	18.6c	30.6de	33.4cd	26.6a	23.1ab	4.8b	1.5c	2.7c	1.7c	13.1b	15.1cd	12.2a
P. caerulea	18.8c	28.7e	29.8d	26.2a	15.2b	5.2b	1.5c	2.2c	1.7c	10.6b	12 .2d	9.8a
Self grafts												
P. molissima	19.9c	43.1b	62.2ab	26.6a	15.7bc	5.3b	1.8c	5.3a	3.9b	11.0b	26.7bc	13.7a
P. flavicarpa	9.6a	78.9a	77.1a	**28.5a**	**28.6a**	4.3b	3.7b	4.9a	2.3bc	10.7b	62.7a	8.7a
P. ligularis	30.5b	42.1c	46.1bc	15.3b	7.8c	4.7b	6.5a	4.6a	7.1a	9.30b	20.3cd	9.7a
Ungrafted												
P. mollisima		_			**38.2**			12.2*			53.0*	
P. flavicarpa		_			106.1*			14.9*			**47.7**	
P. ligularis		_			8.7			9.9*			**44.0**	

[V] Vertical rapture force refers to the force in Pa needed to separate scion and rootstock. [W] Maximum tensile strength measured as the horizontal force needed to break the union or scion stem. [X] Hydraulic conductance measured as the amount of condensed transpired moisture in eight hours.
[Y] Scion length taken in cm from the start of the graft union to the top of the apical bud. [Z] Means followed by the same letter within a column are not significantly different at p = 0.05. * The mean is significantly higher than all other means within a column. Means in **bold** not significantly different p= 0.05.

Table 2: The effect of the length of the cleft graft on mechanical strength, hydraulic conductance and scion growth thirteen weeks after grafting for grafted *Passiflora* plants

	Vertical rupture force [V] (Pa)			Maximum tensile strength [W] (Pa)			Hydraulic conductance [X] (g/cm/day)			Scion length [Y] (cm)		
	Union length			Union leng			Union length			Union length		
Graft combination	1 cm	1.5 cm	2 cm	1 cm	1.5 cm	[illegible]	1 cm	1.5 cm	2 cm	1 cm	1.5 cm	2 cm
Scion *P. edulis*												
P. flavicarpa	16.5b	36.4a	37.4a	5.7a	22.5a	8.9b	3.0a	3.4a	1.9b	**23.7**b	**35.7**a	15.0c
P. ligularis	19.1b	32.8a	33.7a	27.3a	15.6b	7.6c	1.5b	2.8a	1.7b	11.7b	16.0a	12.0ab
P. molisima	19.6b	31.6a	33.4a	22.6a	23.1a	5.8b	1.5c	2.7c	1.7c	13.1a	15.1a	12.2a
P. subpeltata	18.6b	30.6a	33.4a	26.6a	23.1a	4.8b	1.5c	2.7c	1.7c	13.1a	15.1a	12.2a
P. caerulea	18.8b	28.7a	29.8a	26.2a	15.2b	5.2c	1.5c	2.2c	1.7c	10.6a	12 .2a	9.8a
Self grafts												
P. molissima	19.9c	43.1b	62.2a	26.6a	15.7b	5.3c	1.8c	5.3a	3.9ab	11.0c	26.7a	13.7b
P. flavicarpa	39.6b	78.9a	77.1a	28.5a	28.6a	4.3b	3.7a	4.9a	2.3b	10.7b	62.7a	8.7b
P. ligularis	30.5b	42.1a	46.1a	15.3a	7.8b	4.7c	6.5ab	4.6b	7.1a	9.3a	20.3b	9.7b

[V] Vertical rupture force refers to the force in Pa needed to separate scion and rootstock.
[w] Maximum tensile strength measured as the horizontal force needed to the union or scion stem.
[X] Hydraulic conductance measured as the amount of condensed transpired moisture in eight hours.
[Y] Scion length taken in cm from the start of the graft union to the top of the apical bud.
[Z] Means followed by the same letter along each row are not significantly different at p = 0.05

Table 3: Wire displacement force at three points of loading

	Loading distance from wire ends [W]		
	1.0 m	1.25 m	1.5m
Wire diameter (mm)	0.50	0.50	0.50
Wire displacement (m) [X]	0.14	0.28	0.21
Vertical force (Pa) [Y]	43.30	36.30	33.30

[W] Loading distance refers to the point on the trellising wire where the cable tension meter was hooked.
[X] Wire displacement is the vertical distance (downward) the trellising wire moved away from original point before loading.
[Y] Vertical force refers to the force the trellising wire generated when returning to original resting position.
[Z] The trellising wire was 3 m long.

Table 4: Maximum wind velocity and corresponding force resulting from the wind

Air Velocity at 9.144 m (Km/hr)	Maximum air velocity 35 cm above the ground (Km/hr)	Horizontal force (10^3) Pa
50	2.10	1.19
100	2.32	5.17
150	2.46	11.64 [Z]
200	2.56	20.70
250	2.64	32.35
300	2.71	46.58

[Z] the highest horizontal force 35 cm above the ground calculated from the strongest wind recorded in Njoro (Kenya) in 2008.

4. DISCUSSION

Graft formation is most rapid when scion stem tissues are matched with those of the rootstock. Further, the tensile strength of the graft is reduced markedly when the diameter of the tissues is mismatched [5]. In the current experiment it seems that the interaction between the union length, and the rate of graft formation was responsible for the low vertical rapture forces compared to self grafts (Table 1). However, when horizontal force was applied results for the 1 and 1.5 cm graft union lengths were not significantly different except in the *P. ligularis* by *P. edulis* 1.5 cm long graft combination. This suggested that the smaller the graft union the faster and the healing of the graft union. The rate of graft healing is directly related to the strength of the union [9].

Generally there was no significant difference in the hydraulic conductance in all the graft combinations indicating that all graft combinations and union lengths affected the seedlings the same way. The same trend was seen for scion length except for *P. flavicarpa* by *P. edulis.* This finding suggested that in this graft combination the rootstock may have had a positive influence on the scion. Un-grafted plants transpired two or more times more water than the grafted plants depending on the graft combinations. Since water is the medium of transport of nutrients from the soil to the leaves [7], this limitation in water movement may have been the reasons why vine length was reduced by grafting.

Contact between the scion and the rootstock affect cambial formation between the scion and the rootstock and cambial formation can be delayed if the cambial tissue of the scion and rootstock is misaligned [3]. Also, the strength of the graft union depends on the contact surface area between the scion and rootstock which is directly related to the union length [5]. Findings in the present experiment are consistent with this observation since 1.5 cm and 2 cm union lengths needed more vertical force to break (Table 1). However, when horizontal force was applied results were in the contrary. This suggested that in most graft combinations involving different species, cellular connections between the scion and the rootstock were first developed such that the scion was held to resist greater vertical than horizontal force.

The stems rupture above the graft union when vertical force was applied suggesting that the graft union was stronger than the stem of the scion. An analysis of the strength of wind on the graft union revealed that the minimum wind speed needed to break the weakest unions (*P. flavicarpa* by *P. edulis*, and *P. ligularis* by *P. edulis* (both graft union length 2 cm) was 150 Km/hr (2.32 Km/h at the union) (Table 2). This wind speed was higher than the maximum recorded in Nakuru County i.e. 102.15 Km/hr.

5. CONCLUSIONS AND RECOMMENDATIONS

The strength of wind needed to break the weakest unions (*P. flavicarpa* by *P. edulis*, and *P. ligularis* by *P. edulis* (both graft union length 2 cm) 150 Km/hr (2.32 Km/h at the union) was higher than the maximum recorded in Nakuru County i.e. 102.15 Km/hr. This meant passion fruit growers in Nakuru do not need wind breaks in their orchards.

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