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Development of a grafting protocol for the commercial propagation of three West Indian breadfruit cultivars

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Grafting breadfruit (*Artocarpus altilis*) on chataigne (*Artocarpus camansi*) rootstock can potentially benefit commercial establishment of breadfruit, but a suitable protocol needs to be developed. The objective of this study was to evaluate the effect of the grafting technique (whip and tongue, spliced side and top wedge), rootstock age (6, 9 and 18 week old), scion cultivar (two breadfruit cultivars from Trinidad- 'Yellow' and 'White', a Jamaican accession- 'JA1', and chataigne as the control) and season on grafting success. There were significant ($p < 0.05$) differences in length of survival neither among grafting technique nor rootstocks of different ages. Among scion cultivar, 'White' and chataigne scions generally survived longer ($p < 0.05$) than those of other cultivars. Grafting done in the wet season had significantly ($p < 0.05$) higher survival rate compared to those done in the dry season. Although not directly evaluated, scion quality and post-grafting environment were two factors that emerged as important to grafting these two species. The data suggest that season of grafting, scion quality and post-grafting environment were important determinants of grafting success. Scion harvested from juvenile mother plants during the wet season, matched with rootstock of similar diameter and grafted plants maintained in an environment which minimize water loss for both scion and rootstock for at least 4 weeks after grafting were essential for successful grafting of these selected breadfruit cultivars. When all these requirements were met, survival percentages of 97%, 83%, 80% and 80% for 'White', 'JA1', 'Yellow' and chataigne, respectively, were achieved.

Keywords: Grafting factors, Moraceae, breadnut, scion, rootstock

The Caribbean Community is highly dependent on imported food, which consists primarily of rice, wheat and corn (Wickham 2001, 11) which undermines food and nutrition security. This situation can be minimized through the development of carbohydrate rich crops, such as breadfruit. Fruits of this crop consist of a high percentage of carbohydrate (84%), appreciable quantities of calcium, magnesium, iron, potassium and phosphorus compared with other traditional staple starch crops and are a good source of riboflavin and niacin (Graham and Negron de Bravo 1981, 538; Jones 2010, 31). Furthermore, Roberts-Nkrumah (1998, 33) reported an annual estimated yield potential of 50,000 kg ha^{-1} for 4 to 5 years-old trees.

However, for the commercial production of breadfruit, focus must first be placed on developing a propagation method that can provide adequate quantities of good quality planting material in a rapid and sustainable manner. Due to triploidy of the seedless types, asexual propagation methods must be used (Ragone 2001, 693). Root cuttings and excised adventitious shoots (a modification of root cuttings) are the two methods being used currently by commercial nurseries in Jamaica and Trinidad and

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Tobago, respectively (Roberts-Nkrumah 1993, 24; Webster 2006, 33). Although the latter method can produce many more plants in a much shorter time than the root cuttings, both of these methods cause harm to the parent plant when roots are harvested, increasing the entry of pathogens via wounded areas. Another constraint is that tree decline caused by either biotic or abiotic factors or both (Zaiger and Zentmyer 1966, 896; Trujillo 1971, 8; Weir et al. 1982, 20; Hodges and Tenoria 1984, 335; Coates-Beckford and Pereira 1992, 62) affects established trees in some parts of the region. These problems can thwart the potential contribution of breadfruit to food security, therefore better propagation methods are necessary.

However, there is no evidence that tree decline affects chataigne (*A. camansi*), a close seed-producing relative of breadfruit. Furthermore, the results of a survey conducted in Trinidad and Tobago showed that although the tree populations of both species were highest in wetter regions, chataigne was more widely adapted, possibly because of its tap root system. Thus, more trees of chataigne grew in the drier regions than those of the breadfruit (Roberts-Nkrumah, pers. comm.).

Grafting breadfruit onto chataigne rootstock has potential for commercial production, since it eliminates damage to the roots of parent trees, could increase distribution of the breadfruit trees to drier regions, and more plants can be produced in a shorter period compared to methods of propagation currently used (author's observation).

Although chataigne is thought to be a parent of breadfruit (Zerega et al. 2004, 765), variable levels of success have been achieved by grafting these species, and the requirements for a successful graft union have not been elucidated. Galang and Elayda (1924, 204) and Padolina (1931, 350) reported grafting breadfruit on chataigne using the inarching method. Inarching requires established plants to be used as scion material (Hartmann et al. 2011, 464), which would rely on other vegetative propagation methods and is not very efficient for commercial production. Rowe-Dutton (1976, 252) cited Wester as reporting no success in their attempt to graft these two species.

In an evaluation of the effect of rootstock age, Medagoda and Chandrarathna (2007, 151) reported 83% success on 45-day-old rootstock using top wedge grafting. Studies on grafting Jackfruit (*Artocarpus heterophyllus*) and *Artocarpus lakoocha* showed that factors such as grafting method, rootstock age, grafting environment, juvenility of scion material and season of grafting affected successful grafting (Kelaskar et al. 1991, 58; Kelaskar et al. 1993, 113; Islam et al. 2003, 1047; Sharma and Thakur 2005, 259; Mannan et al. 2006, 77; El-Zaher 2008, 1; Selvi et al. 2008, 341). The objective of this study was to examine the effect of grafting technique, rootstock age, season of collection of scion material and cultivar on grafting success.

Materials and Methods

This study was conducted during the period February 2006 to March 2010 at the University of the West Indies, St. Augustine Campus Trinidad and Tobago W.I. using planting material from the breadfruit germplasm collection at the University's Field Station (Roberts-Nkrumah 1998, 39). The study examined the effect of grafting technique, rootstock age, season of collection of scion material and cultivar on grafting success. These factors were examined progressively in six experiments based on the results of previous experiments.

Experiment 1 examined the effect of grafting technique (whip and tongue, spliced side and top wedge) and age of rootstock (6, 9 and 18 week old). The breadfruit scion material for this experiment consisted of epicormic shoots. Epicormic buds, on the lower branches of selected breadfruit trees were forced to break dormancy by bending the distal end of the branches to approximately 30 - 60 cm from the ground level. Five (5) cm long horizontal cuts at 15 cm apart were made through the bark along the upper surface from the proximal to the distal end of these branches. After, 7 – 8 weeks epicormic buds that developed into shoots were selected as scion material. These shoots ranged between 8 - 9 mm in diameter and 9 - 11 cm in length and with approximately 3 dormant axillary buds and terminal bud. For the rootstock, chataigne seeds with approximately 0.5 cm of the embryo emerging were selected from freshly harvested ripe fruits and soaked in Mankocide™ solution (Copper Sulphate as its active ingredient) (7g/L) for 5 to 7 minutes. The seeds had an average weight, length and width of 7.7g, 3 cm and 2 cm, respectively. The chataigne seedlings were established in potting bags with a soil mixture consisting of soil: manure: sharp sand in a 3:2:1 ratio, and placed under shade in a greenhouse and watered once daily. Grafting was done above or at the first node in the green to brown region of the rootstock. After grafting the entire plant and potting bag was covered with clear plastic bags and placed on benches under shaded (70%) greenhouse conditions.

A completely randomized design was used for the 9 treatment combinations, each with 30 replicates.

Experiment 2 examined the effect of cultivar on successful grafting. The cultivars were two breadfruit cultivars from Trinidad- 'Yellow' and 'White', a Jamaican accession- 'JA1', and chataigne as the control. Epicormic shoots were used as scion material. These shoots were derived from buds that broke dormancy by removing terminal buds of lower lateral branches of mature trees. The scion material was of similar morphology to those described in experiment 1 and the material was 5 – 6 weeks old. Breadfruit scion materials were grafted using top wedge onto 6-week-old chataigne rootstocks, which were grown in potting bags containing a soil mix. Six week old chataigne rootstock and the top wedge grafting technique remained constant for all subsequent experiments. After grafting, the entire grafted plant and potting bag were covered with a plastic bag and placed under similar post-grafting conditions as Experiment 1. The four treatment cultivars were replicated 20 times.

The objectives of Experiments 3 and 4 were to re-examine the effect of cultivar and to determine the effect of season in which the scion was collected and in which grafting was done on the successful grafting of breadfruit and chataigne. Scion material for Experiment 3 and Experiment 4 was collected in wet and dry season, respectively. The scion material consisted of axillary shoots collected from juvenile adventitious breadfruit plants, that is, suckers that had not borne fruit, or from chataigne seedlings in the field.

Approximately 6 to 7 weeks after pruning the terminal buds of these adventitious plants and seedlings, the dormant axillary buds that developed into shoots were harvested as scion material. These shoots harvested for Experiment 3, had also been pruned of their terminal buds and ranged 6 to 7mm in diameter and 8 to 10 cm in length, consisted of 3 to 4 developing secondary axillary buds. Although the scion material source was similar for Experiment 4, the material ranged from 7 and 9 mm in diameter, 8 and 9 cm in length, with 3 to 5 developing axillary buds. With the need to increase efficiency and utilize greenhouse space, chataigne seeds were established in a cone tray system (a seedling tray comprised of cone shaped cells), which had a depth of 21 cm and a top diameter of 3.8 cm with Promix™ used as the planting medium.

After plants were grafted in Experiment 3, they were covered with a transparent plastic bag and tied below the graft union. This was also done for the grafted plants of Experiment 4. However, due to the rapid drying out of the medium observed in Experiment 3, the grafted plants in Experiment 4 were placed in a propagation bin with intermittent misting.

The experimental design and number of replicates were similar to those of Experiment 2. Furthermore, the data for Experiment 3 and 4, were pooled to check the factor of season (wet and dry).This was also done for Experiment 5 and 6.

Experiments 5 and 6 repeated the effect of cultivar and season of scion collection and was conducted during the subsequent wet and dry season, respectively of Experiment 4. The preparation of both scion and rootstock was similar to that in Experiments 3 and 4, except that Ray Leach Single cell Cone-Tainers™ were used for the establishment of the chataigne seedlings. In Experiment 5, the scion material ranged between 6 and 7 mm in diameter, 7 and 8 cm in length, with approximately 3 developing axillary buds and terminal buds removed. The rootstock had a diameter range of 5.5 – 7.0 mm in diameter. Additionally, the post-grafting environment was modified to maintain a relative humidity (RH) of over 95% using intermittent misting and shade reduction of 75%. The scion material collected for Experiment 6, ranged between 7 and 8 mm in diameter 6 and 7 cm in length with 3 – 4 nodes, consisted of shoots that developed much more slowly than those used in Experiment 5 and had shorter internodes and thicker diameters.

In all experiments the numbers of surviving grafts were counted weekly, the data were analysed using ANOVA, and least significant difference (LSD at $P \leq 0.05$) was determined with the Statistical Package for Social Sciences (SPSS) version 17.

Results

Grafting technique and rootstock age

In Experiment 1 the grafted scions were short lived, survived only for approximately 4 weeks and there were no significant differences ($p < 0.05$) in the length of survival of grafted scion among grafting techniques or rootstocks of different ages. In addition, there was no interaction between these two factors (Table 1).

Cultivar

The results of Experiment 2 showed that cultivar significantly ($p < 0.05$) affected the length of survival of the grafted scion. The grafted scions of the 'White' breadfruit cultivar and of chataigne, the control, survived the longest, 7.8 and 6.8 weeks, respectively followed by JAI (4.9 weeks) (Table 2). The 'Yellow' scions survived for the shortest period, 2.6 weeks, while those of 'JA1' were intermediate, 4.9 weeks. Eight weeks after grafting the survival percentage of grafted plants was 90%, 75%, 25% and 15% for 'White', chataigne, 'JA1' and 'Yellow', respectively (Fig. 1). Although grafted plants survived beyond seven weeks, these plants, in subsequent weeks toppled due to detachment of the shoot system from the root system at the point of the cotyledon attachment.

Table 1: Effect of grafting technique on the length of survival of grafted scions on rootstocks of different ages- Experiment 1

Rootstock Age	Mean ± SE Length of Survival (weeks)			Rootstock Means (p = NS)[x]
	Grafting Technique			
	Whip and Tongue	Side	Top Wedge	
7 wk	3.4 ± 0.4	4.1 ± 0.4	3.3 ± 0.4	3.6 ± 0.2
9 wk	4.1 ± 0.4	4.3 ± 0.4	4.6 ± 0.4	4.3 ± 0.3
18 wk	3.8 ± 0.4	3.7 ± 0.4	4.2 ± 0.4	3.9 ± 0.3
Grafting Technique Means (p = NS)[x]	3.7 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	-

Table 2: Effect of cultivar on the length of survival of breadfruit and chataigne scions at eight weeks after grafting – Experiment 2.

Scion Cultivar	Mean ± SE Length of Survival (weeks)
	Experiment 2 Wet Season
'Yellow'	2.6c[z] ± 0.4
'White'	7.8a ± 0.4
'JA1'	4.9b ± 0.5
Chataigne	6.8a ± 0.5
Cultivar Mean	5.5 ± 0.21

[z]Within column means followed by the same letter are not significantly different (P > 0.05) by LSD (0.80)

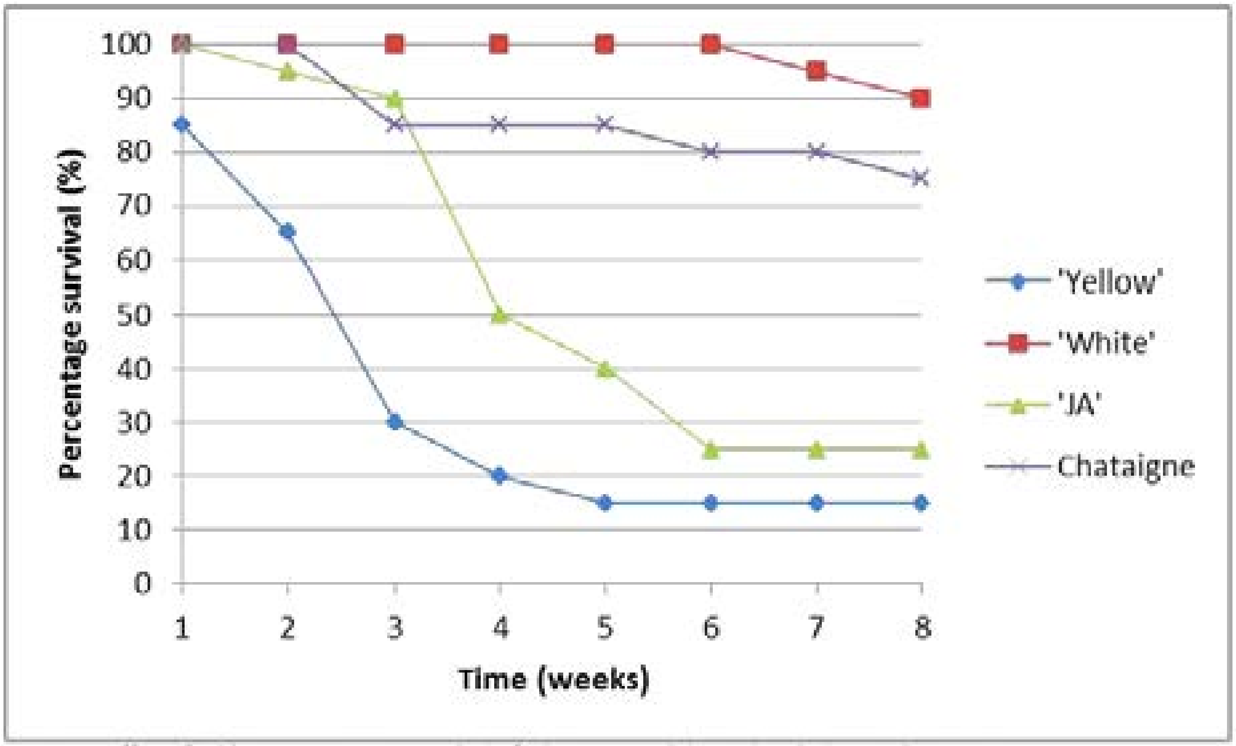

Figure 1 Effect of cultivar on percentage survival of scion over an eight week period- Experiment 2

The response to cultivar in Experiment 3 was different during the subsequent wet season to the one in which the Experiment 2 was conducted. Chataigne accounted for the highest mean length of survival (3.4 weeks) among other cultivars (Table 3). This was followed by ‘JA1’ with 1.4 weeks and both ‘Yellow’ and ‘White’ with 0.9 weeks, respectively. Results showed that cultivar had a significant ($p < 0.05$) effect on the length of survival of the grafted scion, with chataigne and JAI significantly ($p < 0.05$) different from all other cultivars. However, there were no significant ($p < 0.05$) differences observed between ‘Yellow’ and ‘White’ (Table 3). The survival percentage of grafted scions five weeks after grafting for chataigne and each of the selected breadfruit cultivars were 73% and 0, respectively (Fig. 2). Cultivar had a significant ($p < 0.05$) effect on mean length of survival of the grafted scion in Experiment 4. ‘White’ accounted for the highest length of survival, 2.4 weeks, followed by chataigne with 2.0. However, there were no significant ($p<0.05$) differences among ‘White’ and chataigne (Table 3). The survival percentages were 43%, 26%, 20% and 3% for ‘White’, chataigne, ‘JA1’ and ‘Yellow’, respectively (Fig. 3).

Table 3: Effect of scion cultivar on the length of survival of breadfruit and chataigne scions at four weeks after grafting – Experiment 3 and 4

Scion Cultivar	Mean ± SE Length of Survival (weeks): Experiment 3 Wet Season	Mean ± SE Length of Survival (weeks): Experiment 4 Dry Season
‘Yellow’	0.9c[x] ± 0.2	1.3d[y] ± 0.3
‘White’	0.9c ± 0.2	2.4a ± 0.3
‘JA1’	1.4b ± 0.2	1.7b,c ± 0.4
Chataigne	3.4a ± 0.3	2.0 a ± 0.4
Season Mean (NS)[z]	1.7 ± 0.2	1.9 ± 0.23

[x] Within column means followed by the same letter are not significantly different ($P > 0.05$) by LSD (0.44)
[y] Within column means followed by the same letter are not significantly different ($P > 0.05$) by LSD (0.50)
[z] P value not significant ($p > 0.05$)

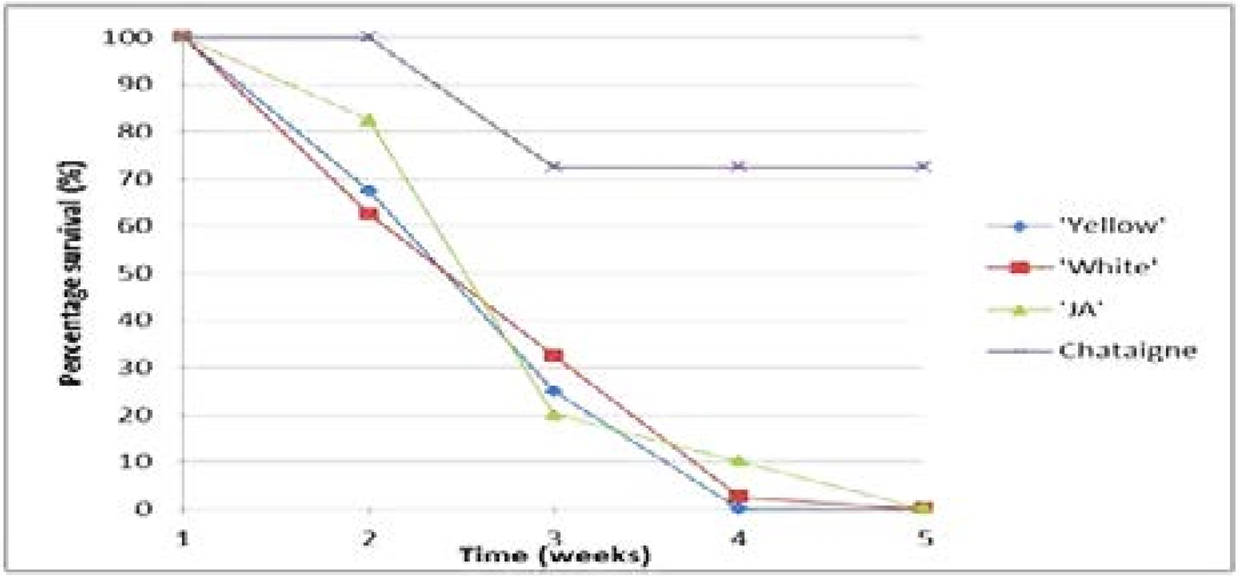

Figure 2: Effect of cultivar on percentage survival of scion over a five- week period-Experiment 3

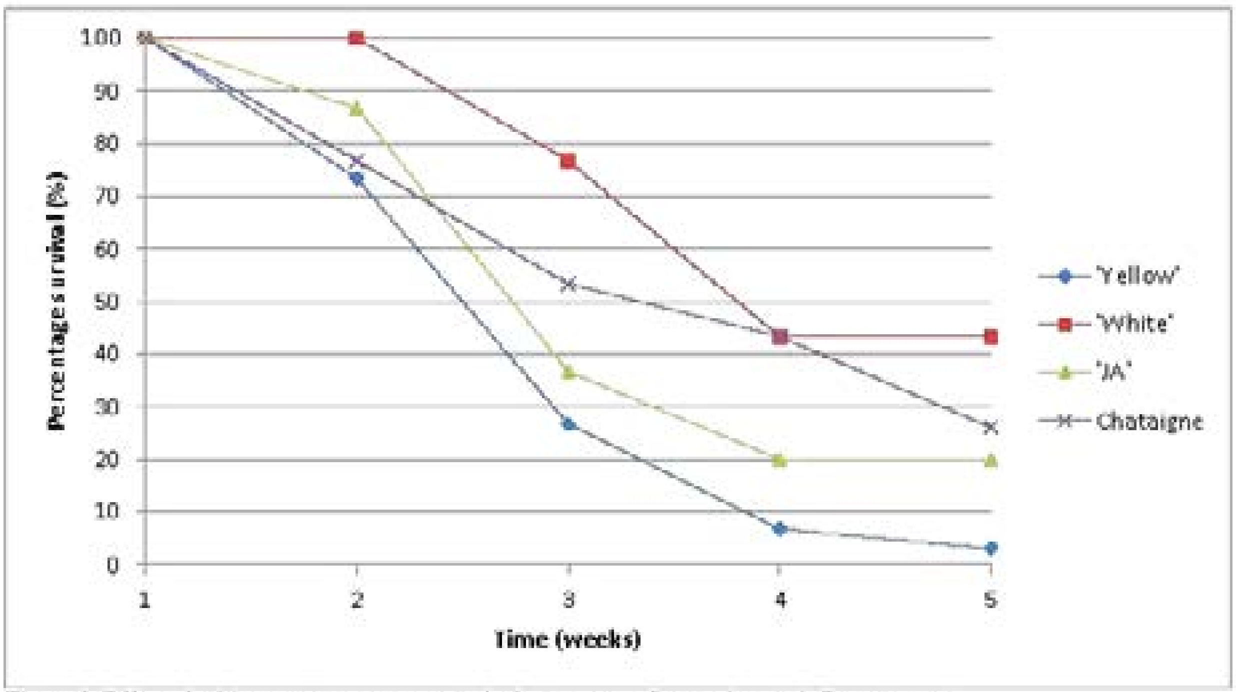

Figure 3: Effect of cultivar on percentage survival of scion over a five week period- Experiment 4

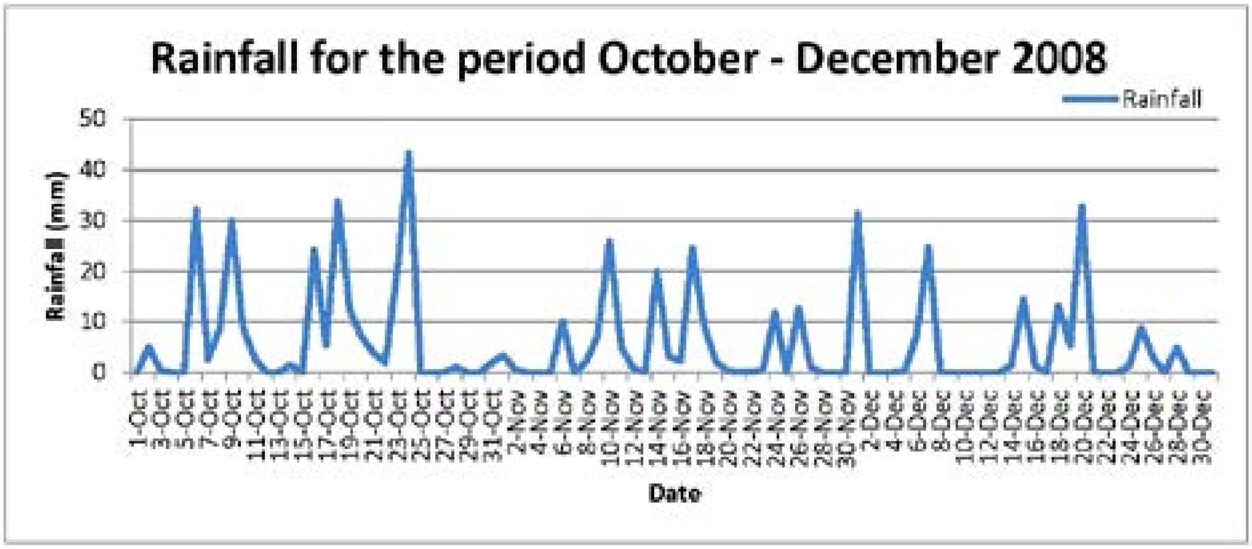

Figure 4: Rainfall pattern for a three-month period prior to collecting scion for Experiment 3 from parent source plants

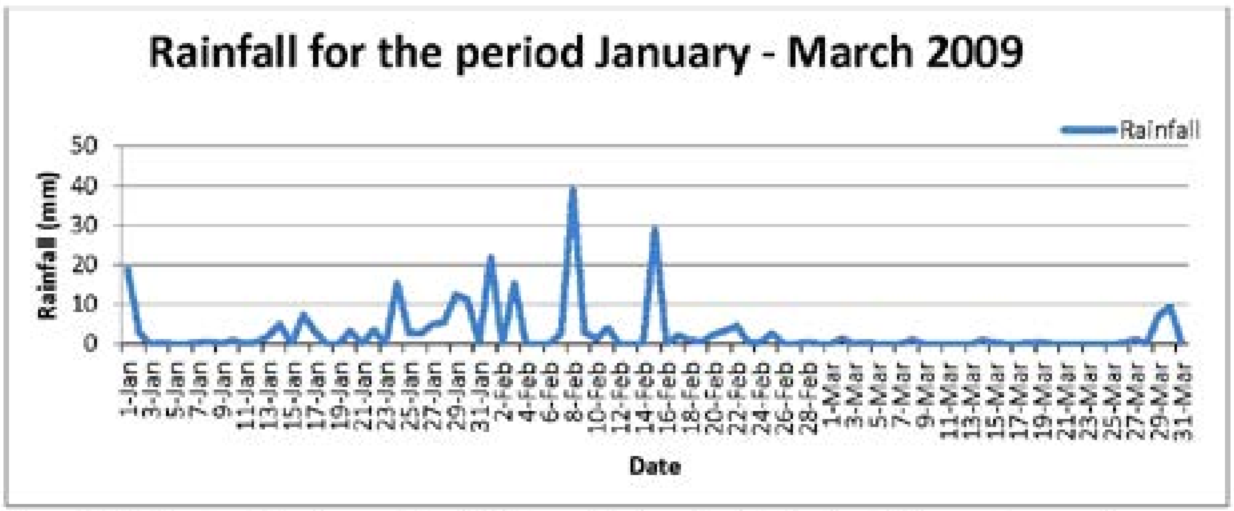

Figure 5: Rainfall pattern for a three month period prior to collecting scion for Experiment 4 from parent source plants

Table 4: Effect of time of grafting on length of survival of breadfruit and chataigne scions at six weeks after grafting

	Mean ± SE Length of Survival (weeks)	
Scion Cultivar	Experiment 5 Wet Season	Experiment 6 Dry Season
'Yellow'	5.5[x] ± 0.4	2.5[x] ± 0.2
'White'	5.9 ± 0.4	2.3 ± 0.1
'JA1'	5.4 ± 0.3	2.1 ± 0.2
Chataigne	5.3 ± 0.5	2.4 ± 0.3
SeasonMean[y]	5.5a ± 0.13	2.3b ± 0.16

[x] Within column means are not significantly different ($p < 0.05$) by LSD (0.56).
[y] Within row means followed by the same letter are not significantly different ($p > 0.05$) by LSD (0.41).

Cultivars had no significant ($p < 0.05$) effect on mean length of scion survival in Experiments 5 and 6, respectively (Table 4).

Season of scion material collection

The response to the effect of season of scion collection on the success of grafting was variable. The lengths of survival for Experiments 3 and 4 were lowest among all experiments. The lengths of survival were significantly ($p < 0.05$) different between Experiments 5 and 6 in which the scion material was collected in wet season (December) and in dry season (March), respectively (Table 4) with mean survival being 5.5 weeks and 2.3

weeks, respectively. The performance of the grafted scions was similar in Experiments 5 and 2, whereas scion survival in Experiment 6 was similar to that in Experiments 3 and 4. The factor of season did not have any significant ($p < 0.05$) effect on variation of the response. The rainfall pattern for the three-month period prior to collecting scion material in the field for Experiment 3 showed a fairly even distribution (Fig. 4). However, in the three-month period prior to collecting the scion material in Experiment 4 the pattern fluctuated during the first two months followed by a dry spell up until scion material was collected (Figs. 4 and 5).

The cultivar effect in Experiment 5 (wet season) displayed an overall mean length of survival of 5.5 weeks, which was similar to results of Experiment 2. 'White' accounted for the highest length of survival, 5.9 weeks, followed by 'Yellow', 'JA1' and chataigne with 5.5, 5.4 and 5.3, respectively (Table 4). Although grafted plants had an overall mean length of survival of 5.5 weeks, beyond the fifth week, grafted plants maintained their current survival percentages (Fig. 6). However, 'Yellow', showed decline during the fifth and sixth weeks and then leveled off. At the end of the seventh week the survival percentages of 'White', 'JA', and both 'Yellow' and chataigne were 97%, 83% and 80%, respectively (Fig. 6).

However, in Experiment 6 (dry season) the cultivar effect on the variation of the response was comparable to the results of Experiment 4, with an overall 2.3 weeks mean survival for cultivars (Table 4). There were sharp decreases in the percentage survival among cultivars during the second and third week followed by steady decline up until the fifth week, where data collection stopped (Fig. 7). The percentage survival for chataigne, 'Yellow', 'White', and 'JA1' were 20%, 15%, 15% and 5%, respectively (Fig. 7).

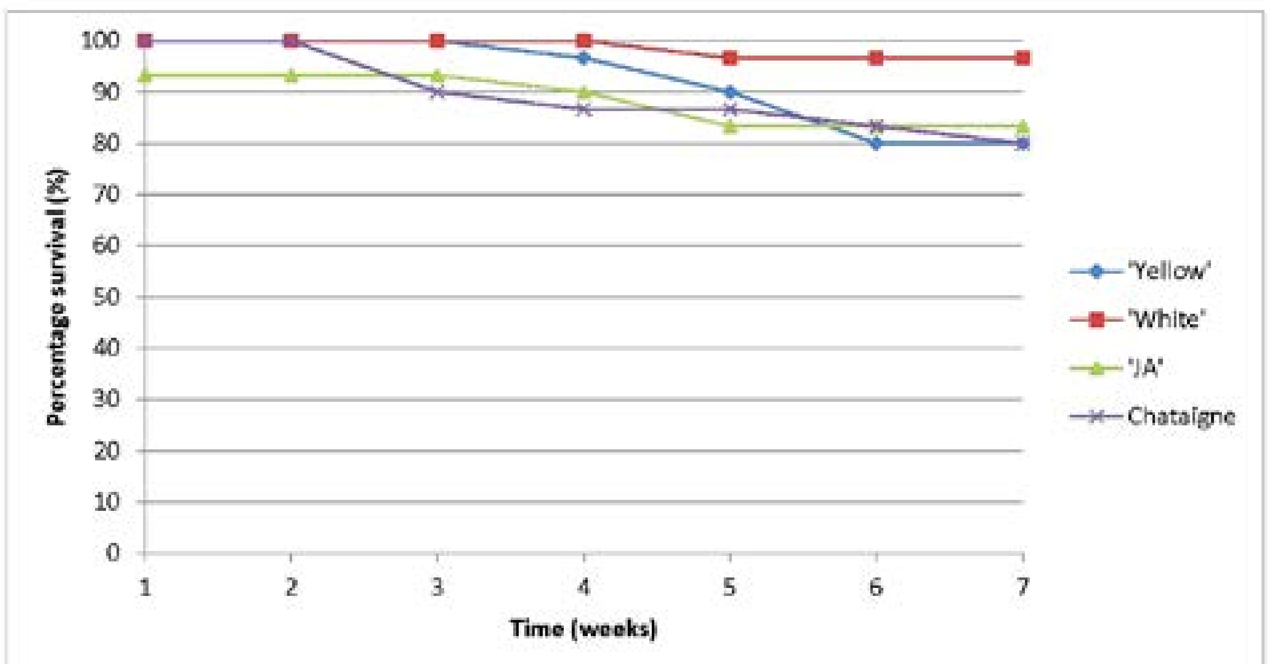

Figure 6: Effect of cultivar on survival percentage of scion over a seven week period- Experiment 5

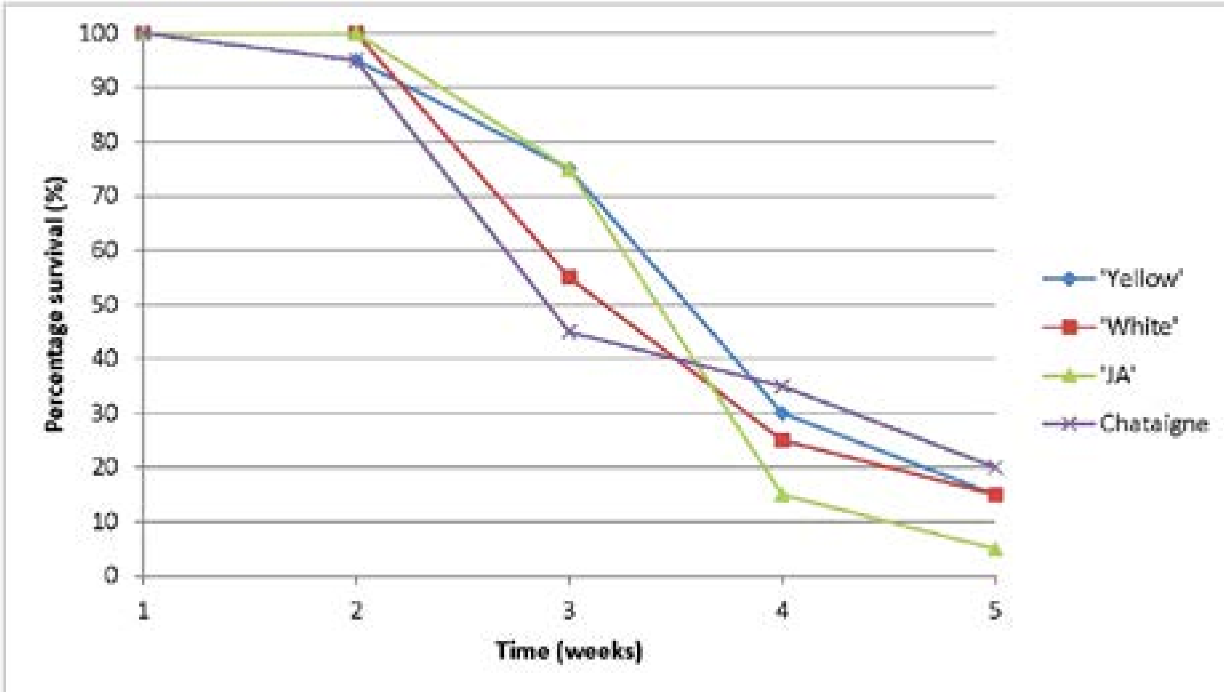

Figure 7: Effect of cultivar on survival percentage of scion over a five week period- Experiment 6.

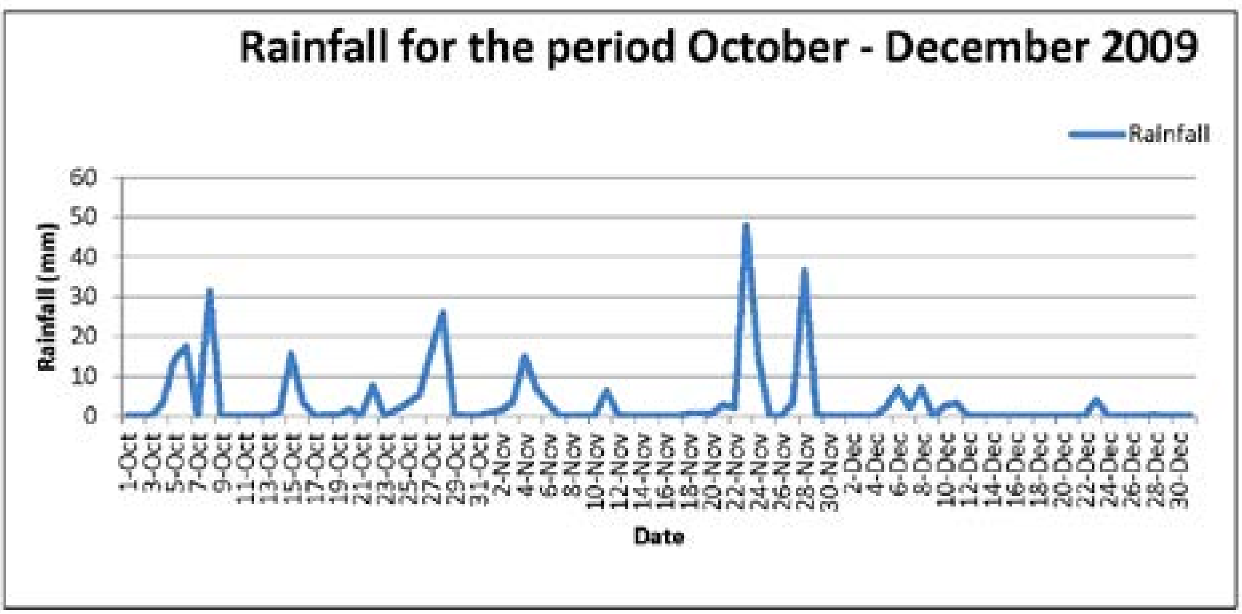

Figure 8: Rainfall pattern for a three month period prior to collecting scion material for Experiment 5 from parent source plants.

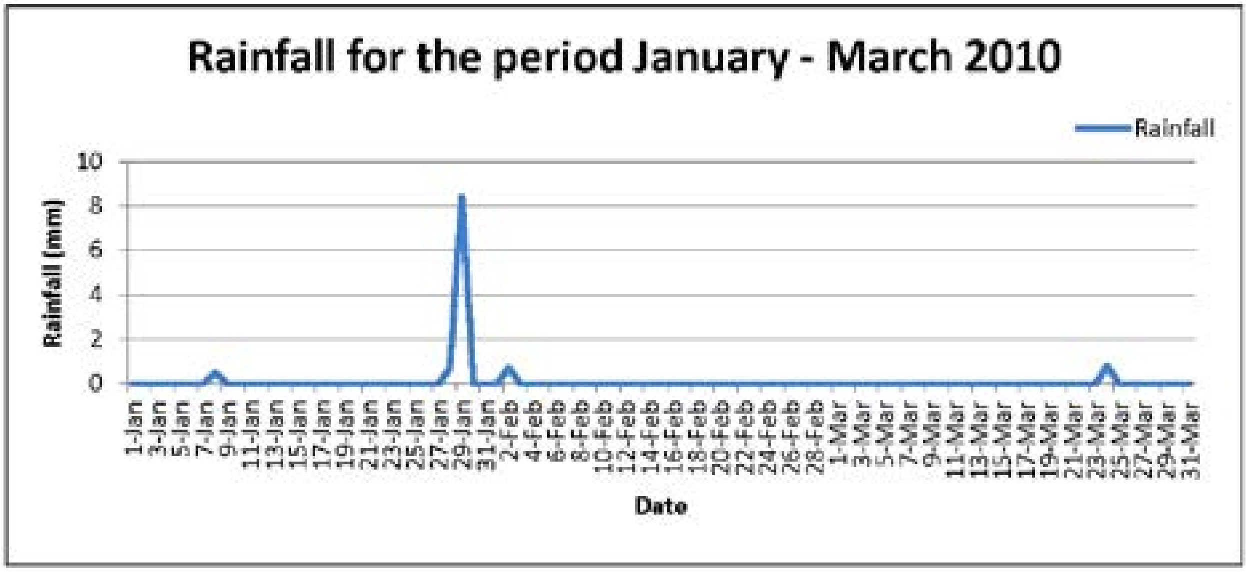

Figure 9: Rainfall patterns for a three month period prior to collecting scion material for experiment 6 from parent source plants.

In the three months leading up to the collection of scion material for the Experiment 5 rainfall was fairly well distributed (Fig. 8). However, scion source parent plants experienced a major drought during the three months prior to collection for Experiment 6, with a total rainfall of 8 mm (Fig. 9). Furthermore, the results of Experiments 5 and 6 showed there was a significant ($p < 0.05$) effect of season on the length of survival of the grafted scion (Table 4).

Discussion

Although, grafting these two species was expected to be highly successful, variable levels of success, ranging from 0 to 83% have been reported (Rowe-Dutton 1976, 253; Galang and Elayda 1924, 204; Padolina 1931, 350; Medagoda and Chandrarathna 2007, 149). This study yielded variable grafting success of 5% to 97%, similar to previous reports. Apparently, these results were characteristic of this genus since reports on grafting success of Jackfruit and *Artocarpus lakoocha* ranged from 2.35% to 75%. Several factors were identified with grafting Jackfruit and *A. lakoocha*. Likewise, the results of the present study indicate that successful grafting of these two species was attributable to several factors.

Grafting method

There have been no reports on evaluation of grafting techniques for breadfruit and chataigne grafting. A basic requirement for a successful graft union is that the cambia of the stock and scion should be in close proximity for interlocking of the parenchyma cells produced from these tissues and for early vascular connection (Hartmann et al. 2011, 462). Therefore, the selection of a grafting method would depend on the rootstock and scion diameter that allow close matching of the cambium regions. Since the diameters of the rootstock and scion increase with age, the choice of the grafting method can be determined by the age of these materials.

Nandwani and Kuniyuki (2005, 308) reported 80% success using approach grafting of one-year old plants but this method would rely on traditional propagation methods to generate entire plants to be used as scion material. This would encounter problems previously stated. Furthermore, because of the plant size at which grafting is done, the method is cumbersome and uses much space which are disadvantages for a commercial planting material production system. Medagoda and Chandrarathna (2007, 149) reported an 83% success rate using the top wedge method on six-week old chataigne rootstocks.

Whip and tongue and top wedge grafting methods are usually used with scion and stock diameters of 6 to 13 mm, while for spliced side grafting a slightly larger diameter range of 6 – 19 mm can be used (Hartmann et al. 2011, 464). The scion and rootstock diameter ranges used in this study for whip and tongue and top wedge grafting were 5.5mm to 9mm and 5.4mm to 14mm, respectively. No significant difference among the grafting techniques were observed possibly because where the diameters of the scion and the rootstock were mismatched, the periderms of both materials were lined up to facilitate close placement of the vascular cambia of both stock and scion, as described in Experiment 1 of this study. In this technique, the union might have been compromised in those regions where the cambium of both stock and scion are not aligned. This may partially explain the short-lived grafts in Experiment 1 after initial indications of successful union. Andrews and Marquez (1993, 200) found that grafts using this technique could eventually display delayed incompatibility.

Age of Rootstock

Medagoda and Chandrarathna (2007, 151) reported only 45% and 25% successful grafting when breadfruit was grafted on 30-day old and 60-day old chataigne rootstocks, respectively compared with 83% success on 45-day old rootstocks and suggested that the significant differences were due to the relative maturity of the rootstocks. However, the results of this present study, with rootstock ages at the time of grafting ranging from 42 to 126 days, did not indicate that this factor significantly influenced successful grafting of these two species. It showed that an average success rate of 51 % could be achieved on the range of rootstock ages that was used.

Nandwani and Kuniyuki (2005, 308) obtained a success rate of 80% with 1-year old breadfruit rootstock and scion materials of different cultivars but did not evaluate the effect of rootstock age. Some studies on grafting jackfruit cultivars showed that the success rate declined as root stock age increased (Aralikatti 2005, 26; Mannan et al. 2006, 77). The variable responses of breadfruit and chataigne grafting to rootstock age may be influenced by other factors. Hartmann et al. (2011, 429) state that scion cultivar, physiology of stock and scion, season of grafting or a combination of these are other factors that determine grafting success.

Cultivar

Variable levels of grafting success were achieved in Experiments 2 to 6 in response to the scion genotype. The overall success rates were highest for chataigne and ‘White’ breadfruit, intermediate for ‘JA1’ and lowest for ‘Yellow’ breadfruit. The high percentage success with chataigne scions was expected because of the genotypic similarity with the rootstock and where success rates were low, other factors discussed above, such as season of scion collection and grafting, maturity of the scion wood and the post-grafting environment, either singly or in combination, were more influential than genotype. Differences in success rates among breadfruit cultivars also strongly suggest genotypic differences in the ability to tolerate less than ideal requirements for these other factors. The longevity of the graft unions and high level of long-term survival of grafted plants (> 90 %) obtained in Experiment 5 clearly demonstrated that high levels of success can be achieved by all breadfruit cultivars evaluated in this study.

Season of grafting

The time of year when jackfruit was grafted was found to be significant. In India, Selvi et al. (2008, 342) reported October was the best month for grafting jackfruit, while Kelaskar et al. (1993, 113) reported that February was the best. The former study corresponded with the rainy season. In this study there were also clear seasonal effects on the rate of success of breadfruit on chataigne stock with the longest survival achieved when scion material was collected and grafted during the wet season of Experiments 2 and 5 (Tables 2 and 4) than during the dry season of Experiments 4 and 6 (Tables 3 and 4). Selvi et al. (2008, 342) found a positive correlation between relative humidity and the grafting success rate in jackfruit and attributed these results to the presence of higher levels of endogenous hormones in the scion that promoted grafting at this time of year.

The season of scion collection and grafting apparently affected the physiological status and morphology of the scion in this study. The scion wood was greener and elongated more rapidly during the wet season, whereas elongation was slower and thicker and lignified stems developed earlier in the dry season. Experiment 2 and the study by Medagoda and Chandrarathna (2007, 150) demonstrated that scion wood from mature breadfruit trees could be grafted successfully if harvested when the trees were exhibiting only vegetative growth after bearing. It can be suggested that scion material collected from parent plants in a vegetative state would have adequate supply storage of carbohydrates, since there are no competing sinks. The importance of the quality of the scion material in terms of its physiological status is indicated further by the difference between Experiment 2 and Experiment 5 in the percentage of successful grafts that survived the hardening period. Scion material was taken from mature trees in Experiment 2 where the average percentage survival was 51% (Fig. 1), whereas with scion from juvenile suckers in Experiment 5, more than 80% (Fig. 6) of the grafts survived in the long-term. Although, similar scion sources were used in Experiments 5 and 6, the duration of graft survival and ultimately, the success rate were significantly lower in the latter experiment, which emphasised the importance of the season of scion collection even from juvenile plants.

Scion quality

In the context of this study the quality of the scion material referred to its suitability in terms of its apparent morphological and physiological status, or both, for use in achieving a good quality graft union. While this factor was not evaluated directly, it appeared to emerge as an important factor in determining successful grafting in breadfruit and chataigne.

There were two types of breadfruit scion material used, which were epicormic shoots from mature trees and axillary shoots from juvenile plants and both achieved high rates of grafting success (Tables 2 and 4), respectively. However, there was a difference between Experiment 2 and Experiment 5 in the percentage of successful grafts that survived the hardening period. This might be explained by the use of scion material collected from mature trees, which had thicker diameters than the rootstock. Additionally, using this type of scion material might have contributed to the toppling and eventual death, stated previously.

On the other hand, the scion material collected from juvenile plants produced shoots that were similar in diameter to the rootstock. Therefore, it could be suggested that the quality of the scion is a factor that influences grafting success, since mismatched scion and rootstock graft unions can lead to incompatibility (Andrews and Marquez 1993, 195). This was observed in Experiment 2. Furthermore, the manipulation for and collection of scion material from mature trees is not sustainable, since this type of material is sourced from the lower branches and, therefore, the quantities needed cannot be supplied in a commercial type propagation system.

Post-grafting environment

Post-grafting environment was another factor that was not evaluated directly; however, it appeared to emerge as an important factor. Bose et al. (1986, 366) and Hartmann et al. (2011, 430) both stated that optimum temperatures between 26 and 29°C and relative humidity above 80% were favourable for the graft union healing process. In Experiments 2, 3 and 4 of this study, an average midday temperature of 29°C was observed in the post-graft environment, while a mean temperature of 24°C was observed for Experiments 5 and 6. Among these experiments, varying levels of successful grafting were achieved, with low reported success in Experiments 3 and 4 (Table 3) and high success in Experiments 2 and 5. These varying results could be explained by the manner in which the RH of the grafted plants were maintained. Although RH was high for the grafted scion in all experiments, the RH of the stock was not maintained in Experiments 3 and 4 when compared with those of Experiments 2 and 5, where RH was maintained for the entire grafted plants. This observation indicates that RH of the entire grafted plant is an important factor in grafting breadfruit on chataigne stock. This is further emphasised by the observation of grafted plants of Experiment 4 that were placed in a propagation bin for the purpose of increasing RH of the entire grafted plant. Due to malfunctioning of the intermittent misting system that caused drying out of the stock and medium, success rate was low.

On the other hand, the results of Experiment 6 of this study showed that even though RH of the entire grafted plant was maintained above 95%, low grafting success was achieved (Table 4). This could be explained by poor quality scion (thicker diameter indicative of slower growth) which resulted from the usually dry period during scion development prior collection (Fig. 9). Hence, the results of these experiments show that in addition to the post-grafting conditions of temperature

(24°C to 29°C) and RH (above 90%) suitable quality scion material was also important.

Conclusion

This study demonstrated that attempts at grafting breadfruit scion on chataigne rootstock could produce variable success rates because several key factors were involved. Rootstocks of any age ranging from 7 to 19 weeks old and any of the grafting techniques evaluated might be used successfully; however, due to its relative ease, the top wedge method might be preferred. The season of scion collection was a very significant factor influencing grafting success because, in addition to the maturity of the scion wood, it affected the quality of the scion in terms of rate of elongation, lignification of the stem, stem diameter and endogenous growth regulators. High levels of grafting success were obtained with all breadfruit cultivars grafted on chataigne but differences among cultivars might reflect differing levels of requirement for scion quality and the post-harvest environment. Although, not directly evaluated, post-grafting conditions for the entire plant of very high relative humidity, with high shade and moderately high diurnal temperatures may be most suitable. Therefore, the recommended protocol for grafting the selected breadfruit cultivars on chataigne rootstock will require using suitable quality scion material, harvested from juvenile mother plants, during wet season, matched with stock of similar diameter and post grafting environmental conditions of 24°C to 29°C and RH above 90% to minimize water loss from both stock and scion.

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