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Short communication

Influence of grafting and rootstock on root traits, growth and cyclone-induced plant damage in sugar apple in eastern coastal region of India

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ABSTRACT

Studies were conducted to assess the impact of grafting approach and rootstock on root traits, plant growth, leaf nutrient status, yield and cyclone-induced plant damage in sugar apple during 2014-19. *In situ* and *ex situ* grafting of sugar apple was done on *A. squamosa* and *A. reticulata* rootstock and their performance was assessed on various parameters. Well-developed root system in terms of spread, tap root length, proportion of primary and secondary roots, root/shoot ratio (0.29) and enhanced trunk cross sectional area, leaf area (30.69 cm^2), total chlorophyll content (3.07 mg/g), leaf nutrient content and fruit yield were recorded in *in situ* grafted plants having *A. squamosa* rootstock. Sugar apple exhibited stionic compatibility with its own rootstock, whereas it was incompatible with *A. reticulata*, as it was evidenced from poor growth of root system and above ground plant parts. When cyclone-induced plant damage (*Fani* cyclone) was taken in account it was observed that *in situ* composite plant grafted on its own rootstock exhibited substantially low intensity of plant damage with markedly low percentage of severely damaged plants (1.2%). On the other hand *ex-situ* grafted plants were severely damaged by cyclone (21.7%). Correlation studies indicated that deep root system possessed by *in situ* grafted plants was instrumental not only in minimising cyclone-induced plant damage, but also in improving leaf nutrient status, plant growth and yield.

Key words*:* *Annona squamosa*, *A. reticulata*, *in situ* grafting, stionic compatibility*,* cyclone.

Annona is the most important genus of family Annonaceae having more than 110 species. Among them, *A. squamosa* (sweet apple, sweetsop, sitaphal), *A. reticulata* (bullock's heart, ramphal), *A. cherimola* (cherimoya, lakshmanphal), *A. atemoya* (hanumanphal) and *A. muricata* (soursop) are commercially important species. In India *A. squamosa* is one of the important tropical fruit crops which is cultivated in more than 46000 hectare area with the production of 4.0 lakh MT ha (Anonymous, 2). It is cultivated mainly in Maharashtra, Chhattisgarh, Gujarat, Madhya Pradesh, Karnataka and Andhra Pradesh. *A. squamosa* is commonly propagated through *ex-situ* grafting by using ramphal (*A. reticulata*) or sitaphal (*A. squamosa*) as rootstock. However, it is also propagated through seeds in some parts of tropical regions of India. Fruit availability of sitaphal and ramphal differs temporally as former is available during July – October, while later during February – March (Awachare *et al*., 4). Root system of plants is much more dynamic in form than their shoots. The crucial role played by root systems in influencing plant growth, stability and survival has become an important area of research in horticultural crops. In perennial fruit crops composite plants (root stock and scion) have been used for many years to understand the communication between root and shoot. Rootstock selection offers a powerful tool for the sustainable intensification of fruit production as it addresses challenges of abiotic and biotic stresses under varied climatic conditions (Marguerit *et al*., 11).

Impact of rootstock on nutrient uptake, dwarfness, canopy architecture, flowering, yield, fruit quality and tolerance against viral and soil borne diseases has been studied in various species of fruit crops (Amiri *et al*., 1, Martinez *et al*., 12, Li *et al*., 10). Root activities in terms of spatial and temporal distribution have also been studied (Kotur, 9). However, unlike the other primary functions, relatively little attention has been paid to the mechanical role of root system in plant anchorage and ability to withstand lateral force such as wind.

Despite substantial advancement in production technology, natural calamity like cyclonic storms pose severe threat to production potential of perennial fruit crops particularly in eastern coastal region of India. Severity of crop damage of *A. squamosa* during cyclonic storms clearly indicated that poor anchorage of plants was a major source of economic loss to growers. Hence scientific approaches are required to strengthen root system of sitaphal in order to enable them to tolerate lateral force particularly in cyclone-prone eastern coastal region of India. In this background, grafting approaches were assessed to

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study the root traits and to minimize the crop loss under the influence of cyclonic winds.

A field experiment was conducted to assess the influence of grafting and rootstocks at the research farm of Central Horticultural Experiment Station (ICAR-IIHR), Bhubaneswar (latitude: 20° 27' N, longitude: 85° 82' E, altitude: 45 masl) during 2014-2019. Soil of the research plot was moderately deep (depth 1.2m), sandy loam in texture and highly acidic (pH 5.3). Experimental plot had moderate content of organic carbon (0.6%), N and K and low content of P. The experiment was laid out in randomized block design with two rootstocks (*A. squamosa* and *A. reticulata*) and two grafting techniques namely *in situ* and *ex situ* (in nursery) and *A. squamosa* var. Arka Neelachal Vikram was taken as a scion. There were four treatments: T1 – *in situ* grafting on *A. squamosa* rootstock; T2 – *ex situ* grafting *A. squamosa* rootstock; T3 - *in situ* grafting on *A. reticulata* rootstock and T4 - *ex situ* grafting on *A. reticulata* rootstock. For *in situ* grafting, both the rootstocks were raised directly in the field, whereas rootstocks were raised in polybags for *ex-situ* grafting. *In situ* and *ex-situ* grafting (wedge method) of sugar apple var. Arka Neelachal Vikram was done on 6 months old seedlings (dia. 8-9 mm) of rootstocks at the height of 15 cm. Grafting was done in February and August on *A. squamosa* and *A. reticulata* rootstock, respectively. There were 100 plants under each treatment. Observation on days to sprouting and graft success was recorded. Four-month-old successful *ex-situ* grafts were planted in the field and their performance was compared with *in-situ* grafts in terms of vegetative growth, root traits, intensity of plant damage due to cyclonic wind, leaf nutrient status, leaf area, leaf chlorophyll content, yield and fruit quality.

Root traits were studied under different treatments through destructive method and Growth parameter was studied in terms of trunk cross sectional area (TCSA). Initially trunk circumference was measured and radius was calculated. TCSA was worked out by using the formula πr^2 considering the cross-sectional area of trunk as a circle and expressed in cm^2. Plant volume was worked out with the help of plant height, canopy spread and canopy height ($V = \pi/6 \times H \times Cs \times Ch$) and expressed in square meter (Zekri, 16). Leaf area was worked out following the formula suggested by Demirsoy *et al* (6), whereas leaf chlorophyll content under different treatments was estimated spectrophotometrically and expressed in mg/g (Arnon, 3). For leaf nutrient analysis 25 fully expanded and recently matured leaves were collected from non-flowering terminal shoots and their nutrient status was determined. Samples were analyzed for N, P, K, Ca, Mg, Cu and Zn. Yield parameters were recorded in terms of number of fruits/plant and fruit weight. Plant damage was categorized on the basis of intensity of damage viz. partial, moderate and severe. Partially damaged plants exhibited lodging of above-ground parts with fully intact root system and high probability of recovery, whereas moderately damaged plants had partially damaged root system (≤25%) with fair chance of recovery. On the other hand severely damaged plants had fully damaged root system with no chance of recovery. Data on growth parameters, root characters, leaf nutrient content, yield characters and plant damage were recorded under different treatments and their means were compared following ANOVA method. The correlation between variables was worked out by partial correlation method and the test of significance was considered at 5% and 1% levels of probability.

Grafting approach and rootstock exhibited significant influence on graft success and growth of composite plants (Table 1). Early sprouting and higher graft success were recorded when *A. squamosa* was used as a rootstock. However moderately higher graft success was also observed with *A. reticulata* rootstock. In was also evident that graft success under *in-situ* condition was also appreciably high, irrespective of rootstock. It may be interpreted that both the rootstocks could facilitate speedy regeneration of vascular tissues under both the grafting approaches. It is also quite apparent from data that in comparison to *A. reticulata*, *A. squamosa* facilitated better growth in plants with the substantial increase in TCSA (> 2.5 times) and leaf area (more than 30%) which indicates better graft compatibility (Fig. 1a). However *in situ* grafted plants exhibited better growth than *ex-situ*. On the other hand, *A. reticulata* could not promote growth in grafted plants with desired pace possibly due to incompatibility (Fig. 1b). When total chlorophyll content (TCC) in leaves was measured, it was evident that *A. squamosa* rootstock contributed substantially in leaf chlorophyll content. However, maximum level of TCC was observed under *in situ* grafting condition. There TCC content in leaves was significantly low when *A. reticulata* was used as a rootstock. When graft region was examined, it was evident that, *A. reticulata* was poorly compatible rootstock for *A. squamosa* (Fig. 1b). The structural integrity of the graft union not only holds the grafted plant together but also ensures physiological activities. However it is the restoration of anatomical and functional continuity between vascular tissues such as xylem and phloem that facilitates translocation of water, minerals and carbohydrates and in turn ensures development and plant growth (Melnyk, 13).

Table 1. Influence of grafting and rootstock on graft success and growth of *A. squamosa.*

Treatments	Days to sprouting	Graft success (%)	TCSA (cm^2)	Leaf area (cm^2)	Total Chl. content (mg/g)
T1 - *in situ* grafting on *A. squamosa* rootstock	8.2^c	89.8^b	52.78^a	30.69^a	3.073^a
T2 - *ex situ* grafting on *A. squamosa* rootstock	7.8^c	92.4^a	42.92^b	27.02^b	2.455^b
T3 - *in situ* grafting on *A. reticulata* rootstock	10.3^b	85.6^c	16.78^c	22.22^c	1.542^c
T4 - *ex situ* grafting on *A. reticulata* rootstock	11.8^a	87.7^b	14.51^d	20.96^c	1.315^d
CD (0.05)	0.77	3.85	2.15	0.73	0.13
CV	5.10	2.71	4.25	1.81	5.11

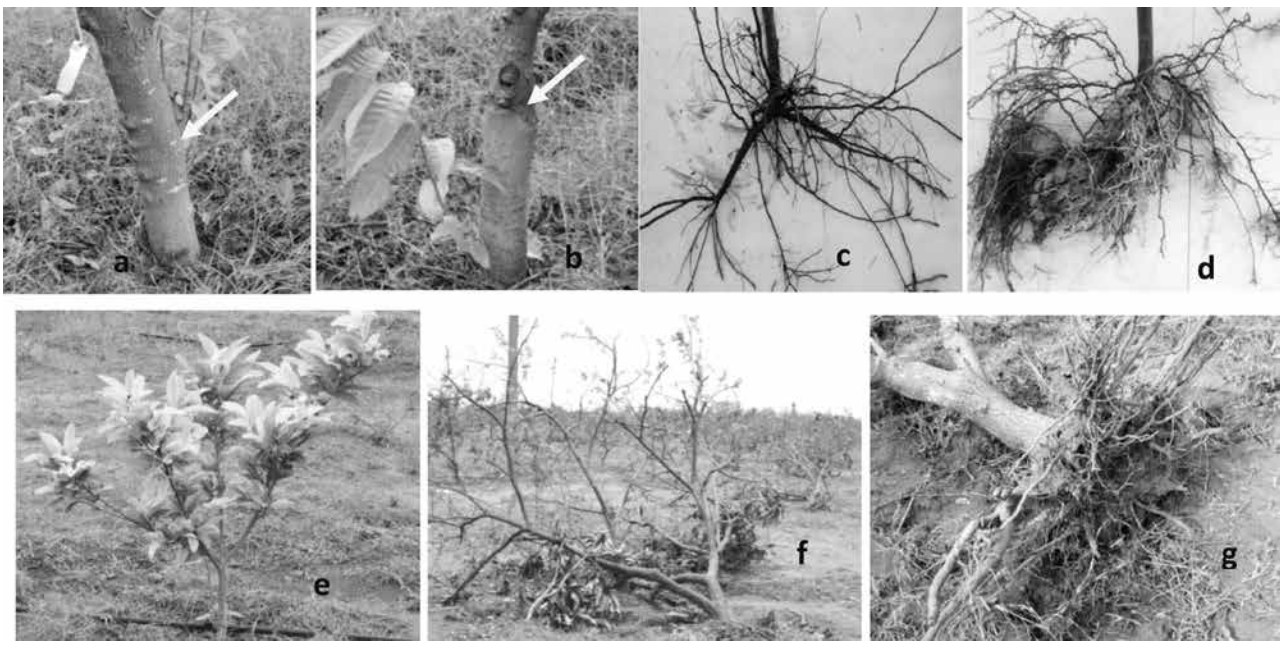

Fig. 1. Stionic compatability, root system and cyclone-induced plant damage in *A. squamosa.*

a. graft compatibility between *A. squamosa* and *A. squamosa* (R/S); b. graft incompatibility between *A. squamosa* and *A. reticulata* (R/S); c. root system of *in situ* grafted plants with *A. squamosa* rootstock; d. root system of *in situ* grafted plants with *A. reticulata* rootstock; e. nutrient deficiency exhibited by *A. squamosa* when grafted on *A. reticulata,* f. severe plant damage of *ex situ* grafted custard apple due to *Fani* cyclone, g. shallow root system of *ex situ* grafted plants.

Root traits were studied in three-year-old plants through destructive method. Rootstocks and grafting approaches exhibited significant influence on root traits and root/shoot ratio (Table 2). There was a marked difference in the root system of both the rootstocks. *In situ* grafted *A. squamosa* had well developed extended root system with deep tap root and high proportion of primary and secondary roots (Fig. 1a), whereas *A. reticulata* was characterized by shallow root system with high proportion of fibrous roots (Fig. 1b). Moreover it also had limited root spread and moderate proportion of primary and secondary roots. Impact of grafting approach on root system was evident as *in-situ* grafted plants had better root system than *ex-situ* grafted plants. Significantly higher plant volume as well as optimized root/shoot ratio were recorded when *A. squamosa* was grafted *in situ* on its own rootstock. On the other hand, *A. reticulata* rootstock exhibited poor plant growth and higher root/shoot ratio. Such situation indicates disproportionate root and shoot growth and in turn stionic incompatibility (Fig. 1b). Whereas *A. squamosa* exhibited balance growth between root and shoot and thus acted as a compatible rootstock (Fig. 1a). The result is in contrary to the findings of Heenkenda *et al.* (8) who reported that scion species of *Annona* on its own rootstock was not the best combination. Tap root and lateral roots

Table 2. Influence of grafting and rootstock on root traits and root/shoot ratio

Treatments	Root length (cm)	Tap root (cm)	Primary root (%)	Secondary root (%)	Tertiary root (%)	Plant volume (m^2)	Root/shoot ratio (w/w)
T1	81.6[a]	63.8[a]	60.1[a]	36.3[a]	3.6[d]	0.94[a]	0.29[b]
T2	71.9[b]	43.7[b]	55.4[b]	33.7[b]	10.9[c]	0.87[b]	0.33[c]
T3	57.4[c]	35.4[c]	54.8[b]	30.8[c]	14.4[b]	0.28[c]	0.37[a]
T4	54.7[d]	33.7[d]	51.9[c]	29.7[c]	18.4[a]	0.24	0.38[a]
CD (0.05)	5.71	3.27	2.58	2.28	1.35	0.03	0.03
CV	5.59	4.68	2.90	4.38	7.16	3.71	4.76

are most important tool for plant anchorage. Plants with thicker and longer tap roots are better anchored due to their bending rigidity and resistance to lateral movement through soil, whereas lateral roots and their interaction contribute significantly to anchorage which might potentially enable manipulation of belowground environment to enhance anchorage (Bailey *et al*., 5).

Leaf nutrient content was significantly influenced by rootstocks and grafting approaches (Table 3). There was a substantial increase in the leaf nutrient content of macronutrients (N, P, K, Ca, Mg and S) as well as micronutrients (Fe, Zn, Mn and Cu) when *in situ* grafting was done on *A. squamosa.* On the other hand, relatively low leaf nutrient content was recorded with *A. reticulata* rootstock. Plants grafted on *A. reticulata* exhibited multiple nutrient deficiencies such as N, Mg, Zn and Fe (Fig. 1d). Nutrient deficiency in *A. reticulata* rootstock was possibly due to stionic incompatibility which could have restricted the transportation of nutrients in above ground plant parts. Rootstock and grafting approach significantly influenced fruiting behaviour, fruit yield and fruit quality (Table 4). Precocity in bearing and high yield were recorded in *in situ* grafted plants with *A. squamosa* rootstock, whereas, e*x-situ* grafted plants with *A. squamosa* rootstock gave moderate yield. Minimum yield was obtained with *A. reticulata* rootstock irrespective of grafting approach. Fruit quality was assessed in terms of TSS and it was observed that *in situ* grafted plants with *A. squamosa* as a rootstock, exhibited high TSS than *ex situ* grafted plants, whereas, lower TSS was recorded with *A. reticulata* rootstock (Table 4). Root system architecture, the overall spatial arrangement of the root system, is an important factor determining how efficiently plants can access resources. Root system having a balance between deep root and top soil foraging roots is considered ideal for acquisition of highly mobile and immobile nutrients (Shahzad and Amatmann, 15). *In situ* grafting approach facilitates better root system architecture in plants and thus ensures efficient absorption of nutrients.

Impact of extremely severe cyclone *Fani* (wind speed >200 km/hr) on plant damage of custard apple was assessed under different grafting approaches (Fig. 2). There was a marked difference in the intensity of damage between *in situ* and *ex situ* grafted plants. Maximum plant damage with the maximum proportion of severely damaged plants was observed in *ex-situ* grafted plants (Fig. 1f). When root systems of cyclone-induced severely damaged plants were studied it was evident that they had shallow root system, which was the major reason for severe plant damage (Fig. 1g). On the other hand, *in-situ* grafted plants not only exhibited low intensity of plant damage but also substantially low proportion of severely damaged plants. However these plants were partially damaged which recovered easily. The intensity of damage was relatively low in *A. reticulata* rootstock since plant

Table 3. Influence of grafting and rootstock on leaf nutrient status.

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
T1	3.64	0.19	1.62	2.27	0.41	0.21	112.7	18.7	344.8	26.4
T2	3.12	0.17	1.23	1.97	0.29	0.18	87.9	15.9	311.6	20.6
T3	2.73	0.11	0.95	0.87	0.15	0.14	38.1	11.2	218.7	12.3
T4	2.24	0.11	0.82	0.79	0.14	0.14	39.5	11.9	198.4	8.9
CD (0.05)	0.12	0.02	0.15	0.10	0.08	0.02	3.83	2.41	11.97	3.12
CV	2.65	9.73	8.10	4.29	21.77	10.95	3.40	10.59	2.79	11.35

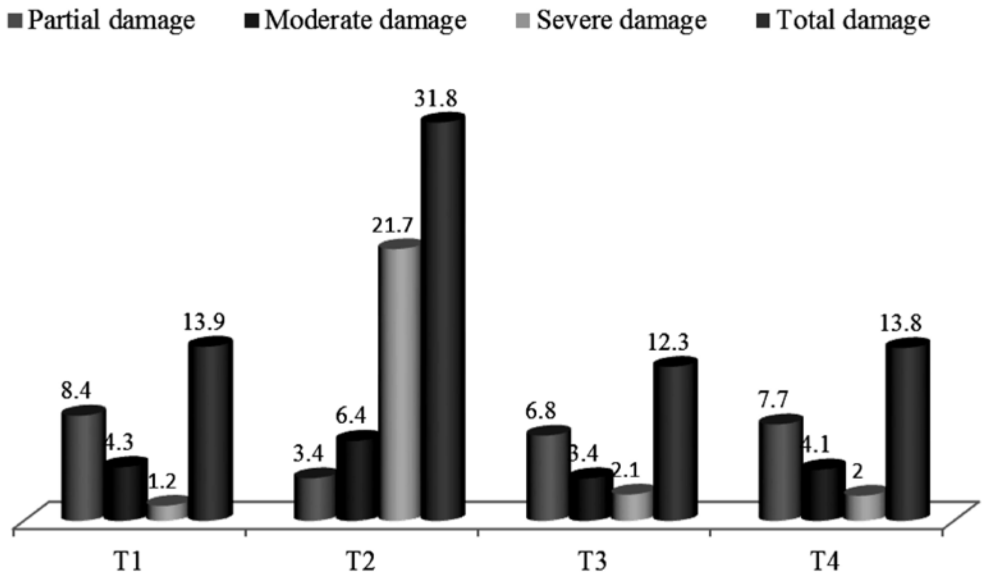

Fig. 2. Influence of grafting and root stock on crop damage due to *Fani* cyclone.

Table 4. Influence of grafting and root stock on yield and quality of custard apple.

Treatments	First fruiting	No. of fruits/plant	Yield/ plant (kg)	TSS (°B)
T1	2nd year	34.7[a]	6.8[a]	23.6[a]
T2	3rd year	23.4[b]	4.5[b]	22.7[b]
T3	3rd year	8.2[c]	1.2[c]	20.9[c]
T4	3rd year	7.3[c]	1.1[c]	20.4[c]
CD (0.05)	-	3.49	0.80	0.82
CV	-	11.91	14.80	2.34

growth was markedly poor. Meteorological conditions, site, topography and tree characteristics are major factors influencing the intensity of storm damage in perennial trees. Among them meteorological conditions as well as tree characteristics are dynamic behaviour. Cyclonic storm is considered as one of the major sources of mechanical loading on plants which, in turn, has a major impact on plant growth and crop yield. It is evident that wind–tree interactions take place at a wide range of temporal and spatial scales and aerodynamic drag at aerial parts of trees causes plant damage. However plant canopy plays vital role in minimizing the impact of aerodynamic drag (Gardiner *et al*., 7, Schindler *et al*., 14).

Correlation among various attributes indicated that root traits had significant correlation with growth, leaf nutrient status, yield and cyclone-induced plant damage. Root length was positively and significantly correlated with TCSA (r= 0.958*), plant volume (r= 0.979**), leaf area (r= 0.948*), total chlorophyll content (r=0.972**), fruit yield (r= 0.945*) and macro and micro nutrient content in leaves. However root length was negatively and significantly correlated with the intensity of damage (r= -0.978**). Similar results were obtained when tap root length and proportion of primary and secondary roots was taken into account. When root and shoot ratio was correlated with other traits it was evident that plant growth (TCSA), plant volume, fruit yield was negatively correlated. Studies clearly indicated that deep root system developed in *in situ* grafted plants was not only facilitated better growth, high leaf nutrient content and yield but also reduced cyclone –induced plant damage by providing better anchor to plants.

In spite of the substantial success achieved in horticulture sector, several constraints still exist. Among them minimization in the impact of natural calamities especially cyclone on plant and crop damage has been a great challenge particularly in eastern coastal region of India. *In situ* grafting approach was found effective in improving root system, acquisition of nutrients, plant growth, fruit yield and most importantly better anchor to plants and substantial reduction in cyclone – induced plant damage of sugar apple. Considering the frequency of occurrence of severe tropical cyclones in this region, *in situ* grafting approach could be instrumental in lowering the impact of cyclones as well as the economic loss of farming community. However impact of tree architecture and geometry on cyclone-induced plant damage will be an important area of future research in cyclone-prone regions of India.

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