Indian Journal of Ecology (2023) 50(5) (SI): 1688-1694
DOI: https://doi.org/10.55362/IJE/2023/4119

Manuscript Number: 4119
NAAS Rating: 5.79

Nursery Performance of different Pear Cultivars on Quince Rootstocks under Sub-temperate Zone of India

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***Abstract*:** Intact stature of plant is basic requirement for any high-density plantation system which can effectively be induced by the use of dwarfing rootstock. In pear, quince rootstocks impart dwarfness; however, it may also result in graft failure due to graft incompatibility. Therefore, morphological and physiological evaluation of pear cultivars including Carmen, Concorde, Red Bartlett and Packham's Triumph on three quince rootstocks (Quince A, BA 29, Quince C) and Kainth was carried out in the northwestern Himalayan region of India. All stionic combinations exhibited successful graft union formation after one year with substantial variations in morphological parameters. Graft success ranged from 61.14 to 90.00% with the highest registered by Carmen grafted on Kainth and Quince A combinations. Plants grafted on Quince A attained maximum mean height while minimum height was acquired by plants on Quince C rootstock. Further, the maximum plant height (95.15 cm), shoot length (74.96 cm), rootstock diameter (10.34 mm), bark thickness (2.02 mm) and wood thickness (7.27 mm) was recorded in plants of Carmen/Quince A stionic combination. Most dwarf and compact plants were obtained in stionic combination of Red Bartlett over Quince C which suggests the suitability of this combination in high density planting system. Graft success was correlated positively with plant height and negatively with graft union diameter. However, further studies are required to validate the long-term efficiency of this rootstock on tree growth, fruit yield and quality characteristics.

***Keywords*:** Quince, Scion-stock, Grafting, Dwarf rootstock, Graft take success

Pear is gaining acceptability and importance worldwide owing to its delicious taste and high nutritional value. Pear cultivation represents a significant market potential for producers. In India, pear cultivars like Bartlett, Conference and Patharnakh are mainly cultivated in hilly sub-temperate to temperate regions. Consumer preference is, however, increasing towards coloured varieties such as Red Bartlett and Carmen; and other European cultivars including Concorde and Packham's Triumph. Carmen (Guyot×Bella di Giugno) is an early bearing pear cultivar with a high yielding capacity and attractive red peel on maturity. The fruits ripen two weeks earlier and have better shelf-life than the Bartlett pears (Ingels 2016), while cultivar Concorde (Conference×Doyenne du Comice) and Packham's Triumph (Uvedale's St. Germain×Williams's) are late-season cultivars having green coloured fruits with the yellow and creamy coloured pulp, respectively (Quinet and Wesel et al 2019). These cultivars were introduced in India in the recent past and the demand for their planting material is escalating as a consequence of better shelf life, attractive shape and fruit colour leading to the high market price. The selection of quality planting material is the foremost requirement of any orchard enterprise.

In India, old plantations of pear are under a conventional low-density planting system which is responsible for its lower productivity in spite of favorable meteorological conditions and the hardy nature of this crop. In the last decades, there has been a tremendous increase towards using grafted/budded plants for orchards. Traditionally, pear plants were raised on Kainth (*Pyrus pashia*) rootstock; however, now-a-days high density orcharding is possible due to availability of different size controlling clonal rootstocks including Quince, 'Old Home' 'Farmingdale' (OHF), Fox and Pyrodwarf (Abdollahi and Hassani 2021). Dwarf plants are easy to maintain and harvest and these plants harness maximum sunlight and produce fruits of superior quality. Rootstocks influence tree morphological parameters like tree growth and vigour, precocity, productivity, and nutrient absorption (Khadivi-Khub and Anjam 2016) and scion also exerts a reciprocal effect on rootstock.

Quince has been proven to induce precocity, improve the productivity and quality of some European pears (Stern et al 2013, Donadio et al 2019), however; prior studies have shown that it exhibits incompatibility with some pear cultivars (Santos-Pereira et al 2021). Incompatibility is the abnormal development of the graft that usually occurs while grafting rootstock and scion from different genera or species. The suitability of rootstocks may vary from region to region due to

prevailing varied climatic conditions. Hence, the selection of rootstock should be made based on the conditions of the region where the orchard is to be established and the cultural practices to be followed (Machado et al 2018). Limited information is available on the impact of Quince rootstocks on newly introduced pear cultivars in the northwestern Himalayan region. Therefore, the study was carried out to check the suitability and determine the effect of the growth and development characteristics of nursery plants of Quince rootstocks on cultivars Carmen, Concorde, Packham's Triumph and Red Bartlett in nursery.

MATERIAL AND METHODS

The study was conducted at Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India (30° 51'N; 77° 88'E; 1300 m amsl) during the year 2018. The climate of this region is sub-temperate with moderate summers and distinct winters. Soil pH and electrical conductivity of the experimental location were 6.8 and 0.32 dSm^{-1}, respectively. Raised nursery beds (3×1 m) were prepared after leveling the surface and one-year-old rootstocks including Quince A, BA 29, Quince C and Kainth were planted with a spacing of 25×20 cm during the last week of December 2018. Bed planting was done in three rows and every row contained ten plants. After proper establishment, these rootstocks were grafted with one year old scion of different cultivars *viz*., 'Carmen', 'Concorde', 'Packham's Triumph' and 'Red Bartlett' at the height of about 15 cm above ground level by using tongue grafting method during the first week of February 2019. The plants were subjected to uniform cultural practices such as mulching, irrigation, de-shooting, weeding and spraying of insecticides and fungicides, which were carried out as per standard practices. The experiment was a randomized complete block with three replications and ten plants per replication. Observations related to morphological parameters such as graft take success, plant height, shoot length, diameter of rootstock, scion and graft union, leaf area, number of stomata, size of stomata, dry weight of root and shoot, root length, wood and bark thickness were recorded at the end of growing season. In order to judge the incompatibility symptoms, overgrowth above and below was observed visually. Data was processed using SAS package (9.3 SAS Institute, Inc, USA). Analysis of variance was carried out with Tukey's HSD for statistical analyses.

RESULTS AND DISCUSSION

Graft take success, plant height and shoot length: Different rootstocks had a significant effect on the graft take success, with maximum value in plants grafted on Kainth rootstock (95.67%), followed by Quince A (91.67%) rootstock. Minimum graft take success to the tune of 81.67% was recorded on Quince C rootstock (Fig. 1). The impact of different cultivars on graft take success was also statistically significant. Cultivar Carmen recorded graft take success of 95.83%, which was significantly higher than all the other cultivars tested, while cv. Red Bartlett had the minimum success (85.83%). The interactions between the rootstocks and scion cultivars were also significant. Cultivar Carmen grafted on Kainth and Quince A rootstocks were superior over all the stionic combinations and recorded the highest graft take success (100%), which was followed by Red Bartlett grafted on Kainth (96.67%). Maximum dwarfing effect was induced by Quince C which suppressed the plant height and shoot length by 22.19% and 29.15%, respectively, in comparison to Quince A. However, with respect to Kainth the reduction in plant height and shoot length on Quince C rootstock was 14.94 and 26.73%, respectively. Considering the cultivars, Carmen registered the maximum plant height and shoot length, followed by Packham's Triumph. Minimum growth was in Red Bartlett showing a reduction of 24.56% plant height and 45.32% shoot length in comparison to Carmen. Among various stionic combinations, the maximum plant height (95.15 cm) and shoot length (74.96 cm) was in plants of Carmen grafted on Quince A rootstock, followed by plants of cultivar Packham's Triumph grafted on Quince A rootstock. However, the lowest plant height (49.34 cm) and shoot length (29.38 cm) were in the plants of cultivar Red Bartlett grafted on Quince C rootstock. Plant height of stionic combination Red Bartlett on Quince C was statistically at par with Red Bartlett on Quince A, while shoot length was found at par with Red Bartlett grafted on BA 29 and Quince A rootstock (Table 1). Higher plant height and shoot growth of Carmen on Quince A and Kainth rootstock might be attributed to high vigour potential of these rootstocks and scions. Differences in plant height could be due to the effect of different levels and proportions of auxin and cytokinin found in the apical meristem of pear varieties (Rahman et al 2017).

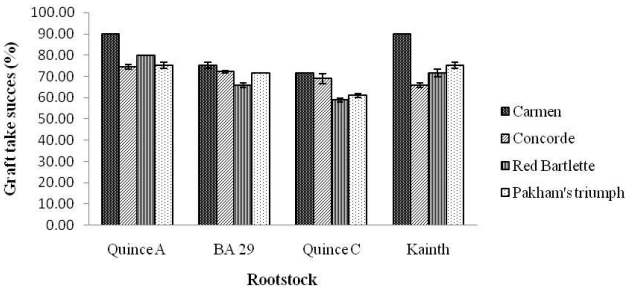

Fig. 1. Influence of different rootstocks and scion combinations on graft take success (%)

Scion, stock and graft union diameter: Growth variations at scion, stock and graft union were reported in all the stionic combinations, with a maximum diameter at the point of graft union followed by rootstock which was measured 5 cm below the graft union and lowest on the scion portion of the plant. Evaluating the rootstocks, plants on Quince A had 20.93 and 11.87% higher rootstock diameter and scion diameter, respectively, than plants on Quince C. However, the graft union diameter was reported maximum in Quince C and BA 29; and was approximately 25.92 and 6.46% greater in comparison to Kainth and Quince A rootstocks, respectively. Considerable effects of scion cultivar on rootstock diameter, scion and graft union diameter were also detected. Scion cultivars brought about smaller changes in rootstock diameter with maximum variation of ~6.40%, whereas the scion diameter was 33.22% higher for Carmen in comparison to Concorde. Cultivar Red Bartlett attained maximum graft union diameter (13.31 mm), which was 13.60% more than Packham's Triumph. In different stionic combinations, the rootstock diameter ranges from 7.18 mm (Concorde on Quince C) to 10.34 mm (Carmen on Quince A), while the scion diameter varied from 5.18 mm (Concorde on BA 29) to 9.95 mm (Carmen on Quince A) and the graft union diameter fluctuated from 9.61 mm (Concorde on Kainth) to 14.72 mm (Red Bartlett on Quince C) (Table 1). The vigorous growth of Carmen on Quince A rootstock might have accounted for higher scion and rootstock diameter. Bartlett has been reported as incompatible with Quince C rootstock (Habibi et al 2022), the higher graft union diameter of Bartlett on Quince C in the present study may be due to poor graft union formation. Machado et al (2015) associated greater vigour with the compatibility in the grafting region, which is due to continuous flow between the conducting vessels of the rootstock and graft. Accumulation of metabolites, presumably phenols and carbohydrates, as a result of partial cambium continuity at the union could be attributed to increased stem diameter at the union (Mng'omba et al 2007). High levels of callus forming into the undifferentiated parenchymatous cells could also cause the union to swell. If the graft partners are of equal size, the scion tends to produce more callus tissue possibly due to increased basipetal transport of photosynthates (Adams 2016).

Leaf area, stomata density and size of stomata: Plants grafted on Quince A rootstock had significantly higher leaf area (16.99 cm^2) while the minimum leaf area was for Quince C rootstock which was 11.83% lower than on the Quince A

Table 1. Effect of different stionic combinations on plant height, shoot length, diameters of root, scion and on graft union

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Plant height (cm)	Quince A	95.15a	69.51cd	52.81ef	89.53a
	BA 29	75.52bc	65.03d	69.15cd	77.58b
	Quince C	68.41d	56.03e	49.34f	65.11d
	Kainth	76.82b	65.93d	67.02	71.05bcd
Shoot length (cm)	Quince A	74.96a	49.68ef	32.76gh	69.41b
	BA 29	56.13cd	46.19f	30.63h	58.05c
	Quince C	47.81ef	37.75g	29.38h	45.76f
	Kainth	57.08c	46.63ef	48.26ef	51.68de
Stock diameter (cm)	Quince A	10.34a	10.16ab	10.12ab	10.25ab
	BA 29	10.13ab	10.06ab	9.86ab	8.28cd
	Quince C	9.16bc	7.18d	8.23cd	7.79d
	Kainth	9.15bc	9.79ab	10.14ab	9.99ab
Scion diameter (cm)	Quince A	9.95a	5.52gh	7.97bcde	8.94ab
	BA 29	8.27bcd	5.177h	7.50cde	7.59cde
	Quince C	8.93ab	5.95gh	6.37fg	7.26def
	Kainth	8.49bc	7.17ef	7.90bcde	8.47bc
Graft union diameter (cm)	Quince A	12.80bc	12.54c	14.35ab	10.68d
	BA 29	13.54abc	13.49abc	14.07abc	12.70bc
	Quince C	13.49abc	12.59c	14.72a	13.03abc
	Kainth	10.60d	9.61d	10.09d	9.60d

Values in same column with different letters indicate statistically significant differences at $p \leq 0.05$

grafted plant. Among cultivars, Carmen had comparatively larger leaves and accounted 29.80% greater leaf area was observed in comparison to the Concorde cultivar having the lowest leaf area. The interactions between rootstock and scion have no significant effect on leaf area (Table 2). Ozturk and Ozturk (2014) reported that leaf area is directly proportional to the vigour of the rootstock and the leaf area ultimately influences the overall growth of the plant. It was observed that only cultivars exhibited a significant influence on stomata density as these are genetically governed characteristics of a species. Statistically higher numbers of stomata (253.44 per mm^2) were in plants of cultivar Carmen, while the other three cultivars including Red Bartlett, Concorde, and Packham's Triumph did not show much variation among each other. Likewise, the size of stomata was maximum in cultivar Carmen (496.67 μ^2) and the minimum size of stomata was observed in cultivar Concorde (376.03 μ^2) (Table 2). These results are in contrast with the findings of Dhillon et al (2008), Serra et al (2014) and Zhou et al (2020) where plants grafted on dwarf rootstocks have lower stomata density and size in comparison to vigorous ones.

Root length and dry weight percentage of roots and shoots Root length was precisely influenced by both scion, rootstock. However, interaction did not have a significant effect on root length (Table 2). Longest roots were depicted on the Quince A rootstock to the tune of 0.93 m, which was statistically at par with the Kainth rootstock (0.91 m), while the Quince C rootstock registered the minimum root length (0.76 m). Among cultivars, Carmen had the maximum root length of 0.93 m, which was approximately 15% higher than Red Bartlett. These results are in consonance with the findings of Harrison et al (2014). The dry weight of shoots was affected by the rootstock and the interaction between rootstock and scion (Table 3). Scion alone didn't contribute to dry matter accumulation in grafted pear plants. The dry matter content of shoots ranged from 48.88 to 63.45% in Red Bartlett on BA 29 and Carmen on Quince A, respectively. Among rootstocks, plants on Quince A had maximum dry matter (59.86%) followed by Kainth (56.06 %). However, dry matter accumulation in roots was affected by rootstock only with the maximum average percentage reported in Quince A (67.91%) and minimum in Quince C (64.82%). The impact of scion on root growth might be due to the hormonal make-up of a plant, which is governed by the scion cultivar. Significant variation in the ability of rootstocks for overall nutrient uptake and their partitioning causes a difference in dry matter accumulation in scion (Valvelri and Kalcsits 2021). The vigorous scion supplies more carbohydrates to the root system, hence positively influencing the root biomass and vice-versa (Valvelri et al 2019).

Bark and wood thickness: The influence of rootstocks on bark thickness was non-significant, but it had a substantial effect on wood thickness (Table 3). The maximum bark (1.79

Table 2. Influence of different stionic combinations on plant leaf area, number of stomata, size of stomata and root length

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Leaf area (cm^2)	Quince A	21.78a	15.28cdef	18.62abc	12.29fghi
	BA 29	20.59ab	14.53efg	17.97bcd	10.78hi
	Quince C	21.69a	14.72defg	17.68bcde	9.80i
	Kainth	18.23bc	13.22fgh	16.96cde	11.52ghi
Number of stomata (Per nm^2)	Quince A	252.50ab	207.30abc	217.71abc	230.84abc
	BA 29	250.42ab	208.34abc	200.42bc	215.00abc
	Quince C	264.59a	200.96bc	212.29abc	226.67abc
	Kainth	246.25abc	209.67abc	189.17c	218.75abc
Size of stomata (μ^2)	Quince A	582.13a	493.72a	331.48a	363.63a
	BA 29	532.60a	563.11a	408.65a	305.78a
	Quince C	444.96a	352.84a	400.65a	386.78a
	Kainth	427.00a	381.71a	537.24a	447.94a
Root length (m)	Quince A	1.00a	0.89cde	0.86def	0.95abc
	BA 29	0.89cde	0.77ghi	0.75hi	0.83defg
	Quince C	0.82efgh	0.74hi	0.70i	0.79fgh
	Kainth	0.99ab	0.88cde	0.85defg	0.92bcd

Values in same column with different letters indicate statistically significant differences at $p \leq 0.05$

mm) and wood thickness (6.04 mm) were in the plants grafted on Quince A rootstock and Kainth, respectively. However, minimum bark thickness (1.67 mm) and wood thickness (5.00 mm) was observed in plants grafted on Quince C rootstock. The effect of scion on bark and wood thickness was significant. Cultivar Carmen attained maximum bark thickness (2.00 mm) and wood thickness (6.34 mm). The second highest value for bark thickness was obtained in the plants of cultivar Packham's Triumph, which was statistically at par with cultivar Concorde. Minimum bark thickness of 1.47 mm and wood thickness of 4.14 mm were recorded in the plants of cultivar Red Bartlett and Concorde, respectively. The maximum value for bark thickness of 2.02 mm and wood thickness of 7.27 mm was recorded in cultivar

Table 3. Influence of different stionic combinations on dry weight of shoots, dry weight of roots, wood thickness and bark thickness

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Dry weight of shoots (%)	Quince A	63.45a	62.47ab	61.76ab	51.56abc
	BA 29	55.73abc	50.82bc	48.88c	56.91abc
	Quince C	52.79abc	50.96bc	55.06abc	51.75abc
	Kainth	56.78abc	56.36abc	53.79abc	57.29abc
Dry weight of roots (%)	Quince A	68.00ab	68.91a	67.48ab	67.24ab
	BA 29	63.79ab	65.78ab	66.43ab	63.99ab
	Quince C	61.72b	64.93ab	66.81ab	65.84ab
	Kainth	66.69ab	64.89ab	66.05ab	66.56ab
Wood thickness (mm)	Quince A	7.27a	3.38f	5.82abc	6.50ab
	BA 29	6.00abc	4.17def	5.56bcd	5.43bcd
	Quince C	6.24ab	3.69ef	4.58cdef	5.49bcd
	Kainth	5.92abc	5.32bcde	6.61ab	6.32ab
Bark thickness (mm)	Quince A	2.02a	1.79abc	1.51bcd	1.85ab
	BA 29	1.99a	1.69abcd	1.47cd	1.78abcd
	Quince C	1.96a	1.66abcd	1.41d	1.67abcd
	Kainth	2.01a	1.79abc	1.49bcd	1.82abc

Values in same column with different letters indicate statistically significant differences at p≤0.05

Table 4. Correlation among different morphological parameters of different stionic combinations

Parameters	Plant height	Rootstock diameter	Scion diameter	Graft union diameter	Number of stomata	Size of stomata	Dry weight of shoot	Dry weight of root	Bark thickness	Wood thickness	Graft take success
Plant height	1										
Rootstock diameter	.400**	1									
Scion diameter	.620**	.311*	1								
Graft union diameter	-.057	.015	-.092	1							
Number of stomata	-.293*	-.112	-.455**	.087	1						
Size of stomata	.247	.459**	.041	-.058	.091	1					
Dry weight of shoot	.903**	.260	.620**	-.080	-.258	.201	1				
Dry weight of root	.875**	.353*	.587**	-.175	-.333*	.242	.941**	1			
Bark thickness	.628**	.187	.470**	-.186	-.074	.212	.675**	.687**	1		
Wood thickness	.537**	.364*	.843**	-.151	-.572**	.063	.508**	.509**	.213	1	
Graft take success	.638**	.437**	.579**	-.319*	-.090	.353*	.697**	.683**	.553**	.527**	1
Leaf sugar	-.177	-.576	-.118	-.246	-.073	-.177	-.194	-.289	-.069	-.197	-.318
Leaf starch	-.775	-.484	-.469	.278	.227	-.183	-.742	-.777	-.531	-.443	-.693

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed)

Carmen grafted on Quince A rootstock, whereas the minimum bark thickness (1.41 mm) and wood thickness (3.38 mm) was in cultivar Red Bartlett grafted on Quince C rootstock and Concorde grafted on BA 29 rootstock, respectively. Maximum wood thickness in Carmen on Quince A might be due to strong compatibility, which causes better growth, more leaf area and assimilation of more photosynthates within the plant. A smaller wood/ bark ratio has been reported in standard-type pears in comparison to dwarf types (Chen et al 2015).

Correlation analysis revealed a positive correlation between plant height and diameters above and below the graft union (scion and stock diameters, respectively), for all the stionic combinations, while a significant negative correlation between the plant height and diameter at the graft union was reported. Higher swelling at the graft union on dwarf plants might be attributed to vascular discontinuity due to phloem degeneration and discontinuity of the xylem vessels in the graft union region. This causes obstruction in the ascending sap flow through the xylem and the descent of photo assimilates through the phloem (Ciobotari et al 2010, Machado et al 2017), which results in poor graft take success and graft incompatibility. The graft take success and graft union diameter were negatively correlated. Certainly, the plant height was positively correlated with the dry weight of shoot and root and graft take success (Bark thickness, wood thickness and plant height were also correlated, although the correlation between bark and wood thickness was weak. The non-significant correlation was registered for the number and size of stomata). Individually, the number of stomata was negatively correlated with plant height, whereas the size of stomata was positively correlated with plant height (Table 4).

CONCLUSION

Overall growth of the plant was affected by use of different rootstocks and scions. The plants grafted on Quince C rootstock and resulted in compact architecture. Quince A was vigorous in comparison to seedling rootstock Kainth. However, the combination of Red Bartlett on Quince C was found to be most dwarfing, which suggests its suitability for high density orcharding. However, in this study the confounding effects of management practices were not considered. Therefore, further studies are required to evaluate the effect of various orchard management practices.

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Received 08 July, 2023; Accepted 22 October, 2023