PERFORMANCE OF DIFFERENT APPLE CULTIVARS GRAFTED ON SEEDLING ROOTSTOCK UNDER NURSERY CONDITION

Thesis

by

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(H-2019-75-M)

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CERTIFICATE - I

This is to certify that the thesis titled **"Performance of different apple cultivars grafted on seedling rootstock under nursery condition"** submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE) SEED SCIENCE AND TECHNOLOGY** in the discipline of **PLANT SCIENCES** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 is a bonafide research work carried out by **Mr ABHISHEK TOMAR (H-2019-75-M)** son of Shri Daleep Singh Tomar under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Nauni, Solan
Dated: 25-09-2021

(Dr C L Sharma)
Major Advisor

CERTIFICATE - II

This is to certify that the thesis titled **"Performance of different apple cultivars grafted on seedling rootstock under nursery condition"** submitted by **Mr Abhishek Tomar (H-2019-75-M)** son of Shri Daleep Singh Tomar to Dr Yashwant Singh Parmar University of Horticulture and Forestry (Nauni), Solan (HP) – 173 230 India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (Agriculture) SEED SCIENCE AND TECHNOLOGY** in the discipline of **PLANT SCIENCES** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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"Words once they are printed have life of their own ".

Place: Nauni, Solan
Date: 25-09-2021 **(Abhishek Tomar)**

CONTENTS

ABBREVIATIONS USED

%	:	Per cent
˚C	:	Degree Celsius
ANOVA	:	Analysis of variance
CD	:	Critical difference
cm	:	Centimetre
cm^2	:	Square centimetre
cv	:	Cultivar
cv(s)	:	Cultivar(s)
DAG	:	Days after grafting
DMSO	:	Dimethyl sulphoxide
et al.	:	et alia (Co-workers)
etc.	:	Et cetera
g	:	Gram
H.P	:	Himachal Pradesh
i.e.	:	id est (that is)
mg/g	:	Milligram per gram
mm	:	Millimetre
Nm	:	Nanometre
SPAD	:	Soil Plant Analysis Development
UHF	:	University of Horticulture and Forestry
viz.	:	videlicet (namely)
YSP	:	Yashwant Singh Parmar

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Chapter-1

INTRODUCTION

Apple (*Malus* × *domestica* Borkh.) is the most valuable and leading commercial temperate fruit in the north-western Himalayan region and is a member of the Rosaceae family. Jammu and Kashmir, Himachal Pradesh and parts of Uttarakhand are the main apple growing areas and are the core sector of economy in these states. It is also grown in Arunachal Pradesh, but to a lesser degree and in the north-eastern region, Sikkim, Nagaland and Meghalaya and the Nilgiri hills in Tamil Nadu. In India, apple acreage occupies 3,01,000 hectares, with a total output of 23,27,000 metric tonnes (Anonymous, 2018). Apples are grown on 1,13,154 hectares in Himachal Pradesh, with a total production of 3,68,603 metric tonnes (Anonymous, 2018).

Horticulture is the prime mover of economic growth in Himachal Pradesh and the state has also craved and a niche as a horticulture state and is also known as 'Fruit Bowl of Nation' (Wani and Songara 2018). Himachal Pradesh has emerged as India's Horticulture state and it has been designated as the apple state of India for producing the finest quality apples. Shimla, Kullu, Chamba, Sirmaur, Lahaul & Spiti and Kinnaur are the primary apple-producing districts in Himachal Pradesh. Farmers in H.P are urged to develop the world's finest and most desirable apple varieties. The state department of horticulture assists them in the upliftment of the rural population and has also generated employment.

In Himachal Pradesh, apple has emerged as a leading cash crop amongst fruit crops. It has revolutionized the socio-economic condition of farmers of the state as 0.2 million families (Anonymous, 2018) are involved in its cultivation and account for 49 per cent area and 88 per cent production of total fruits. Commercial apple industry in Himachal Pradesh is nearly 60 years old and comprises predominantly of the delicious group, which constitutes 90 per cent of the varieties grown. 'Delicious' is the most important cultivar grown, followed by 'Golden Delicious', 'Granny Smith', 'Fuji' and 'Gala'. These varieties represent over 60 per cent of the world's apple production.

In terms of income, the apple is the most profitable temperate crop. The introduction of high yielding spur type colour strains and low chill varieties, which can be grown in areas

that have become marginal for apple cultivation or replacement of traditional high chill varieties due to climatic change, has resulted in a significant increase in area under apple cultivation over the last two decades. Besides this, large plantations are coming up in new areas and old orchards are being replaced due to their declining trend and introduction of new and improved cultivars.

Every year, there is a huge demand for high quality apple plants. To cope up this demand both government and private nurseries are engaged in the production of quality nursery plants. Therefore, State Department of Horticulture, Government of Himachal Pradesh and Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan are making efforts to meet the ever increasing demand of the growers and thus many nurseries in private and public sectors have come up in the state to cope up with the existing demand.

The nursery plants are said to be the foundation on which orchards are built, since the success in fruit growing depends upon the quality of planting material used for establishing orchard. As a result, the availability of high-quality nursery plants is a must in order to satisfy the enormous demand for nursery plants. Apple trees are usually propagated on rootstock rather than on their own roots, because rootstock has numerous advantages. The rootstock has a significant impact on the development, precocity and cropping of scion cultivars grafted on it, as well as conferring resistance to scion cultivars against biotic and abiotic factors.

The quality of planting material used to create an orchard determines whether the orchard succeeds or fails. Nursery plants must not only be true to type, but also stable and of good quality for a successful orchard. Plants raised on seedling rootstocks are long lived, have extensive and strong root system with wide and deep distribution in the soil, which accounts for persistent and adequate annual growth of absorbing roots, thus helping them acclimatize easily in the environment. Also rootstocks exhibit a great effect on production efficiency, yield quality, adaptability, tree vigour, impart resistance to biotic (diseases and insects/pests) and aboitic stresses (salt tolerance and water logging) of scion cultivar with the main function of seedling rootstocks to provide anchorage by growing deep in to the soil and also regulate uptake of moisture and nutrients.

Vegetatively propagated apple rootstocks are released in different countries and have their own quality parameters and often exhibit unequal performance in other countries (Wertheim, 1998), mainly due to ecological conditions. The choice of rootstock or of the

rootstock/cultivar combination is important, not only in the orchard, but also in the propagation fields.

In the recent past (1995-2000), large number of colour strains and varieties of apple were introduced in the state and some of which have performed well under different agro climatic conditions. The best performing varieties like Early Red One, Scarlet Spur II, Oregon Spur II, Golden Delicious, Granny Smith, Gale Gala and Gibson Golden were introduced at different Horticulture Research and Training Station & Krishi Vigyan Kendras of Dr YSP UHF Nauni, Solan during 2005 mainly for the multiplication of plants and supply of bud wood to the stakeholders.

The performance of apple cultivars and rootstocks is critical for determining the most productive orchard systems in each area. Almost all rootstock research is focused on orchard results, but there is very little research done in the nursery performance of various cultivars. Some trials have recently been set up in countries with their own rootstock breeding programmes (Fazio and Robinson, 2008).

In Himachal Pradesh, seedling rootstock is the most popular and widely used apple rootstock. On seedling rootstock, plants are multiplied through bench grafting with the scion of desired cultivars. In hilly areas with short growing seasons, nursery plants develop slowly over a period of 6 to 7 months and a significant percentage of them do not reach their full potential at the end of the season. Furthermore, majority of apple orchards in Himachal Pradesh are located under marginal and unfavourable conditions in respect of climate, altitude, topography, soils etc. and apple cultivation is carried out mostly on sloppy and marginal lands and almost entirely under rain fed conditions. It has been observed that around 50 per cent rootstock seedlings in apple fail to attain the graftable size at the end of first growing season.

Keeping above perspectives in view, the present studies have been planned with the following objective:

- To study the growth parameters of different apple cultivars grafted on seedling rootstocks in nursery

Chapter-2

REVIEW OF LITERATURE

Seedling rootstock is the most popular and widely used apple rootstock in Himachal Pradesh. The success or failure of an orchard is determined on the quality of the planting material utilized to produce it. Plants raised on seedling rootstocks are long lived, have a extensive and robust root system and have a significant impact on yield quality, adaptability and tree vigour, impart resistance to biotic and aboitic stresses. However the literature on the performance of various cultivars under nursery condition is scanty, yet the work done on the **"Performance of different apple cultivars grafted on seedling rootstock under nursery condition"** is revealed under the following sub heads:

2.1 GRAFT SUCCESS

Koyuncu and Ersoy (2011) conducted an experiment on nursery growing in controlled green house and orchard by using various grafting methods in apple. They found that grafting success in the greenhouse was 88 per cent and 65 per cent in the exterior environment; the height of the saplings in the greenhouse was 24.93 cm and 23.29 cm in the outdoor environment. The rootstock diameters ranged from 7.59 to 9.06 mm, whereas the scion diameters ranged from 6.83 to 8.38 mm. Summer Red (100 %) grafted with whip grafting in greenhouse and Pink Lady (93 %) grafted with whip grafting had the best proportions of grafting success. Whip grafting outperformed chip budding in both the greenhouse and the outdoor environment.

Ilyefalvi *et al*. (2013) investigated the technological and histological aspects of graft union formation between apple varieties and apple rootstock, newly bred pear varieties and quince rootstock in order to determine the best bench mechanical grafting technique and to examine compatibility/incompatibility related growth characteristics in the early stages. At SCDP Bistrita, two bench grafting procedures were used for apple and pear propagation and graft combinations were evaluated in greenhouse and open field conditions. Scions of 'Golden Delicious' and 'Florina' were bench grafted on M26 apple rootstock with omega "Ω" and "V" top grafting methods, whereas pear cultivars 'Argessis', 'Monica' and 'Carpica' grafted on BN70 quince rootstock. Graft unions were reported to be successful in all

combinations and samples; nevertheless, sapling growth differed according to the two techniques. The total percentage of graft survival was observed to be 80 per cent at omega grafting and 85 per cent at “V” grafting in apple, respectively while 65 per cent at omega grafting and 80 percent at V top grafting at pear combinations.

Negi and Upadhayay (2017) conducted an experiment to standardize the various summer grafting dates in apple cultivar Scarlet Gala onto seedling rootstock under polyhouse conditions with the goal of reducing nursery production duration and ensuring a consistent supply of plants to growers. Tongue grafting performed on June 12, 22 and July 1 yielded 100% bud take success with adequate wound healing of graft unions. Plants grafted on June 12 reached their greatest height (71.17 cm) at the conclusion of the growth season, although it was statistically equal to plants grafted on June 22 and July 1. Likewise, the number of laterals and root length were found to be greatest in plants grafted on these dates. The grafting dates also had a major impact on the plants foliar characteristics. The leaf area, fresh and dry weight of the leaf and number of leaves per plant were highest in plants with vigorous growth and a greater number of lateral branches. They concluded that tongue grafting conducted in the second week of June to the first week of July is the ideal period for doing summer grafting in apple under polyhouse conditions in mid hill regions of Himachal Pradesh, when both components (scion and rootstocks) are in active growing stage.

Devkota *et al.* (2019) performed studies on the effect of grafting dates and wrapping materials of grafting success in apple and found that the treatment of grafting date March 11 and grafting tape resulted in minimum days (24.38) for first sprouting, minimum days (28.88) for 50% sprouting, maximum success percentage (92.51%) and maximum increment in length (54.88 cm) of grafted scions at 90 DAG (days after grafting). According to their findings, the best period to graft a Royal Delicious apple was between the first and second week of March and the best wrapping material is grafting tape.

2.2 PLANT HEIGHT AND GROWTH

Cranko (1979) studied the performance of Jonathan and Starking Delicious apple on different rootstocks. They found that rootstock MM-106 produced medium sized and well anchored trees. Similarly, MM-106 has also been found to show best performance in terms of vegetative growth than seedling rootstock.

Strauss *et al*. (1980) investigated the output of different apple cultivars such as Golden Delicious, Red Delicious and McIntosh on M-1, M-2, M-4, M-7, M-9, M-11, M-26, MM-106, MM-109, MM-111, A 2 and two seeding rootstocks and found that M-2, M-4, M-26, MM-106 and MM-111 rootstocks formed medium-growing plants.

William *et al*. (1985) recorded the effects of stem piece and rootstock combinations on growth, leaf mineral concentrations, yield and fruit quality of apple trees and found that height and spread of Empie apple trees on M-26, M-9/MM-106 and M.27/MM-111 were similar and were greater than those on M-9 and M-27.

Larsen *et al*. (1992) studied the influence of nine rootstocks on growth of cultivars 'Goldspur' (GS) and 'Wellspur Delicious' (WS) and of three rootstocks on growth of cultivars 'Red King Delicious' (RK) and 'Golden Delicious' (GD) apple. The largest plant heights were found on seedlings of the MM-104 and MM-109 rootstocks, while the smallest were found on the M-26 rootstock.

Chandel and Chauhan (1994) conducted studies on trees grafted on eleven different rootstocks of the cultivar Starking Delicious (M.2, M.4, M.7, M.9, M.25, M.26, MM.104, MM.106, MM.109, MM.111 and seedling rootstock). Plants on rootstock M.25 had the greatest height and shoot growth, whereas M.9 had the least height and shoot growth. Water stress circumstances had the least effect on the development and vitality of trees growing on MM.111, MM.106, MM.104, M.4 or MM.109 rootstocks, making these combinations more drought tolerant.

Rodriguez *et al*. (1998) investigated the performance of Abbel Fetel and Conference cultivars of pear grafted on three Quince rootstocks, BA-29, Province and MA, with seedling *Pyrus communis* as the control rootstock. After five years, they found that vegetative growth on Quince stocks was lower than on seedling stocks for both the cultivars.

Talaie *et al*. (2000) examined the impact of six clonal and seedling rootstocks on the growth characteristics of four Iranian commercial apples *viz.*, Golab Kohanz, Shatiabadi, Red Delicious and Goldan Smoothe, grown on MM-106, MM-111, M-9, B-9, M-26 and M-27. The trees with the MM-111 and MM-106 rootstocks grew the most in height and annual extension.

Mataa (2000) evaluated the adaptability of ten apple cultivars (*Malus* × *domestica* Borkh.) for tropical Zambian conditions: Ein Shemer, Anna, Rome Beauty, Tropical Beauty, Alexander, Orleans, Winter Banana, Black John, Starking Delicious and Red Delicious. Winter Banana, Black John, Starking Delicious and Red Delicious, all high-chill cultivars, had poor vegetative development and shoot growth and the majority of the trees died before reaching maturity.

Middleton *et al.* (2001) investigated the performance of Royal Gala, Red Fuji, Pink Lady and Sundowner apple cultivars on the rootstocks M 9, Mark, Ottawa 3, M 26, Northern Spy, MM 106 and MM 111. When compared to other rootstocks, the MM 106 and MM 111 rootstocks were found to be more vigorous with all cultivars.

Uselis (2001) investigated the success of twenty apple cultivars grown on M.26 rootstock in Lithuania. Rubin, Elstar and Staris were found to be the most vigorous cultivars, while Delikates was the least vigorous. In terms of vigour, Noris, Arlet's, Antej, Cortland and Paulared were less robust.

Wazbinska *et al.* (2003) studied the performance of eighteen apple cultivars that were evaluated in a field experiment conducted in Poland in 2000-02. Varieties were grouped into early and late cultivars, where Katja was the earliest. Elstar recorded the maximum cross-section, whereas Red Gala and Ligor recorded the minimum.

Tworkoski and Miller (2007) reported that apple scions with diverse growth habits were grafted on various size-controlling rootstocks and seedling rootstock and morphological characteristics were measured. Overall tree height was most influenced by scion. Rootstock size-controlling effects were as expected and the most-to-least dwarfing rootstocks were M.9, M.7, MM.111 and seedling rootstock. This research demonstrates that rootstock controls the size but does not markedly alter growth habit of apple shoots.

Bhat *et al*. (2006) studied the performance of ten apple cultivars under high altitudes conditions of Pahnoo Shopian, Jammu and Kashmir. The maximum plant height (254.00 cm) was found in 'Vance Delicious' followed by 'Tydeman's Early Worcester' (226.00 cm) and least in 'Mollies Delicious' (126.00 cm).

Gudumac *et al*. (2007) evaluated the cultivars Idared, Golden Delicious Reinders, Jonagold Boerekamp Early Queen, Granny Smith, Jonagold, Gloster and Champion grafted

on the M9 rootstock in an experiment. The striking grade of the bench grafts of the varieties from the first field of fruit nursery was determined to be 96.00-99.00 percent; the scions height was determined to be 94-126 cm. The acquired findings in the second field correspond to the first category of the real standards, with a tree height of 166-189 cm and a trunk diameter of 16.5-17.2 mm.

Dierend and Bier (2009) studied the influence of dwarf apple rootstock *i.e* M-9, Fleurone 56, Supporter 1, P 16, P 22, M-27 and seedling rootstock, on growth of apple cultivars Elastar, Elshop, Boskoop and Jonagored and found that all rootstocks induced less vegetative growth than M-9 rootstock.

Claudio *et al*. (2009), while comparing the effect of interstocks M-9 and M-27 on vegetative growth of apple cultivar Annurca, found lower vegetative growth on seedling rootstock with M-9 and M-27 as a interstock as compared to seedling rootstock alone. Different interstem/rootstock combinations were compared, using seedling as rootstock and alternatively, two weak interstocks, with the objective of getting apple plants with deep and expanded root apparatus, which are better suited for establishing apple orchards in dry, windy areas and higher altitudes.

Hampson *et al*. (2009) analysed ten Canadian apple breeding selections and two common cultivars of apple at four separate sites. Royal Gala and Summerland McIntosh, two common cultivars, had high tree vigour and precocity. At all sites, no single cultivar outperformed the others in these areas. In terms of tree vigour and survival, S23-06-153 and 8S-27-43 had consistently strong performance.

Gudumac *et al*. (2010) investigated the growth vigour of two apple varieties (Idared and Golden Reinders) bench-grafted on five rootstocks (M 9, M 26, M 7 and MM 106) in 2008-2009. According to the findings of the studies, the main indicators of apple tree growth in the first and second fields of the fruit nursery show significant increases in response to increases in the vigour of the rootstocks used in the grafting process.

Comparative performance of different apple cultivars at the nursery level, according to Gangwar *et al.* (2010), is an effective tool for obtaining superior quality planting material before developing a new orchard. Jonagold out performed the other apple cultivars in terms of height (149.33 cm), scion girth (2.03 cm) and stock girth (2.36 cm).

Kosina (2010) experimented on fourteen clonal apple rootstocks (M.9, M.26, M.27, MM.106, J-TE-E, J-TE-F, J-TE-G, J-TE-H, J-OH-A, Jork 9, Pajam 1, Pajam 2, Burgmer M.9-751 and Burgmer M.9-984) in two experimental orchards using scion cultivars Golden Delicious, Melrose, Jonagold, Rubin and Florina. Rootstocks Jork 9, Pajam 1, Pajam 2, M.9-751 and M.9-984 produced better results than original rootstock M.9. The growth vigour of trees grafted on Pajam 2, M.9-751 and M.9-984 was somewhat larger than those on M.9. Rootstock J-TE-H was semi-vigorous and grafted trees had low yield efficiency. Clone Pajam 1 had the similar growth vigour as M.9 trees on Jork 9 grew significantly weak in comparison with M.9.

Boston (2010) carried out an experiment in which apple cultivars Idared, Golden Reinders and Gala Mast were bench-grafted on rootstock M9. According to the findings of the study, the height of bench-grafted apple trees ranged from 109 to 124 cm, the diameter at 10 cm above the point of grafting was 8.3-9.4 mm and the leaf surface was 0.20-0.27 m^2/tree. The bioconstructive parameters of apple trees in the nursery's second field matched to the Republic of Moldova's current norm. The tree height ranged from 180.0 to 187.5 cm. The trunk diameter was 15.00-16.33 mm at 10 cm above the graft site. The Gala Mast cultivar produced the most normal branches (4.00-4.50 pcs/tree), whereas the Idared cultivar produced the least (3.50-4.00 pcs/tree). The studies revealed that superior values of apple trees in the first and second fields of the fruit nursery were recorded at the variety of prospective Gala Mast, whose vigour of development and capacity to emit sylleptic shoots was larger than the Idared variety

Karamursel and Kalyoncu (2011) investigated the advantages of apple nursery growing in greenhouse rather than outdoor medium. Scions of Red Chief (dwarf), Braeburn (semi dwarf) and Mondial Gala (vigorous) apple varieties were grafted by the bench grafting and chip budding techniques on MM106 and M9 apple rootstocks. In result to evaluation of all factors, it was found that the percentage of graft survival was between 82% (greenhouse) and 69% (outdoor), sapling height 84.86 cm (outdoor) and 146 cm (greenhouse).

Ahmed *et al*. (2013) investigated the effect of an apple cultivar grafted on two rootstocks in Jammu Kashmir's sub-humid temperate climate. The growth characteristics of nine apple cultivars (Starking Delicious, Kala Kulu, Fuji, Red Chief, Royal Gala, Red

Labnani, Red Delicious, Star Crimson and Sky Spur) grafted on local crab apple and MM-111 were studied. On crab apple, Red Chief had the highest plant height.

Mushtaq *et al.* (2019) evaluated four new exotic varieties of apple *viz.*, Super Chief Sandidge, Gala Redlum, Fuji Zhen Aztec and Golden Clone B for their various growth and phenological characteristics. The study showed statistically significant differences among varieties in their various characters. Tree morphological characteristics revealed variety Super Chief Sandidge to be the most dwarf variety with least tree height (1.31 m) and incremental growth in tree height (23.64 cm), while the variety Fuji Zhen Aztec reported to be most vigorous with an average tree height of (1.96 m) and highest increase in tree height in a season (31.04 cm).

2.3 NUMBER OF LEAVES, NUMBER OF NODES AND LEAF AREA

Rud *et al*. (1977) investigated the impact of various rootstocks on the Jonathan apple cultivar. Trees with M4 rootstocks had the most leaf area compared to those with other rootstocks. Starking Delicious apple plants grafted on M9 rootstocks had substantially less leaf area than plants grown on MM111 and seedling rootstocks, (Chandel and Chauhan, 1992).

Rana (1985) in an experiment on physiological studies on clonal rootstock and scion interaction of apple reported that MM-106 rootstock produced maximum leaf area as compared to MM-111, MM-103, MM-104, MM-105, MM-109, MM-111 and seedling rootstocks.

Ussahatanonta and Simons (1985) found that Golden Delicious apple seedlings grown on semi dwarfing MM-106, M-7 and regular seedling rootstocks had larger leaves than those grown on dwarfing M-9 rootstock.

Fouad *et al.* (1995) investigated the influence of MM-111, MM-106, M-9 and seedling rootstocks on the growth of Anna apple and discovered that MM-111 had the most nodes per shoot while M-9 had the fewest. Plant height and scion circumference had the greatest values on MM-111, followed by MM-106 and had the lowest values on seedling. Similarly, MM-111 had the greatest shoot length, diameter, number of nodes per shoot and leaf area.

Costes (2003) reported that leaf area be considered as one of the most important components of the fruiting structures involved in the fruit size and quality because branches with a larger leaf area present a higher photosynthetic capacity, reducing the competition for photosynthates with other branches.

Sharma *et al*. (2004) conducted an experiment on twelve low chilling 15 years old apple cultivars raised on seedling rootstock during 1999-2001 at Solan. The finding revealed that 'Tropical Beauty' was the best genotype for the character of leaf area (60.67 cm^2).

Dimri *et al.* (2005) observed that in the apple cultivar Red Fuji, tongue grafting outperformed the other graftage procedures in terms of maximum scion girth (1.03 cm), total leaf dry matter content (5.75 %) and leaf area production (1108.33 cm^2). The numbers of nodes (37.15), number of leaves (62.30), proportion of saleable plants (91.90 %) were recorded under tongue grafting and was found significantly higher than all other dates.

Blanco *et al*. (2008) reported that Jonagold grafted onto M9 had a longer internodal length of 19.6 mm than P16 rootstock, which had 17.9 mm. The M9 rootstock had a larger leaf area (32.9 cm^2) than the P16 rootstock (31.1 cm^2). In the tests, apple cv. Jonagold specimens grafted onto P16 rootstocks were compared to those grafted onto M9 rootstocks. The dwarfing characteristics of P16 rootstock were quite powerful. The shoot lengths and leaf area of 'Jonagold' trees grafted onto these rootstocks were shorter than those grafted onto M9 rootstocks.

Bhardwaj (2010) studied the effect of rootstocks on leaf area of apple trees and reported that leaf area was significantly higher on seedling rootstock as compared to those on M-9, MM-106, M-7 and MM-111 rootstocks.

Hassan *et al.* (2010) investigated the effect of two training systems (tiller and open central leader) on the leaf mineral content and growth of the "Anna" apple cultivar in a private orchard located on the Cairo Alexandria desert route about 80 kilometres from Cairo. The tiller training technique considerably improved leaf Nitrogen and Potassium content, according to the results. Furthermore, as compared to the open central leader training technique, tiller training increased shoot length, diameter and leaf area considerably (control). The current investigation may lead to the conclusion that tiller training systems have a substantial impact on apple plant growth.

Dalal *et al*. (2011) found that punched black polyethylene has a substantial influence on the development of nursery plants. Maximum height growth (43.5 cm), girth increase (0.75 cm), number of feathers (4.36 cm) and length of feathers (27.95 cm) were observed with unpunched black polyethylene followed by pierced black polyethylene and then control.

Kviklys *et al*. (2011) reported the effects of apple rootstocks M.9, M.26, MM.106, B.118, B.396, P.60, P.2, P.22, P. 59 and 'Antonovka' seedlings on the quality of one year old planting material. Significant differences among rootstocks were found when tree height, stem diameter, leaf area and leaf weight were measured. The tallest one year old trees grew on B.118, M.9 and 'Antonovka' seedling rootstocks. Leaf area and leaf dry weight usually correlate with the intensity of photosynthesis. Presumable larger leaf area and higher leaf dry weight correspond to stronger vegetative growth. Rootstocks M.9T337, B.118, P.22 and P.59 427 had the largest leaves. Significantly smaller leaves were on trees with M.26, P.2, MM.106 and seedling rootstocks.

Devi (2012) performed an experiment consisted of ten treatment combinations of five rootstocks *viz*., EMLA 9, ELMA 26 EMLA 7, EMLA 106 and EMLA 111 and two cultivars *viz*., Scarlet Gala and Red Fuji. Among the rootstocks EMLA 111 rootstock recorded the maximum increase in plant height, whereas maximum leaf area was recorded in EMLA 7 rootstock.

Sotirov *et al.* (2016) studied the performance of nursery trees grafted on the 'MM 106' rootstock of 24 introduced apple cultivars and hybrids. The rootstocks were chip budded at a height of 15 cm from the ground. During the study, the percentage of developed buds, nursery tree growth dynamics, the number of plants with sylleptic shoots, nursery tree height and thickness were recorded at the end of the growing season. The highest percentage of developed buds was found in Hybrid No 6 and Rubin, while the lowest values were found in Red General and Pinova. Remo, Free Redstar, Melfree, Gold Millennium, Reandra, Primera, Hybrid No 6 and Red General had vigorous growth and Brina, Pacific Rose, Longlu, Honglu, the hybrid 'Pinova' × 'Fuji', Goldrush, Yanga 1 and Renora had weaker growth, compared to the standard (Granny Smith) and the rest of cultivars. In the nursery, the cultivars Granny Smith, Longlu, Yanga and Pacific Rose showed a proclivity for forming sylleptic shoots. Hybrid No 6, Granny Smith and Rubin showed the maximum percentage of standard planting material, while Brina, Pacific Rose and the hybrid 'Pinova' × 'Fuji' generated the lowest.

Srivastava *et al*. (2016) performed a study in which the rootstocks were chosen based on 11 main pomological features. CITH-Apple rootstock-04 had the largest leaf area (3.80

cm^2), while USA 106 had the smallest (1.96 cm^2). The highest number of leaves per plant was noted in Brookfield (79.00), which was closely followed by Jonagold (77.33). The minimum number of leaves per plant was counted in cv. Galaxy (35.67). However, the cultivars Braebrun (55.67), Scarlet Gala- Regala (55.33), Aztec (52.67), Red Delicious (51.00), Royal Gala (47.67) and Aroura (48.00) were found at par to each other.

Malasi *et al*. (2017) studied three rootstocks namely M-793, M-7 and MM-111 and three scion wood *viz*., Vance Delicious, Gold Spur and Oregan Spur selected and nine combinations of these rootstock and scion wood were made and grafted with three replications. The different parameters for this rootstock and scion combinations were recorded to evaluate the best combination. The maximum leaf area (15.58 cm^2) was recorded with T_6 (MM- 111 + Gold Spur) and maximum number of leaves 105.07 on the treatment T_1 (M-793 + Vance Delicious).

Rahman *et al.* (2017) carried out an experiment to evaluate the comparative study on compatibility and growth response of pear varieties on different rootstocks at nursery stage. Six pear cultivars (four exotic such as William, Santa Maria, Hosuai and Shinsui and two indigenous such as Khan Tango and Shaghuri) were grafted on two rootstocks (Quince and *Pyrus pashia* L., locally known as tangai). Various growth parameters like percent graft success, percent survival rate, plant height and diameter were recorded. Variety William showed higher graft success per cent, plant height and survival percentage. However, lower number of graft take success per cent, plant height and plant diameter and survival percentage were observed on Quince rootstocks.

Inna *et al*. (2020) investigated the leaf area of the apple varieties Gala Buckeye Simmons, Granny Smith, Red Velox and Golden Delicious Reinders. During the development stage of the trees, shoots constitute the majority of the leaf area (68.9-76.1 per cent) whereas spurs and bourse shoots form only 23.9-31.1 per cent. When compared to the Gala Buckeye Simmons and Red Velox types, the Granny Smith and Golden Delicious Reinders kinds had a bigger leaf area (8.34-8.85 m^2/plant).

2.4 SCION AND STOCK DIAMETER

Fouad *et al.* (1995) studied the effect of MM111, MM106, M9 and seedling rootstocks on the growth of Anna apple and observed the shoot length and diameter and number of nodes per shoot were the highest on MM111 and the least on M9.

According to Kumar and Ananda (2004), tongue grafting, chip budding, shield budding and annular budding were the four techniques of propagation that exhibited the most linear and radial growth of the scion and rootstock. In terms of the influence of propagation methods on feather production, tongue grafting resulted in the most number and length of feathers emerging in both Redspur and Wellspur cultivars. The maximum linear growth was recorded with 15 cm height, but no distinct pattern was detected in regard to radial growth among the three propagation heights (15, 20 and 25 cm).

Singh and Ananda (2005) studied rootstock and scion interaction as well as growth characteristics in apple and found that plant girth on M9 was more (4.40 cm) as compared to the seedling (3.65 cm). Shoot length was shortest on M-9 and it increased with MM-111 and seedling rootstock.

Karamursel and Kalyoncu (2011) explored the benefits of growing apples in a greenhouse rather than outdoors. On MM 106 and M 9 rootstocks, scions of the apple varieties Red Chief, Braeburn and Mondial Gala were grafted using bench grafting and chip budding techniques. Following an evaluation of all parameters, it was reported that the shoot diameter for outdoor plants were 6.84 mm and 10.71 mm for greenhouse plants.

Rabi *et al*. (2012) investigated how apple cultivars responded to graft take success on apple rootstock. Bench grafting was done of five apple cultivars (Royal Gala, Mondial Gala, Treoo Gala, Gala Mast and Spartan) on rootstocks MM-111, MM-106, M-9, M-26 and crab apple. In cultivar Gala Mast with rootstock crab apple, there was an increase in graft take success (91.10 %), plant height (107.97 cm), scion diameter (9.38 mm) and number of leaves per plant (116.5).

Amiri *et al*. (2013) studied the impacts of four rootstocks (M.9, MM.106, MM.111 and local seedling) on the scion leaf and fruit mineral concentrations, as well as tree development characteristics of ‘Golden Delicious’ and ‘Royal Gala’ apples across four seasons (2008-2011). The mechanism behind the rootstock’s influence on scion vigour and yield was that the rootstock exerted its influence on the scion by altering the quantities of minerals taken up and translocated to the scion. On seedling, ‘Royal Gala’ and ‘Golden Delicious’ trees showed the best efficiency in calcium (Ca) and potassium (K) absorption. Trees of these cultivars on M9, on the other hand, were more efficient in N, Mn and Fe absorption.

Dremak *et al.* (2015) studied the growth characteristics of 39 apple cultivars in integrated and organic farming systems. According to our findings, the thickness of the central axis of apple trees differed significantly between integrated and organic systems. The axis of trees with thinner trunks tapers more slightly in the integrated production system than the axis of trees with larger trunks in the organic system. Thicker axis does not correspond to thicker trunk, *i.e*. the thickness of the central leader begins to decline more rapidly in the organic production system than in the integrated one.

Malasi *et al*. (2017) studied three rootstocks namely M-793, M-7 and MM-111 and three scion wood *viz*., Vance Delicious, Gold Spur and Oregan Spur selected and nine combinations of these rootstock and scion wood were made and grafted with three replications. The different parameters for this rootstock and scion combinations were recorded to evaluate the best combination. The treatment T_1 (M-793 + Vance Delicious) had maximum rootstock diameter and scion diameter (*i.e*., 10.12 mm and 9.96 mm respectively).

Srivastava *et al*. (2016) investigated whether exotic and native apple rootstocks can thrive in India's temperate climate. The rootstocks were selected based on 11 main pomological characteristics. The data on scion girth also varied significantly with the various apple cultivars and highest value was noticed with cv. Jonagold (2.03 cm) which was closely followed by cv. Braeburn (2.00 cm), while the minimum value was found in cv. Galaxy (1.00 cm). The values on stock girth indicated significant effect of different scion cultivars on radial growth of the rootstock. It ranged from 2.36 cm in cv. Jonagold to 1.26 cm in cv. Galaxy.

Banday *et al.* (2020) investigated the effects of several mulching treatments on the growth characteristics of Firdous, Shireen, Red Delicious and Golden Delicious apple cultivars grown under nursery conditions. When compared to alternative mulching treatments, black polyethylene resulted in enhanced plant height, plant girth, scion weight and root weight which was followed by clean cultivation. In terms of different growth characteristics, the cultivar Red Delicious outperformed Firdous, Shireen and Golden Delicious.

2.5 CHLOROPHYLL CONTENT

Quamme *et al*. (1997) observed that the total chlorophyll content was significantly higher on *Malus communis* during the three successive seasons, while MM-106 reflected higher chlorophyll content during the first season only.

Sabajeviene *et al*. (2006) studied the photosynthetic pigment system in the leaves of apple tree cv. 'Auksis' on different rootstocks in Lithuanian Institute of Horticulture during 2003-2005 that include twelve rootstocks *viz.,* Bulboga, Pure 1, York 9, B.9, B.396, B.416, B.491, M.9, M.26, P 2, P 60 and P 22. The photosynthetic pigment content and ratios of apple tree cv. 'Auksis' on different rootstocks varied between years. The amount of photosynthetic pigment and the chlorophyll a:b ratio in apple leaves are affected by crop load. The higher the crop, the more photosynthetic pigment is present and the chlorophyll a:b ratio is reduced. Rootstock genotype determines accumulation of photosynthetic pigments. M.9 and York 9 apple rootstocks accumulate more total chlorophyll and carotenoid content than M.26. Apple trees on P 22 had a lower chlorophyll a:b ratio than those on P 60, B.9 and B. 146, with a higher ratio on P 60, B.9 and B. 146.

Prsa *et al*. (2007) conducted an experiment to determine the impact of various rates of soil-applied nitrogen on leaf nitrogen, chlorophyll content and photosynthesis in 'Golden Delicious' apple trees. The N-250 treatment increased chlorophyll content, while the N-80 treatment had a comparable impact later in the season. When leaf thickness increased, the SPAD values and chlorophyll content in the leaves went up as well.

Sharma and Sharma (2008) found that plants raised on clonal quince rootstock had substantially higher leaf chlorophyll content than those raised on seedling rootstock in case of pear cv. Flemish Beauty. Similarly leaf chlorophyll a and b content of apple plants grafted on seedlings was higher (Kultebaev, 1975).

Mizania and Hajnajarib (2013) studied rootstock affects growth traits, chlorophyll concentration and fruit set in Iranian semi-arid conditions and observed that the chlorophyll content, leaf width and length were higher in 'Gala' than 'Gala Schniga'.

2.6 ROOT LENGTH, ROOT AND SHOOT WEIGHT

Dalal *et al.* (2011) observed that perforated black polyethylene has a substantial influence on the development of nursery plants. Maximum primary root length (19.87 cm), secondary root length (13.46 cm), number of primary roots (23.52) and number of secondary roots (9.74) were recorded in unpunched black polyethylene.

Srivastava *et al.* (2016) conducted an experiment to determine which exotic and indigenous apple rootstocks are appropriate for India's temperate region. The rootstocks were

chosen based on 11 main pomological characteristics. The data revealed the maximum number of primary and secondary roots in MM.106 and USA 106 was 93.40, 92.76 and 92.0 in CITH- rootstock-01, respectively. The longest primary roots (19.83 cm) were found in EMLA 106, while the shortest primary roots (6.47 cm) were found in ALNARP. M.27 rootstock had the longest secondary roots (11.83 cm) and ALNARP rootstock had the shortest secondary roots (2.10 cm).

Malasi (2017) studied three rootstocks namely M-793, M-7 and MM-111 and three scion wood *viz*., Gold Spur, Vance Delicious and Oregan Spur selected and nine combinations of these rootstock and scion wood were made and grafted with three replications. The treatment T_1 (M-793 + Vance Delicious) had maximum root length 25.27 cm and root diameter 12.03 mm.

Chapter-3

MATERIALS AND METHODS

The present investigations entitled, "**Performance of different apple cultivars grafted on seedling rootstock under nursery condition**" were carried out at the Experimental Farm of Department of Seed Science & Technology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P) during 2020-21. The experiment was laid out in Randomized Complete Block Design with 18 treatments of different cultivars on seedling rootstock.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experimental farm is located at an altitude of 1250 metres above mean sea level having latitude of 35.5° N and longitude of 77.8° E. The area falls in the mid hill zone of Himachal Pradesh.

3.1.2 Climate

Climate of the area is sub-temperate and semi-humid mostly characterized by mild summers and cold winters. Generally, December and January months are the coolest, while May and June are the hottest months.

3.1.3 Rainfall, Temperature and Relative Humidity

Meteorological data (rainfall, maximum and minimum temperature, relative humidity) as recorded at the meteorological observatory of the Department of Environmental Sciences, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P) during cropping period (January-December, 2020) are presented graphically through Figure 1 and Figure 2. The important meteorological observations during the period of investigation have been presented in Appendix-I.

Fig 1: Graphical representation of monthly meteorological data pertaining to the temperature and relative humidity during the crop season (January-December, 2020)

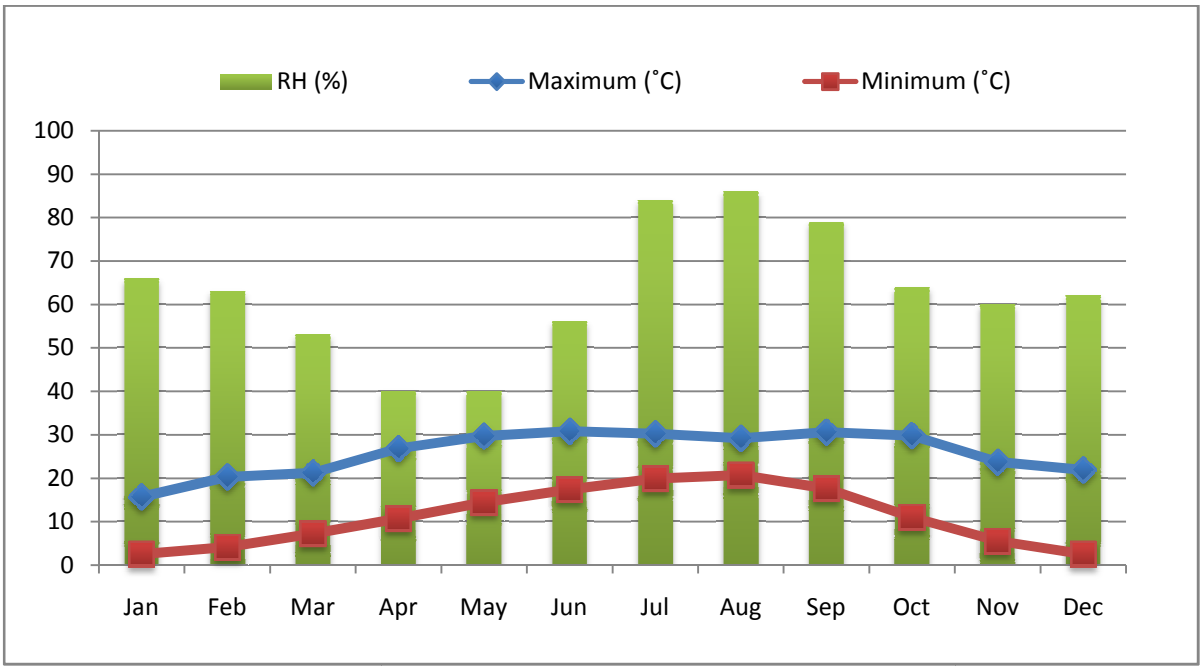
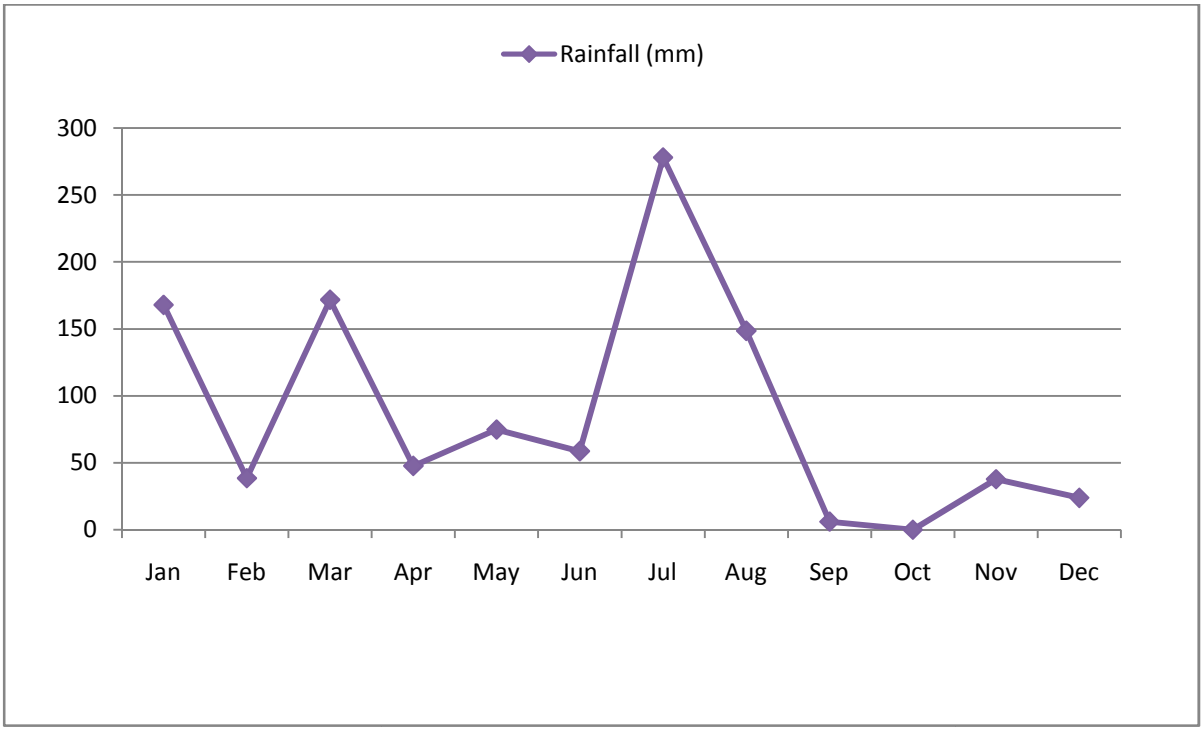


Fig 2: Graphical representation of monthly meteorological data pertaining to the rainfall during the crop season (January-December, 2020)



Source: Meteorological Observatory, Department of Environment Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan (H.P) 173 230

3.1.4 Soil

The soil of experimental field is loam to clay loam having pH ranging from 6.85-7.05.

3.2 EXPERIMENTAL DETAILS

Number of Treatments	**:**	18
Number of Replications	**:**	3
Number of Plots	**:**	54
Plot Size	**:**	2.0 × 1.0m
Design	**:**	Randomized Completely Block Design
Crop	**:**	Apple
Date of planting	**:**	21st February 2020 to 28th February 2020
Spacing	**:**	30 × 15cm

3.3 TREATMENTS DETAILS

Treatment Code		**Treatment Details**
T_1	**:**	Royal Delicious grafted on seedling rootstock
T_2	**:**	Vance Delicious grafted on seedling rootstock
T_3	**:**	Super Chief grafted on seedling rootstock
T_4	**:**	Anna grafted on seedling rootstock
T_5	**:**	Jeromine grafted on seedling rootstock
T_6	**:**	Red Velox grafted on seedling rootstock
T_7	**:**	Scarlet Spur II grafted on seedling rootstock
T_8	**:**	Red Chief grafted on seedling rootstock
T_9	**:**	Schelet Spur grafted on seedling rootstock
T_{10}	**:**	Chelan Spur grafted on seedling rootstock
T_{11}	**:**	Early Red One grafted on seedling rootstock
T_{12}	**:**	King Roat grafted on seedling rootstock
T_{13}	**:**	Vista Bella grafted on seedling rootstock
T_{14}	**:**	Red Cap grafted on seedling rootstock
T_{15}	**:**	Redlum Gala grafted on seedling rootstock
T_{16}	**:**	Gale Gala grafted on seedling rootstock
T_{17}	**:**	Gala Mast grafted on seedling rootstock
T_{18}	**:**	Granny Smith grafted on seedling rootstock

3.4 DETAILS OF MATERIALS AND METHODOLOGY ADOPTED

One year old seedlings were procured by the university on tender basis from outside during first week of January. Uniform seedlings of pencil thickness were selected for planting. The roots of seedlings were slightly trimmed and dipped in Bavistin solution (0.3 %) for fifteen minutes. Then after half an hour seedlings were planted in the beds of 2×1 m at a spacing of 15 cm from seedling and 30 cm from row to row. After planting the beds were immediately given light irrigation. The budwood of different varieties were procured from Department of Fruit Science, Soil Science and different research stations of University of Horticulture and Forestry Nauni, Solan (H.P). The bench grafting was initiated from 21st February onwards with the scionwood of different cultivars having 2-3 intact buds. The details of materials used in the experiments and the methodology adopted were as follows:

3.5 OBSERVATIONS RECORDED

To check the performance of different apple cultivars grafted on seedling rootstock following observations were recorded during the course of present investigations

3.5.1 Per cent sprouting

The data on sprouting percentage was recorded by counting the number of seedling sprouted out of the total number of seedlings planted in the end of April and was expressed in percentage.

3.5.2 Per cent graft success

The data on graft success was recorded in the month of July by counting the number of successfully sprouted scion out of total number of grafted seedlings and was expressed in percentage.

3.5.3 Plant height (cm)

The data on the average plant height was recorded at the end of the growing season in the month of November by selecting five random graftable plants per replication. The plant height was measured with the help of a measuring tape from the ground level to the tip of the shoot and was expressed in centimetres.

3.5.4 Stock diameter (mm)

The data on stock diameter was recorded by selecting five random grafted seedlings and measuring the diameter of the shoot 5 cm below the graft union with the help of Vernier Calipers. The recorded diameter was expressed in millimetres.

3.5.5 Scion diameter (mm)

The data on scion diameter was recorded by selecting five random grafted seedlings and measuring the diameter of the shoot 5 cm above the graft union with the help of Vernier Calipers. The recorded diameter was expressed in millimetres.

3.5.6 Number of leaves per plant

The observations on the number of leaves were recorded by counting the leaves emerged on each of five randomly selected grafted plants per replication in the month of October. The average numbers of leaves per plant were calculated.

3.5.7 Leaf area (cm^2)

Five fully expanded leaves were collected at random from different plants per replication. The leaves were taken from the middle part of the plant during the month of October. The leaf area was measured with the help of 'LI-COR' leaf area meter (Model LI-3000C and was expressed in square centimetres (cm^2).

3.5.8 Chlorophyll content (mg/g) of fresh weight

Five fully expanded and mature leaves from each replication were collected in the month of November during morning hours (Halfacre *et al*., 1968), immediately placed in ice box and brought to the laboratory. The samples were then kept in the refrigerator to avoid degradation of chlorophyll pigments.

Extraction

Leaves from each sample were washed and chopped into fine pieces under subdued light and 100 mg of chopped material was placed in vial containing 7 ml of dimethyl sulphoxide (DMSO**).** The contents of the vials were incubated at 65°C temperature for 30 minutes and then extract was transferred to graduated test tube and the final volume was made to 10 ml with dimethyl sulphoxide (Hiscox and Israelstam, 1979).

Estimation

Optical density (OD) of the above extract was recorded on Spectronic 20 D at 645 nm and 663 nm wavelength against a DMSO blank and total chlorophyll content was calculated by using the following formula:

$$\text{Total chlorophyll} = \frac{20.2\ A_{645} + 8.02\ A_{663}}{A\ \times\ 1000\ \times\ W} \times V$$

Where,

V	=	Volume of extract used
A	=	Length of the light path in cell (1 cm)
W	=	Weight of the sample (g)
A_{645}	=	Absorbance at 645 nm wavelength
A_{663}	=	Absorbance at 663 nm wavelength

The results were expressed as chlorophyll content in mg/g of fresh weight.

3.5.9 Internodal length (cm)

The height of each plant was measured with a measuring tape and total numbers of nodes were counted above graft union in the month of November. The internodal length was then calculated by dividing the scion height to the total number of nodes and was expressed as average internodal length in centimetres (cm).

3.5.10 Average root length (cm)

Five plants per replication were randomly selected from the uprooted plants in the month of December. The average length of root was calculated by measuring the highest, lowest and medium root length and expressed as average root length in centimetres (cm)

3.5.11 Fresh weight of roots (g)

The root portion of five plants per replication was used for recording data on fresh weight on roots. The roots were cut into small pieces and fresh weight was weighed and recorded on top pan electronic balance and expressed in grams per plant.

3.5.12 Dry weight of roots (g)

The roots cut for recording the fresh weight were dried in an oven at temperature of 65°C for about 72 hours. The dry weight of roots was weighed and recorded on top pan electronic balance and expressed in grams per plant.

3.5.13 Fresh weight of shoots (g)

The shoot portion of five plants per replication was used for recording data on fresh weight of shoots. The shoots were cut into small pieces and fresh weight was weighed and recorded on top pan electronic balance and expressed in grams per plant.

3.5.14 Dry weight of shoots (g)

The shoots cut for recording the fresh weight were dried in an oven at temperature of 65°C for about 72 hours. The dry weight of shoot was weighed and recorded on top pan electronic balance and expressed in grams per plant.

3.5.15 Total biomass of nursery plants (g)

The total dry weight of shoots and roots recorded was added to work out the total biomass of plants and expressed in grams (g) on dry weight basis.

3.5.16 Disease incidence (%)

The data on major disease incidence was recorded at the time of uprooting of plants in December by counting the total number of infected plants out of the total number of survived healthy plants and were expressed in percentage.

3.5.17 Per cent survival

Data on survival of plants was taken at the end of the experiment during December by counting the number of grafted plants that survived in each bed prior to uprooting and was then expressed in per cent. The survival (%) of plants was calculated using the formula:

$$\text{Survival (\%)} = \frac{\text{Number of surviving plants}}{\text{Total number of seedlings planted}} \times 100$$

3.5.18 Per cent healthy plants

The data on percent healthy plants was recorded by counting the number of survived, non infectious grafted seedlings after uprooting out of the total number of seedlings planted and were expressed in percentage.

3.5.19 Per cent saleable plants

During last week of December, all plants were uprooted and plants were inspected by inspection committee constituted by Director of research UHF Nauni. The plants with a height

of more than 90 cm with pencil thickness diameter or more, with well developed roots and free from insect pests and diseases were considered to be saleable and the proportion of such plants was calculated for each treatment on a per cent basis.

3.6 STATISTICAL ANALYSIS

The experiment was laid out in Randomised Completely Block Design and the data obtained from the present investigations were subjected to statistical analysis in accordance with the method described by Gomez and Gomez (1984). The level of significance was tested for different variables at 5 per cent level of significance.

ANOVA for RCBD was as follows:

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**$F_{(cal)}$**
Treatments	(t-1)	S_t	$M_t = \frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Replications	(r-1)	S_r	$M_r = \frac{S_r}{(r-1)}$	$\frac{M_r}{M_e}$
Error	(r-1)(t-1)	Se	$M_e = \frac{Se}{(r-1)(t-1)}$	
Total	(rt-1)	S_T	$\frac{S_T}{(rt-1)}$	

Where,

r = Number of replications

t = Number of treatments

S_r = Sum of squares due to replications

S_t = Sum of squares due to treatments

S_e = Sum of squares due to error

S_T = Total sum of squares

M_r = Mean sum of squares due to replications

M_t = Mean sum of squares due to treatments

M_e = Mean sum of squares due to error

The replication and treatment mean sum of square shall be tested against mean sum of squares due to error by 'F' test at (r-1), (r-1) (t-1) and (t-1), (r-1) (t-1) degree of freedom for RCBD at 5% level of significance. The calculated F-values shall be compared with tabulated

F- value. When F- test will be found significant, critical difference will be calculated to find out the superiority of one treatment over the other.

Critical difference (CD) shall be calculated as follows:

$CD_{0.05}$ = S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) df

SE (d) ± = $\sqrt{\frac{2Me}{r}}$

SE (m) ± = $\sqrt{\frac{Me}{r}}$

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference of mean

$CD_{0.05}$ = Critical difference at 5 per cent level of significance

Chapter-4

RESULTS AND DISCUSSION

The present investigations entitled "**Performance of different apple cultivars grafted on seedling rootstock under nursery condition**" were carried out at the Experimental Farm of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP during 2020-21. The results obtained during the course of investigations have been presented and discussed as under:

4.1 PER CENT SPROUTING

The data regarding the per cent sprouting of seedling of different apple cultivars grafted on seedling rootstock are depicted in Table 4.1.

The perusal of data (Table 4.1) reveals that the range of per cent sprouting of seedling was from 97.67 per cent - 100.00 per cent. Maximum per cent sprouting of seedling (100 %) was recorded in T_{13} (Vista Bella grafted on seedling rootstock), which was statistically at par with T_{16} (Gale Gala grafted on seedling rootstock), T_{17} (Gala Mast grafted on seedling rootstock), T_1 (Royal Delicious grafted on seedling rootstock), T_2 (Vance Delicious grafted on seedling rootstock), T_{10} (Chelan Spur grafted on seedling rootstock), T_{11} (Early Red One grafted on seedling rootstock), T_{15} (Redlum Gala grafted on seedling rootstock) and T_6 (Red Velox grafted on seedling rootstock), exhibiting 99.67 per cent, 99.67 per cent, 99.33 per cent, 99.33 per cent, 99.33 per cent, 99.33 per cent, 99.33 per cent and 99.00 per cent survival of seedling, respectively.

Minimum sprouting of seedling (97.67 %) was recorded in T_{12} (King Roat grafted on seedling rootstock) followed by T_3 (Super Chief grafted on seedling rootstock), T_4 (Anna grafted on seedling rootstock), T_7 (Scarlet Spur II grafted on seedling rootstock) all having 98.00 per cent sprouting of seedling.

Table 4.1 Per cent sprouting of seedling of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Sprouting of seedling (%)
T_1	Royal Delicious grafted on seedling rootstock	99.33 (10.02)
T_2	Vance Delicious grafted on seedling rootstock	99.33 (10.02)
T_3	Super Chief grafted on seedling rootstock	98.00 (9.95)
T_4	Anna grafted on seedling rootstock	98.00 (9.95)
T_5	Jeromine grafted on seedling rootstock	98.33 (9.97)
T_6	Red Velox grafted on seedling rootstock	99.00 (10.00)
T_7	Scarlet Spur II grafted on seedling rootstock	98.00 (9.95)
T_8	Red Chief grafted on seedling rootstock	98.67 (9.98)
T_9	Schelet Spur grafted on seedling rootstock	98.33 (9.97)
T_{10}	Chelan Spur grafted on seedling rootstock	99.33 (10.02)
T_{11}	Early Red One grafted on seedling rootstock	99.33 (10.02)
T_{12}	King Roat grafted on seedling rootstock	97.67 (9.93)
T_{13}	Vista Bella grafted on seedling rootstock	100.00 (10.05)
T_{14}	Red Cap grafted on seedling rootstock	98.67 (9.98)
T_{15}	Redlum Gala grafted on seedling rootstock	99.33 (10.02)
T_{16}	Gale Gala grafted on seedling rootstock	99.67 (10.03)
T_{17}	Gala Mast grafted on seedling rootstock	99.67 (10.03)
T_{18}	Granny Smith grafted on seedling rootstock	98.33 (9.97)
	$CD_{0.05}$	0.06

*Figures in parenthesis are square root transformed values

Per cent sprouting of seedling is entirely dependent on rootstock characteristics, its viability, favourable environmental conditions, soil condition and biotic or abiotic stresses (Kviklys *et al*. 2008). Sprouting is influenced by temperature and low sub zero temperature on early dates of grafting, could have delayed the sprouting, while comparatively higher temperature and humidity on later dates may have helped in early sprouting (Pathak, 1991). Further, few of the seedlings might remain dormant and thus were not able sprout as during spring, after the chilling requirement is completed, seedlings are paradormant until temperatures are high enough to permit resumption of growth (Faust, 1989). In our findings the variable sprouting may be due to the genetic variation among seedlings and temperature fluctuations after planting the seedlings.

4.2 PER CENT GRAFT SUCCESS (%)

The data on the per cent graft success of different apple cultivars grafted on seedling rootstock are presented in Table 4.2.

It is evident from the data (Table 4.2) that the range of graft success of different cultivars on seedling rootstock ranged between 90.21 per cent to 95.98 per cent. Highest graft success (95.98 %) was recorded in T_{16} (Gale Gala grafted on seedling rootstock), which was statistically at par with T_{17} (Gala Mast grafted on seedling rootstock), T_{10} (Chelan Spur grafted on seedling rootstock), T_4 (Anna grafted on seedling rootstock), T_7 (Scarlet Spur II grafted on seedling rootstock) and T_{12} (King Roat grafted on seedling rootstock) with graft success of 94.93 per cent, 94.26 per cent, 94.18 per cent, 94.15 per cent and 93.81 per cent, respectively. The graft success (90.21 %) was recorded lowest in T_{11} (Early Red One grafted on seedling rootstock) and was followed by T_8 (Red Chief grafted on seedling rootstock) having 90.83 per cent.

Table 4.2 Per cent graft success of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Graft success (%)
T_1	Royal Delicious grafted on seedling rootstock	92.55 (9.67)
T_2	Vance Delicious grafted on seedling rootstock	93.58 (9.73)
T_3	Super Chief grafted on seedling rootstock	92.79 (9.68)
T_4	Anna grafted on seedling rootstock	94.18 (9.76)
T_5	Jeromine grafted on seedling rootstock	93.56 (9.72)
T_6	Red Velox grafted on seedling rootstock	93.22 (9.71)
T_7	Scarlet Spur II grafted on seedling rootstock	94.15 (9.76)
T_8	Red Chief grafted on seedling rootstock	90.83 (9.58)
T_9	Schelet Spur grafted on seedling rootstock	93.52 (9.72)
T_{10}	Chelan Spur grafted on seedling rootstock	94.26 (9.76)
T_{11}	Early Red One grafted on seedling rootstock	90.21 (9.55)
T_{12}	King Roat grafted on seedling rootstock	93.81 (9.74)
T_{13}	Vista Bella grafted on seedling rootstock	92.26 (9.66)
T_{14}	Red Cap grafted on seedling rootstock	92.49 (9.67)
T_{15}	Redlum Gala grafted on seedling rootstock	91.90 (9.64)
T_{16}	Gale Gala grafted on seedling rootstock	95.98 (9.85)
T_{17}	Gala Mast grafted on seedling rootstock	94.93 (9.80)
T_{18}	Granny Smith grafted on seedling rootstock	92.16 (9.65)
	$CD_{0.05}$	0.11

*Figures in parenthesis are square root transformed values

Generally, a successful grafting includes the formation of necrotic layer, callus production, first cohesion of stock and scion by the callus junction, subsequent reduction or elimination of necrotic layer in callus, differentiation of some cells to the cambial cells, bridging of cambium tissues of stock and scion and finally formation and strong connection of vascular tissues (Estrada-Luna *et al*., 2002; Sitarek, 2006; Pina and Errea, 2008). In fact, these processes are independent events. While necrotic layer formation and cohesion are common to grafts in all treatments, one or more of the process of callus formation, necrotic layer removal and vascular differentiation can be absent. In each plant, grafting includes the formation of a necrotic layer and its subsequent reduction or elimination (Stoddard and McCully, 1980). Necrotic layer formation as a result of wounding, which compartmentalizes the rest of the plant as a defensive mechanism to eliminate invasion of pathogens, is the independent event that is not affected by the scion and rootstock (Stoddard and McCully, 1980; Hartmann *et al*., 1997; Estrada-Luna *et al*., 2002). Injury to the scion during grafting or improper grafting technique is also a big reason for graft failure and incompatibility.

Graft success is influenced by a variety of factors, including ecological, physiological, morphological and genetic factors. Temperature, humidity, the rootstock's growth stage, scion collection time, the time of taking grafted scion parts, grafting technique, skill of the grafting expert and botanical relatedness between the scion and stock are all important factors. Graft incompatibility can result in failure of grafting that is appropriate for the technique and time, as well as a low rate of graft take (Lewis and Alexander, 2008; Hartmann *et al*., 2011). Graft incompatibility is a possibility, particularly when different species/genera are grafted on top of each other.

Our findings are in agreement with the results obtained by Devkota *et al.* (2019), who recorded maximum graft success (92.50 %) in Royal Delicious cultivar of apple at nursery stage. Karamursel and Kalyoncu (2011) also obtained similar observations in per cent graft success rate of Red Chief and cultivars of Gala series in their experiment at nursery stage. In this study, it was determined that rootstocks and cultivars/genotypes had an important effect on the graft sprout ratio. The temperature immediately after grafting has a direct impact on its success and in order for the callus tissue to form the graft,

the environmental conditions, particularly the temperature and humidity, must be ideal. (Hartmann *et al*., 2011; Dolkar *et al*., 2018; Baron *et al*., 2019).

4.3 PLANT HEIGHT (cm)

The data pertaining to the plant height of different apple cultivars grafted on seedling rootstock are given in Table 4.3.

It is clear from the data (Table 4.3) that the maximum height (182.67 cm) was recorded in T_{15} (Redlum Gala grafted on seedling rootstock), which was statistically at par with T_{16} (Gale Gala grafted on seedling rootstock) having the height of 177.83 cm. Minimum plant height (130.50 cm) was reordered in T_9 (Schelet Spur grafted on seedling rootstock) followed by T_8 (Red Chief grafted on seedling rootstock) having height of 132.67 cm.

Table 4.3 Plant height of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Plant height (cm)
T_1	Royal Delicious grafted on seedling rootstock	153.33
T_2	Vance Delicious grafted on seedling rootstock	147.00
T_3	Super Chief grafted on seedling rootstock	138.67
T_4	Anna grafted on seedling rootstock	145.83
T_5	Jeromine grafted on seedling rootstock	169.33
T_6	Red Velox grafted on seedling rootstock	151.67
T_7	Scarlet Spur II grafted on seedling rootstock	158.00
T_8	Red Chief grafted on seedling rootstock	132.67
T_9	Schelet Spur grafted on seedling rootstock	130.50
T_{10}	Chelan Spur grafted on seedling rootstock	144.33
T_{11}	Early Red One grafted on seedling rootstock	140.50
T_{12}	King Roat grafted on seedling rootstock	134.83
T_{13}	Vista Bella grafted on seedling rootstock	146.33
T_{14}	Red Cap grafted on seedling rootstock	170.33
T_{15}	Redlum Gala grafted on seedling rootstock	182.67
T_{16}	Gale Gala grafted on seedling rootstock	177.83
T_{17}	Gala Mast grafted on seedling rootstock	157.17
T_{18}	Granny Smith grafted on seedling rootstock	139.50
	$CD_{0.05}$	8.65

Plant growth is the process by which a plant grows in size through cell division and enlargement, which includes the synthesis of new cellular material and the organisation of subcellular organelles. Plant growth is measured by the increase in plant height, fresh and dry weight of various plant parts. The height of the plant is greatly influenced by the rootstock and scion cultivar and is result of the genetically coded characteristics of the cultivars. Tworkoski and Miller (2007) observed that dwarfing rootstock M-9 had the lowest plant height and scion diameter in apple, while seedling rootstock had the highest. Sotirov *et al.* (2016) reported plant height (119.5 cm) in Granny Smith which he used as control in his performed experiment under nursery condition.

Differences in graft shoot length were most likely due to genetic, ecological and cultivation practices, or could be due to genetic differences between the cultivar and rootstock, ecology and growing conditions (Hartmann *et al*., 2011). Our findings are in consonance with Karamursel and Kalyoncu (2011), who observed maximum plant height and vegetative growth, in Gala series (Mondial Gala) than other apple cultivars at nursery stage. Plant height of Anna cultivar of apple (132.3 cm) was recorded higher by Verma *et al*. (2015) in their experiment conducted at nursery stage. Also, Mohamed *et al*. (2007) conducted an experiment in which they measured the plant height of the Anna cultivar for two years in a row and their findings were analogous to ours. Similarly, Nasr and Soliman (2020) reported the plant height (136.70 cm) of Anna cultivar of apple at nursery stage which resembles with our recorded findings.

Gangwar *et al.* (2010) and Banday *et al* (2020) also reported similar findings regarding plant height of Royal Delicious cultivar in their respective experiments. Gudumac *et al*. (2007) reported scion height (112 cm) in Granny Smith in their experiment which is in accordance to our findings. Csihon (2014) reported that ‘Gala’ cultivar produced the maximum value in terms of tree height among cultivars of the same age, while the ‘Fuji SW’ and the ‘Red Delicious’ sport provided the lowest value. Tree height of 187.50 cm (Golden Reinders) and 185.00 cm (Gala Mast) was reported in his experiment performed by Bostan (2010).

Redlum Gala on seedling rootstock

Royal Delicious on seedling rootstock

Chelan Spur seedling rootstock

Anna on seedling rootstock

Plate 1. Growth performance of different apple cultivars

4.4 STOCK DIAMETER (mm)

The data regarding the stock diameter of different apple cultivars grafted on seedling rootstock are depicted in Table 4.4.

It is evident from the data presented (Table 4.4) that T_{10} (Chelan Spur grafted on seedling rootstock) has the maximum stock diameter (10.85 mm) which was statistically at par with T_9 (Schelet Spur grafted on seedling rootstock), T_5 (Jeromine grafted on seedling rootstock), T_7 (Scarlet Spur II grafted on seedling rootstock) and T_{17} (Gala Mast grafted on seedling rootstock) with stock diameter 10.77 mm, 10.75, 10.70 mm and 10.62 mm, respectively.

Minimum stock diameter (9.47 mm) was recorded in T_{13} (Vista Bella grafted on seedling rootstock) which remained at par with T_{12} (King Roat grafted on seedling rootstock) measuring 9.67 mm stock diameter.

Table 4.4 Stock diameter of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Stock diameter (mm)
T_1	Royal Delicious grafted on seedling rootstock	10.15
T_2	Vance Delicious grafted on seedling rootstock	9.98
T_3	Super Chief grafted on seedling rootstock	9.75
T_4	Anna grafted on seedling rootstock	10.38
T_5	Jeromine grafted on seedling rootstock	10.75
T_6	Red Velox grafted on seedling rootstock	9.90
T_7	Scarlet Spur II grafted on seedling rootstock	10.70
T_8	Red Chief grafted on seedling rootstock	10.02
T_9	Schelet Spur grafted on seedling rootstock	10.77
T_{10}	Chelan Spur grafted on seedling rootstock	10.85
T_{11}	Early Red One grafted on seedling rootstock	9.98
T_{12}	King Roat grafted on seedling rootstock	9.67
T_{13}	Vista Bella grafted on seedling rootstock	9.47
T_{14}	Red Cap grafted on seedling rootstock	10.35
T_{15}	Redlum Gala grafted on seedling rootstock	10.55
T_{16}	Gale Gala grafted on seedling rootstock	10.54
T_{17}	Gala Mast grafted on seedling rootstock	10.62
T_{18}	Granny Smith grafted on seedling rootstock	9.75
	$CD_{0.05}$	0.25

Generally size and diameter of seedling used as rootstock is of pencil thickness (>7 mm). After successful grafting with the scion, the vigour and increase in growth of the stock completely depends upon the genetic characteristics of the rootstock, cultivar grafted on it and environmental conditions (Dolgun *et al*., 2009). Our results are in agreement with the results obtained by Malasi (2017) who conducted experiment on response of different rootstock and scion combinations on the success of grafting in Apple, observed similar trends regarding spur cultivars showing higher stock diameter than other cultivars. Kumar and Ananda (2004) also recorded greater radial growth of tongue grafted with apple cv. Redspur on seedling rootstock. Gangwar *et al.* (2010), in their experiment recorded similar observation of stock girth in Red Delicious cultivar similar to our findings. Negi and Upadhayay (2017) recorded stock diameter of Scarlet Gala in their experiment and results were in accordance to our recorded findings in Gala cultivars under nursery conditions. Sotirov *et al.* (2016) recorded similar stock diameter (10.1 mm) of Granny Smith in their performed experiment under nursery conditions.

4.5 SCION DIAMETER (mm)

The data pertaining to the scion diameter of different apple cultivars grafted on seedling rootstock are shown in Table 4.5.

The data presented (Table 4.5) showed T_{10} (Chelan Spur grafted on seedling rootstock) recorded significantly higher scion diameter 10.45 mm followed by T_9 (Schelet Spur grafted on seedling rootstock) having scion diameter of 10.37 mm. Minimum scion diameter 9.04 mm was recorded in T_{13} (Vista Bella grafted on seedling rootstock) followed by T_3 (Super Chief grafted on seedling rootstock) with 9.22 mm scion diameter.

The stock or scion radial growth is dependent on the vegetative growth characteristics of scion cultivars. The differential growth varies differently for standard and spur type cultivars. The results of our findings are in agreements with the results recorded by Malasi (2017), where similar results of spur varieties showing higher scion diameter than other varieties in the experiment were obtained, as due to compact height of spur cultivars, which resulted in significantly thick scion diameter than other standard

Jeromine on seedling rootstock

Red Cap on seedling rootstock

Vista Bella seedling rootstock

Gale Gala on seedling rootstock

Plate 2. Growth performance of different apple cultivars

apple cultivars. The above findings are also in accordance with Maata (2000), who discussed about vegetative growth including scion girth of Anna cultivar. Verma *et al*. (2015) recorded scion girth (8.73 mm) in his performed experiment on Anna cultivar of apple under nursery conditions. Our observations are in consonance with Mohamed *et al*. (2007), who in their experiment on Anna cultivar recorded the scion diameter 0.81 cm and 0.82 cm for successive years at nursery stage.

Table 4.5 Scion diameter of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Scion diameter (mm)
T_1	Royal Delicious grafted on seedling rootstock	9.55
T_2	Vance Delicious grafted on seedling rootstock	9.30
T_3	Super Chief grafted on seedling rootstock	9.22
T_4	Anna grafted on seedling rootstock	9.67
T_5	Jeromine grafted on seedling rootstock	10.31
T_6	Red Velox grafted on seedling rootstock	9.61
T_7	Scarlet Spur II grafted on seedling rootstock	10.21
T_8	Red Chief grafted on seedling rootstock	9.33
T_9	Schelet Spur grafted on seedling rootstock	10.37
T_{10}	Chelan Spur grafted on seedling rootstock	10.45
T_{11}	Early Red One grafted on seedling rootstock	9.37
T_{12}	King Roat grafted on seedling rootstock	9.30
T_{13}	Vista Bella grafted on seedling rootstock	9.04
T_{14}	Red Cap grafted on seedling rootstock	9.48
T_{15}	Redlum Gala grafted on seedling rootstock	9.89
T_{16}	Gale Gala grafted on seedling rootstock	9.92
T_{17}	Gala Mast grafted on seedling rootstock	9.98
T_{18}	Granny Smith grafted on seedling rootstock	9.26
	$CD_{0.05}$	0.12

Gudumac *et al*. (2007) reported scion diameter (9.20 mm) in Granny Smith in their experiment which is in consonance to our observation recorded. The average stem diameter 8.3 mm (Golden Reinders) and 9.4 mm (Gala Must) at 10 cm above the graft's place in the experiment was recorded by Botsan (2010). Our recorded scion diameter of Granny Smith was in accordance to scion diameter of Granny Smith (9.5 mm) noticed by Sotirov *et al*. (2016) at nursery stage.

4.6 NUMBER OF LEAVES PER PLANT

The data presented in Table 4.6 depicts the number of leaves per plant of different apple cultivars grafted on seedling rootstock.

The perusal of data (Table 4.6) reveals that the number of leaves per plant (44.33) was found significantly higher in T_1 (Royal Delicious grafted on seedling rootstock) which was statistically at par with T_5 (Jeromine grafted on seedling rootstock), T_7 (Scarlet Spur II grafted on seedling rootstock) and T_{15} (Redlum Gala grafted on seedling rootstock) having 42.33, 41.33 and 40.33 leaves per plant. However, the minimum number of leaves per plant (34.33) was recorded in T_{13} (Vista Bella grafted on seedling rootstock) followed by T_3 (Super Chief grafted on seedling rootstock) with 35.00 leaves per plant. The variation in number of leaves is mostly dependent on the plant height and number of nodes. Standard and spur type cultivars varies in their shoot growth and thus giving rise to variation in number of leaves

Table 4.6 Number of leaves per plant of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Number of leaves/plant
T_1	Royal Delicious grafted on seedling rootstock	44.33
T_2	Vance Delicious grafted on seedling rootstock	39.33
T_3	Super Chief grafted on seedling rootstock	35.00
T_4	Anna grafted on seedling rootstock	38.00
T_5	Jeromine grafted on seedling rootstock	42.33
T_6	Red Velox grafted on seedling rootstock	39.00
T_7	Scarlet Spur II grafted on seedling rootstock	41.33
T_8	Red Chief grafted on seedling rootstock	36.00
T_9	Schelet Spur grafted on seedling rootstock	37.67
T_{10}	Chelan Spur grafted on seedling rootstock	38.00
T_{11}	Early Red One grafted on seedling rootstock	37.33
T_{12}	King Roat grafted on seedling rootstock	36.33
T_{13}	Vista Bella grafted on seedling rootstock	34.33
T_{14}	Red Cap grafted on seedling rootstock	38.33
T_{15}	Redlum Gala grafted on seedling rootstock	40.33
T_{16}	Gale Gala grafted on seedling rootstock	39.67
T_{17}	Gala Mast grafted on seedling rootstock	40.00
T_{18}	Granny Smith grafted on seedling rootstock	35.67
	$CD_{0.05}$	4.10

Our findings are in consonance with Gangwar *et al.* (2010), who recorded similar results in number of leaves per plant in Red Delicious cultivar of apple under nursery conditions which may be due to its vigorous nature. Higher number of leaves in Scarlet Spur II might be attributed to more condensed growth of the scion cultivar (Gangwar *et al.*, 2010). Negi and Upadhayay (2017) recorded number of leaves in Scarlet Gala (ranging from 29.03 to 32.00), which are in accordance to our observations regarding number of leaves per plant in Gala cultivars studied in this experiment under nursery conditions.

4.7 LEAF AREA (cm^2)

The data pertaining to the leaf area of different apple cultivars grafted on seedling rootstock are revealed in Table 4.7.

It is evident from the data (Table 4.7) that maximum leaf area (56.23 cm^2) was recorded in T_{13} (Vista Bella grafted on seedling rootstock). This treatment recorded significantly higher leaf area than all the other treatments. It was followed T_1 (Royal Delicious grafted on seedling rootstock) and T_4 (Anna grafted on seedling rootstock) having leaf area of, 34.20 cm^2 and 32.98 cm^2, respectively.

Treatment T_8 (Red Chief grafted on seedling rootstock) recorded minimum leaf area with 24.84 cm^2 closely followed by T_3 (Super Chief grafted on seedling rootstock) having leaf area of 25.60 cm^2.

The size of the leaf is predominantly dependent on the genetic characteristics of the cultivar grafted on the rootstock and then followed by rootstock characteristics, environmental conditions and topography of the nursery. Leaf area and other vegetative growth are also linked with the water supply restriction to the scion induced by anatomical characteristics of the rootstock (Atkinson *et al*., 2003). The leaf area of Anna plant at nursery stage varies from 22.32 cm^2 to 29.29 cm^2 in their experiment conducted by Verma *et al*. (2015) which are in accordance to our observations. Similarly, El-Din *et al.* (2012) had reported leaf area (24.15 cm^2) of Anna cultivar of apple in their experiment under nursery conditions. Negi and Upadhayay (2017) recorded leaf area in

Scarlet Gala ranging from 30.20 cm^2 to 32.77 cm^2, which is in close resemblance to our leaf area observations recorded in Gala cultivars under nursery conditions.

Table 4.7 Leaf area of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Leaf Area (cm^2)
T_1	Royal Delicious grafted on seedling rootstock	34.20
T_2	Vance Delicious grafted on seedling rootstock	32.56
T_3	Super Chief grafted on seedling rootstock	25.60
T_4	Anna grafted on seedling rootstock	32.98
T_5	Jeromine grafted on seedling rootstock	31.27
T_6	Red Velox grafted on seedling rootstock	30.76
T_7	Scarlet Spur II grafted on seedling rootstock	31.39
T_8	Red Chief grafted on seedling rootstock	24.84
T_9	Schelet Spur grafted on seedling rootstock	26.19
T_{10}	Chelan Spur grafted on seedling rootstock	26.44
T_{11}	Early Red One grafted on seedling rootstock	30.72
T_{12}	King Roat grafted on seedling rootstock	29.71
T_{13}	Vista Bella grafted on seedling rootstock	56.23
T_{14}	Red Cap grafted on seedling rootstock	29.58
T_{15}	Redlum Gala grafted on seedling rootstock	31.25
T_{16}	Gale Gala grafted on seedling rootstock	28.80
T_{17}	Gala Mast grafted on seedling rootstock	31.05
T_{18}	Granny Smith grafted on seedling rootstock	30.07
	$CD_{0.05}$	1.65

Our findings are in line with Mohamed *et al.* (2007), who in their experiment recorded similar observations on the leaf area of Anna cultivar for two consecutive years. Blanco *et al.* (2008) recorded higher leaf area in 'Jonagored' apple cultivar under nursery conditions. Dhiman *et al.* (2018) in their experiment recorded leaf area (29.30 cm^2) in Jeromine cultivar which is in accordance to our observations recorded for Jeromine pertaining to leaf area in nursery. Rabi *et al.* (2016) recorded maximum leaf area (40.8 cm^2) in the Gala Mast cultivar on crab apple, whereas apple cultivar Spartan grafted on M-9 rootstock achieves minimum leaf area of 12.05 cm^2. The studies found that apple cultivars grafted on vigorous apple rootstock have more leaf area. These findings corroborate a previous study that showed scions on low-vigour rootstocks had 50 per cent less leaf area than scions on the most vigorous rootstocks. (Micheal *et al*., 2006).

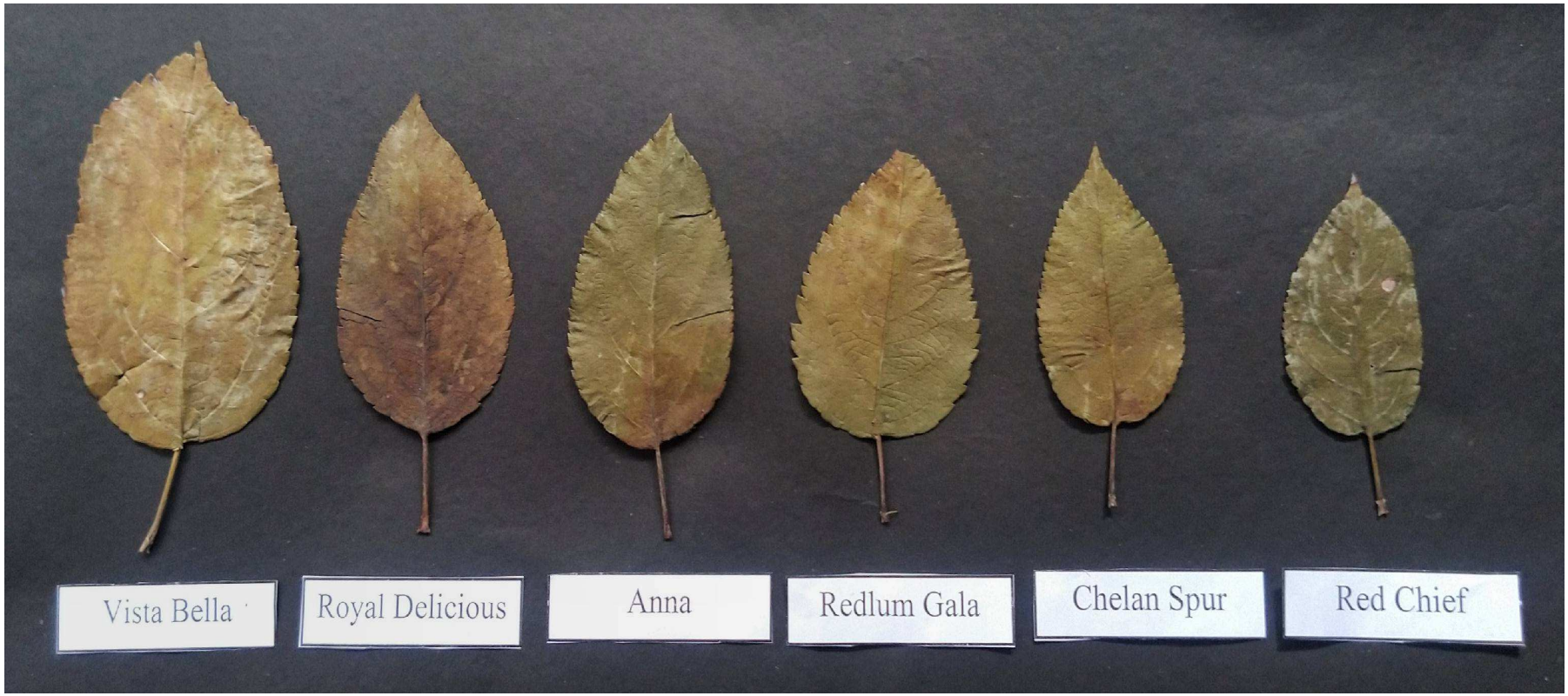


Plate 3. Leaf area of different apple cultivars

4.8 CHLOROPHYLL CONTENT (mg/g)

The data related to the chlorophyll content of the leaves of different apple cultivars grafted on seedling rootstock are depicted in Table 4.8.

It is pertinent from the data (Table 4.8) that the maximum chlorophyll content (2.78 mg/g) was recorded in T_{14} (Red Cap grafted on seedling rootstock) and was significantly higher than other treatments. It was followed by T_{12} (King Roat grafted on seedling rootstock) having chlorophyll content of 2.63 mg/g. Minimum chlorophyll content (2.11 mg/g) was recorded in T_{15} (Redlum Gala grafted on seedling rootstock) followed by T_1 (Royal Delicious grafted on seedling rootstock) having chlorophyll content 2.19 mg/g.

Table 4.8 Chlorophyll content of the leaves of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Chlorophyll content (mg/g)
T_1	Royal Delicious grafted on seedling rootstock	2.19
T_2	Vance Delicious grafted on seedling rootstock	2.32
T_3	Super Chief grafted on seedling rootstock	2.59
T_4	Anna grafted on seedling rootstock	2.34
T_5	Jeromine grafted on seedling rootstock	2.41
T_6	Red Velox grafted on seedling rootstock	2.52
T_7	Scarlet Spur II grafted on seedling rootstock	2.55
T_8	Red Chief grafted on seedling rootstock	2.46
T_9	Schelet Spur grafted on seedling rootstock	2.20
T_{10}	Chelan Spur grafted on seedling rootstock	2.29
T_{11}	Early Red One grafted on seedling rootstock	2.53
T_{12}	King Roat grafted on seedling rootstock	2.63
T_{13}	Vista Bella grafted on seedling rootstock	2.51
T_{14}	Red Cap grafted on seedling rootstock	2.78
T_{15}	Redlum Gala grafted on seedling rootstock	2.11
T_{16}	Gale Gala grafted on seedling rootstock	2.28
T_{17}	Gala Mast grafted on seedling rootstock	2.36
T_{18}	Granny Smith grafted on seedling rootstock	2.32
	$CD_{0.05}$	0.12

The chlorophyll content may vary depending on genetic makeup of plant and leaf area. Photosynthetic activity and absorption of nutrients also influences the chlorophyll content of the different cultivars. Our findings are in accordance with those of Mohamed *et al.* (2007), who used the Anna cultivar in an experiment and tracked the higher total chlorophyll content for successive years. Apple plants grafted on seedling rootstocks showed greater chlorophyll a and b levels in their leaves (Kultebaev, 1975). Westwood and Zielinski (1966) discovered that the chlorophyll level of Starkrimson was higher than that of the Starking Delicious variety of apple.

The leaves of dwarfing apple trees have the highest photosynthetic productivity when compared to robust rootstocks (Titova and Shishkanu, 1976; Maidebura *et al*., 1978; Trunov and Muromtsev, 1980). In other studies of apple cultivars Ferree *et al*. (1975) found that the leaves of Red Spur Delicious had higher net photosynthesis than Rich-a-Red apples. Similarly, when compared to other rootstocks, apple leaves on M9 exhibited greater leaf chlorophyll content (Rud *et al*., 1977; Makariev *et al*., 1986; Chandel and Chauhan, 1992) and photosynthetic intensity (Andryushchenko *et al*., 1977). According to Fallahi *et al*. (2001), leaf photosynthesis was lower in the leaves of "BC-2 Fuji" apple trees grown on Bud.9 rootstock than in those grown on Ottawa 3 and M.7 EMLA rootstocks.

4.9 INTERNODAL LENGTH (cm)

The data related to the internodal length of different apple cultivars grafted on seedling rootstock are given in Table 4.9.

The perusal of data (Table 4.9) reveals that the significantly more internodal length (3.57 cm) was recorded in T_{13} (Vista Bella grafted on seedling rootstock) which was statistically at par with T_1 (Royal Delicious grafted on seedling rootstock), T_2 (Vance Delicious grafted on seedling rootstock, T_{16} (Gale Gala grafted on seedling rootstock) and T_{15} (Redlum Gala grafted on seedling rootstock) having internodal length of 3.41 cm, 3.31 cm, 3.28 cm and 3.23 cm, respectively. The minimum internodal length (2.70 cm) was recorded in T_9 (Schelet Spur grafted on seedling rootstock) closely followed by T_{10} (Chelan Spur grafted on seedling rootstock) recording 2.78 cm internodal length.

The internodal length is dependent on type of cultivars. Standard cultivars exhibit greater internodal length than spur type cultivars. Negi and Upadhayay (2017) recorded maximum internodal length in Scarlet Gala. Large leaf size, less scion diameter and standard size might be the reason for less number of leaves in the Vista Bella, which might have caused higher internodal length of Vista Bella. However in spur cultivars due to compact height, the number of leaves significantly increase which resulted in less internodal length of spur cultivars (Gangwar *et al*., 2010). Karamursel and Kalyoncu (2011) recorded maximum vegetative growth and growth parameters in Gala series cultivars compared to other apple cultivars at the nursery stage.

Table 4.9 Internodal length of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Internodal length (cm)
T_1	Royal Delicious grafted on seedling rootstock	3.41
T_2	Vance Delicious grafted on seedling rootstock	3.31
T_3	Super Chief grafted on seedling rootstock	2.85
T_4	Anna grafted on seedling rootstock	2.93
T_5	Jeromine grafted on seedling rootstock	3.07
T_6	Red Velox grafted on seedling rootstock	2.96
T_7	Scarlet Spur II grafted on seedling rootstock	3.02
T_8	Red Chief grafted on seedling rootstock	2.91
T_9	Schelet Spur grafted on seedling rootstock	2.70
T_{10}	Chelan Spur grafted on seedling rootstock	2.78
T_{11}	Early Red One grafted on seedling rootstock	2.93
T_{12}	King Roat grafted on seedling rootstock	2.81
T_{13}	Vista Bella grafted on seedling rootstock	3.57
T_{14}	Red Cap grafted on seedling rootstock	3.12
T_{15}	Redlum Gala grafted on seedling rootstock	3.23
T_{16}	Gale Gala grafted on seedling rootstock	3.28
T_{17}	Gala Mast grafted on seedling rootstock	3.05
T_{18}	Granny Smith grafted on seedling rootstock	2.91
	$CD_{0.05}$	0.36

4.10 ROOT LENGTH (cm)

The data related to the root length of different apple cultivars grafted on seedling rootstock is given in Table 4.10.

Table 4.10 Root length of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Root length (cm)
T_1	Royal Delicious grafted on seedling rootstock	22.00
T_2	Vance Delicious grafted on seedling rootstock	21.33
T_3	Super Chief grafted on seedling rootstock	19.83
T_4	Anna grafted on seedling rootstock	22.17
T_5	Jeromine grafted on seedling rootstock	23.67
T_6	Red Velox grafted on seedling rootstock	21.00
T_7	Scarlet Spur II grafted on seedling rootstock	23.10
T_8	Red Chief grafted on seedling rootstock	19.17
T_9	Schelet Spur grafted on seedling rootstock	20.50
T_{10}	Chelan Spur grafted on seedling rootstock	20.83
T_{11}	Early Red One grafted on seedling rootstock	23.17
T_{12}	King Roat grafted on seedling rootstock	21.50
T_{13}	Vista Bella grafted on seedling rootstock	22.67
T_{14}	Red Cap grafted on seedling rootstock	26.50
T_{15}	Redlum Gala grafted on seedling rootstock	23.00
T_{16}	Gale Gala grafted on seedling rootstock	25.17
T_{17}	Gala Mast grafted on seedling rootstock	21.67
T_{18}	Granny Smith grafted on seedling rootstock	22.33
	$CD_{0.05}$	2.55

It is evident from the data presented in Table 4.10 that significantly maximum root length (26.50 cm) was observed in T_{14} (Red Cap grafted on seedling rootstock) which was statistically at par with T_{16} (Gale gala grafted on seedling rootstock) recording 25.17 cm root length. Minimum root length (19.17 cm) was observed in T_8 (Red Chief grafted on seedling rootstock) closely followed by T_3 (Super Chief grafted on seedling rootstock) having 19.83 cm root length.

It is generally mistaken that the vigour and growth of root is solely dependent on the type of rootstock used, but the type of cultivar grafted on the stock also plays a crucial role in determination of root vigour and growth as after successful grafting and healing genetically coded characteristics of the cultivar or variety exhibits its impact on role of xylem and phloem, nutritional requirement in the plant. Even sometime during uprooting, due to the presence of taproot system in seedling rootstock, the main primary root gets broken as it penetrates deep in the soil and sometime cannot be fully uprooted. The standard cultivar exhibit vigorous shoot growth which results into more root growth. Negi and Upadhayay (2017) recorded maximum root length (25.78 cm) in Scarlet Gala, which were closely similar to our findings, where more root length was recorded in Gala cultivars under nursery conditions. Rabi *et al*. (2016) recorded maximum root length (20.10 cm) in Gala Mast grafted on crab apple as crab apple, rootstock penetrate deeper and spread horizontally than M26 due to the presence of taproot system.

4.11 FRESH WEIGHT OF ROOT (g)

The data pertaining to the fresh weight of root of different apple cultivars grafted on seedling rootstock are presented in Table 4.11.

It is clear from the data (Table 4.11) that the significantly more fresh weight of root (56.17 g) was recorded in T_5 (Jeromine grafted on seedling rootstock), which was statistically at par with T_{14} (Red Cap grafted on seedling rootstock) having 53.17 g of fresh weight of root. Minimum fresh weight of root (30.17 g) was recorded in T_3 (Super Chief grafted on seedling rootstock) followed by T_8 (Red Chief grafted on seedling rootstock) having fresh weight of root 31.50 gram.

It is evident that different type of scion impacts differently on the rootstock growth and vigour according to its genetic makeup, which include length of root, diameter of primary and secondary root and size of the root. So the fresh weigh of root may be attributed to the fact that scion plays a crucial role in the development of root, which further also depends upon the physical conditions of the soil, insect or disease attack and environmental conditions. Total number of leaves, total leaf area and chlorophyll content also contribute towards the more synthesis of photo assimilates,

which further translocated to the roots. Verma *et al*. (2015) recorded fresh weight of root (14.72 g) in Anna cultivar of apple in his performed experiment under nursery conditions might be due to its standard growth habit. Higher fresh weight in Jeromine and Red Cap might be due to its vigorous growth and more accumulation of assimilates in the root system.

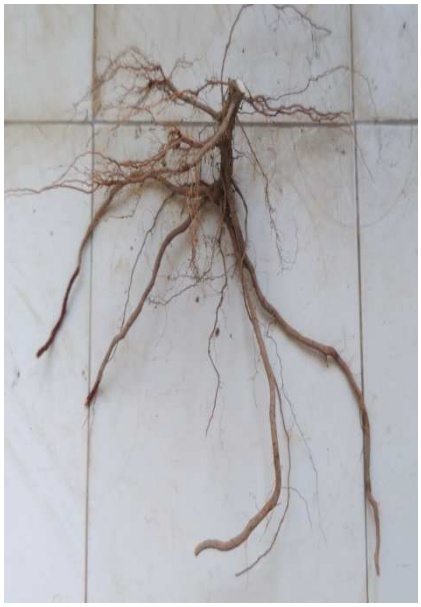
Table 4.11 Fresh weight of root of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Fresh weight of root (g)
T_1	Royal Delicious grafted on seedling rootstock	37.33
T_2	Vance Delicious grafted on seedling rootstock	34.33
T_3	Super Chief grafted on seedling rootstock	30.17
T_4	Anna grafted on seedling rootstock	43.67
T_5	Jeromine grafted on seedling rootstock	56.17
T_6	Red Velox grafted on seedling rootstock	49.83
T_7	Scarlet Spur II grafted on seedling rootstock	49.17
T_8	Red Chief grafted on seedling rootstock	31.50
T_9	Schelet Spur grafted on seedling rootstock	35.00
T_{10}	Chelan Spur grafted on seedling rootstock	37.33
T_{11}	Early Red One grafted on seedling rootstock	43.67
T_{12}	King Roat grafted on seedling rootstock	38.67
T_{13}	Vista Bella grafted on seedling rootstock	33.83
T_{14}	Red Cap grafted on seedling rootstock	53.17
T_{15}	Redlum Gala grafted on seedling rootstock	49.17
T_{16}	Gale Gala grafted on seedling rootstock	51.33
T_{17}	Gala Mast grafted on seedling rootstock	42.67
T_{18}	Granny Smith grafted on seedling rootstock	40.17
	$CD_{0.05}$	4.74

4.12 DRY WEIGHT OF ROOT (g)

The data related to the dry weight of root of different apple cultivars grafted on seedling rootstock is presented in Table 4.12.

Roots in Red Chief cultivar



Roots in Red Cap cultivar

Fresh weight of root of Jeromine cultivar

Dry weight of root of Jeromine cultivar

Plate 4. Root length, fresh weight and dry weight of root of different cultivars of apple

It is pertinent from the data presented (Table 4.12) that significantly higher dry weight of root (35.17 g) was recorded in T_{14} (Red Cap grafted on seedling rootstock), which was statistically at par with T_5 (Jeromine grafted on seedling rootstock) with 34.83 grams of dry weight. Minimum dry weight of root (18.33 g) was recorded in T_3 (Super Chief grafted on seedling rootstock), followed by T_8 (Red Chief grafted on seedling rootstock) having dry weight of root 19.50 grams.

Table 4.12 Dry weight of root of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Dry weight of root (g)
T_1	Royal Delicious grafted on seedling rootstock	22.67
T_2	Vance Delicious grafted on seedling rootstock	21.33
T_3	Super Chief grafted on seedling rootstock	18.33
T_4	Anna grafted on seedling rootstock	28.50
T_5	Jeromine grafted on seedling rootstock	34.83
T_6	Red Velox grafted on seedling rootstock	28.17
T_7	Scarlet Spur II grafted on seedling rootstock	29.17
T_8	Red Chief grafted on seedling rootstock	19.50
T_9	Schelet Spur grafted on seedling rootstock	19.83
T_{10}	Chelan Spur grafted on seedling rootstock	20.17
T_{11}	Early Red One grafted on seedling rootstock	28.17
T_{12}	King Roat grafted on seedling rootstock	24.83
T_{13}	Vista Bella grafted on seedling rootstock	21.33
T_{14}	Red Cap grafted on seedling rootstock	35.17
T_{15}	Redlum Gala grafted on seedling rootstock	28.33
T_{16}	Gale Gala grafted on seedling rootstock	25.83
T_{17}	Gala Mast grafted on seedling rootstock	26.50
T_{18}	Granny Smith grafted on seedling rootstock	22.17
	$CD_{0.05}$	4.62

The difference between high and low dry matter content of the roots may be attributed to the fact that different rootstock have their own genetically coded dry matter content, which is further influenced by the type of cultivar grafted with and biotic and abiotic stresses. Some rootstock have high dry matter content which results in high dry weight and some have the opposite. This phenomenon is not solely the genetic characters of the rootstock and is also influenced by type of scion and some biotic & abiotic

stresses. Our findings are in consonance with those of Lehman *et al*. (1990), who in their performed experiment recorded greater dry weight of root of Delicious cultivar (283.30 g) grafted on seedling rootstock than Delicious cultivar on M 26 rootstock (250.00 g). They recorded lower dry weight of root of Red Chief cultivar on seedling rootstock (111.20 g) than on M 26 rootstock (138.3 g) in a two year old nursery of apple. Verma *et al*. (2015) recorded dry weight of root of Anna cultivar (8.23 g) in their performed experiment.

4.13 FRESH WEIGHT OF SHOOT (g)

The data presented in Table 4.13 depicts the fresh weight of shoot of different apple cultivars grafted on seedling rootstock

Table 4.13 Fresh weight of shoot of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Fresh weight of shoot (g)
T_1	Royal Delicious grafted on seedling rootstock	58.67
T_2	Vance Delicious grafted on seedling rootstock	53.83
T_3	Super Chief grafted on seedling rootstock	41.17
T_4	Anna grafted on seedling rootstock	56.67
T_5	Jeromine grafted on seedling rootstock	68.00
T_6	Red Velox grafted on seedling rootstock	55.50
T_7	Scarlet Spur II grafted on seedling rootstock	62.83
T_8	Red Chief grafted on seedling rootstock	39.67
T_9	Schelet Spur grafted on seedling rootstock	40.17
T_{10}	Chelan Spur grafted on seedling rootstock	57.83
T_{11}	Early Red One grafted on seedling rootstock	50.83
T_{12}	King Roat grafted on seedling rootstock	46.17
T_{13}	Vista Bella grafted on seedling rootstock	40.83
T_{14}	Red Cap grafted on seedling rootstock	62.83
T_{15}	Redlum Gala grafted on seedling rootstock	70.50
T_{16}	Gale Gala grafted on seedling rootstock	66.83
T_{17}	Gala Mast grafted on seedling rootstock	57.67
T_{18}	Granny Smith grafted on seedling rootstock	44.83
	$CD_{0.05}$	4.87

The perusal of data (Table 4.13) reveals that the fresh weight of shoot was recorded maximum (70.50 g) in T_{15} (Redlum Gala grafted on seedling rootstock), which was statistically at par with T_5 (Jeromine grafted on seedling rootstock) and T_{16} (Gale Gala grafted on seedling rootstock) recording fresh weight of shoot of 68.00 g and 66.83 g, respectively. Minimum fresh weight of shoot (39.67 g) was recorded in T_8 (Red Chief grafted on seedling rootstock) followed by T_9 (Schelet Spur grafted on seedling rootstock) and T_{13} (Vista Bella grafted on seedling rootstock) having fresh weight of shoot 40.17 g and 40.83 g, respectively.

Plant growth is the process by which a plant grows in size through cell division and enlargement, which includes the synthesis of new cellular material and the organisation of subcellular organelles. Plant growth is measured by the increase in plant height, size development of scion and stock diameter, water content stored in the plant itself etc. Fresh weight of the plant is greatly influenced by the rootstock and scion cultivar and is result of the genetically coded characteristics of the cultivar. Vegetative growth is linked with the water supply restriction to the scion induced by anatomical characteristics of the rootstock (Atkinson *et al*., 2003). Higher fresh weight of shoots in Redlum Gala, Jeromine and Gale Gala might be due vigorous shoot and root growth. High photoassimilates might have contributed to the more fresh weight of these cultivars.

4.14 DRY WEIGHT OF SHOOT (g)

The data pertaining to the dry weight of shoot of different apple cultivars grafted on seedling rootstock are given in Table 4.14.

It is clear from the data (Table 4.14) that the significantly higher dry weight of shoot (38.50 g) was recorded in T_5 (Jeromine grafted on seedling rootstock), which was statistically at par with T_7 (Scarlet Spur II grafted on seedling rootstock) and T_{15} (Redlum Gala grafted on seedling rootstock) having dry weight of 38.17 g and 38.00 g respectively. Minimum dry weight of shoot (22.00 g) was recorded in T_3 (Super Chief grafted on seedling rootstock) followed by T_8 (Red Chief grafted on seedling rootstock) and T_9 (Schelet Spur grafted on seedling rootstock) having 22.33 g and 23.83 g of dry weight of shoot, respectively.

Table 4.14 Dry weight of shoot of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Dry weight of shoot (g)
T_1	Royal Delicious grafted on seedling rootstock	32.17
T_2	Vance Delicious grafted on seedling rootstock	29.83
T_3	Super Chief grafted on seedling rootstock	22.00
T_4	Anna grafted on seedling rootstock	30.50
T_5	Jeromine grafted on seedling rootstock	38.50
T_6	Red Velox grafted on seedling rootstock	29.20
T_7	Scarlet Spur II grafted on seedling rootstock	38.17
T_8	Red Chief grafted on seedling rootstock	22.33
T_9	Schelet Spur grafted on seedling rootstock	23.83
T_{10}	Chelan Spur grafted on seedling rootstock	33.17
T_{11}	Early Red One grafted on seedling rootstock	29.00
T_{12}	King Roat grafted on seedling rootstock	27.67
T_{13}	Vista Bella grafted on seedling rootstock	27.67
T_{14}	Red Cap grafted on seedling rootstock	37.17
T_{15}	Redlum Gala grafted on seedling rootstock	38.00
T_{16}	Gale Gala grafted on seedling rootstock	34.33
T_{17}	Gala Mast grafted on seedling rootstock	30.00
T_{18}	Granny Smith grafted on seedling rootstock	28.00
	$CD_{0.05}$	3.92

The difference between high and low dry matter content of the shoot may be attributed to the fact that different cultivars have their own genetically coded dry matter content which is further influenced by the type of rootstock it is grafted on and biotic and abiotic stresses. Some cultivars have high dry matter content, which results in high dry weight and some have the opposite. This phenomenon is solely the genetic characters of the cultivars and is only influenced by type of stock and some biotic and abiotic stresses. In standard cultivars there is more shoot and root growth. Therefore, more accumulation of photosynthates and more absorption of nutrient might be the reason for accumulation of more dry matter content. Our findings are in accordance with Lehman *et al*. (1990) who in their performed experiment recorded higher dry weight of shoot of Delicious

cultivar grafted on M26 rootstock (356.60 g) than Delicious cultivar grafted on seedling rootstock (314.90 g) in a two year old apple nursery.

4.15 BIOMASS OF NURSERY PLANT (g)

The data pertaining to the biomass of nursery plant (without leaves) of different apple cultivars grafted on seedling rootstock are presented in Table 4.15.

It is evident from the data (Table 4.15) that the maximum biomass (73.33 g) was observed in T_5 (Jeromine grafted on seedling rootstock), which was statistically at par with T_{14} (Red Cap grafted on seedling rootstock), T_7 (Scarlet Spur II grafted on seedling rootstock) and T_{15} (Redlum Gala grafted on seedling rootstock) having biomass of 72.33 g, 67.33 and 66.33 g respectively.

Table 4.15 Biomass of nursery plant (without leaves) of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Biomass (g)
T_1	Royal Delicious grafted on seedling rootstock	54.83
T_2	Vance Delicious grafted on seedling rootstock	51.17
T_3	Super Chief grafted on seedling rootstock	40.33
T_4	Anna grafted on seedling rootstock	59.00
T_5	Jeromine grafted on seedling rootstock	73.33
T_6	Red Velox grafted on seedling rootstock	57.37
T_7	Scarlet Spur II grafted on seedling rootstock	67.33
T_8	Red Chief grafted on seedling rootstock	41.83
T_9	Schelet Spur grafted on seedling rootstock	43.67
T_{10}	Chelan Spur grafted on seedling rootstock	53.33
T_{11}	Early Red One grafted on seedling rootstock	57.17
T_{12}	King Roat grafted on seedling rootstock	52.50
T_{13}	Vista Bella grafted on seedling rootstock	49.00
T_{14}	Red Cap grafted on seedling rootstock	72.33
T_{15}	Redlum Gala grafted on seedling rootstock	66.33
T_{16}	Gale Gala grafted on seedling rootstock	60.17
T_{17}	Gala Mast grafted on seedling rootstock	56.50
T_{18}	Granny Smith grafted on seedling rootstock	50.17
	$CD_{0.05}$	6.70

Minimum biomass (40.33 g) was observed in T_3 (Super Chief grafted on seedling rootstock) followed by T_8 (Red Chief grafted on seedling rootstock) and T_9 (Schelet Spur grafted on seedling rootstock) having biomass of 41.83 and 43.67 g respectively. The biomass of nursery plant of different apple cultivars was calculated by adding the dry weight of shoots and dry weight of roots.

The higher biomass of plants is dependent on the more shoot and root dry matter content stored in the plants. Lehman *et al*. (1990) recorded the total biomass or dry matter of tree (root and shoot excluding leaves) of a two year old apple nursery and observed that biomass of Delicious cultivar grafted on M26 rootstock (606.60 g) was recorded to be higher than Delicious cultivar grafted on seedling rootstock (598.10 g). He observed the same trend in Red Chief cultivar on M26 rootstock (385.10 g) having greater biomass than Red Chief cultivar grafted on seedling rootstock (307.30 g).

4.16 DISEASE INCIDENCE

The data pertaining to the disease incidence of different apple cultivars grafted on seedling rootstock are presented in Table 4.16.

The perusal of data (Table 4.16) reveals that the maximum disease incidence of crown gall (9.33 %) was observed in T_{12} (King Roat grafted on seedling rootstock) and was significantly higher than other treatments. It was followed by T_{18} (Granny Smith grafted on seedling rootstock), T_{13} (Vista Bella grafted on seedling rootstock) and T_8 (Red Chief grafted on seedling rootstock) having crown gall incidence of 8.33 per cent, 6.67 per cent and 6.67 per cent, respectively. Minimum crown gall incidence (3.33 %) was observed in T_{15} (Redlum Gala grafted on seedling rootstock) followed by T_2 (Vance Delicious grafted on seedling rootstock) having crown gall incidence of 3.67 per cent. Maximum disease incidence of hairy root (4.67 %) was recorded in T_7 (Scarlet Spur II grafted on seedling rootstock) which was found to be statistically at par with T_2 (Vance Delicious grafted on seedling rootstock), T_3 (Super Chief grafted on seedling rootstock), T_4 (Anna grafted on seedling rootstock), T_{10} (Chelan Spur grafted on seedling rootstock), T_5 (Jeromine grafted on seedling rootstock) and T_1 (Royal Delicious grafted on seedling rootstock) having hairy root incidence of 3.67 per cent, 3.67 per cent, 3.67 per cent, 3.33

per cent and 3.00 per cent, respectively. Minimum hairy root incidence was recorded in T_{16} (Gale Gala grafted on seedling rootstock), T_{11} (Early Red One grafted on seedling rootstock), T_{13} (Vista Bella grafted on seedling rootstock) and T_{14} (Red Cap grafted on seedling rootstock) and T_{18} (Granny Smith grafted on seedling rootstock) all having hairy root incidence of 2.00 per cent.

Table 4.16 Disease incidence of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Disease Incidence (%)	
		Crown Gall	Hairy Root
T_1	Royal Delicious grafted on seedling rootstock	4.67 (2.37)	3.00 (2.00)
T_2	Vance Delicious grafted on seedling rootstock	3.67 (2.16)	3.67 (2.16)
T_3	Super Chief grafted on seedling rootstock	6.00 (2.64)	3.67 (2.16)
T_4	Anna grafted on seedling rootstock	4.33 (2.31)	3.67 (2.16)
T_5	Jeromine grafted on seedling rootstock	5.33 (2.51)	3.33 (2.07)
T_6	Red Velox grafted on seedling rootstock	5.67 (2.58)	2.67 (1.87)
T_7	Scarlet Spur II grafted on seedling rootstock	4.67 (2.38)	4.67 (2.38)
T_8	Red Chief grafted on seedling rootstock	6.67 (2.77)	2.67 (1.90)
T_9	Schelet Spur grafted on seedling rootstock	5.33 (2.52)	2.67 (1.91)
T_{10}	Chelan Spur grafted on seedling rootstock	5.67 (2.58)	3.33 (2.08)
T_{11}	Early Red One grafted on seedling rootstock	6.33 (2.67)	2.00 (1.72)
T_{12}	King Roat grafted on seedling rootstock	9.33 (3.21)	2.67 (1.91)
T_{13}	Vista Bella grafted on seedling rootstock	6.67 (2.77)	2.00 (1.72)
T_{14}	Red Cap grafted on seedling rootstock	4.67 (2.38)	2.00 (1.72)
T_{15}	Redlum Gala grafted on seedling rootstock	3.33 (2.08)	3.00 (1.99)
T_{16}	Gale Gala grafted on seedling rootstock	4.00 (2.23)	2.00 (1.72)
T_{17}	Gala Mast grafted on seedling rootstock	5.00 (2.45)	3.00 (1.99)
T_{18}	Granny Smith grafted on seedling rootstock	8.33 (3.05)	2.00 (1.73)
	$CD_{0.05}$	0.28	0.39

*Figures in parenthesis are square root transformed values

Crown gall is caused by a rod shaped flagellated, gram negative soil borne bacterium *Agrobacterium tumefaciens* (Smith and Townsend, 1907), (now name changed to *Rhizobium radiobacter*). The galls provide a nutrient rich environment for the growth of *A. tumefaciens* and it returns to the soil as the galls decompose (Gillman, 2005). Crown gall tumours result from overproduction of two plant growth hormones, auxin and

cytokinin, in plant cells transformed by *A. tumefaciens.* (Winans 1992; Zambryski 1992). In the soil, survival of the organism is well documented (Burr and Katz, 1983). From the soil, with the help of flagella they swim towards photoassimilates that accumulate in the rhizosphere around roots. Some strains may chemotactically move towards chemicals that indicate a wounded plant cell, where they colonize on the plant's wounded tissue. These wounds may be made by use of agriculture tools while grafting, cultivation practices or frost injury cracks. *A. tumefaciens* manages to survive in the rhizosphere on materials that leak from wounded host plant stems and roots; these are sugars and phenolic compounds and attract the motile crown gall bacteria.

Similar to crown gall, hairy root (causal organism: *Rhizobium rhizogenes*) is a soil dwelling bacteria which lives on the rhizosphere of plant roots. These bacteria are capable of gene transfer and thus some strains of R. *rhizogenes* have acquired the ability to cause crown galls but *R. rhizogenes* are most commonly known for causing hairy root (De Cleene and De Ley, 1981). When a plant is wounded, it releases compounds that are sensed by bacterium in the soil. *R. rhizogenes* is attracted to plant wounds and can transfer its DNA into the host cell by transferring a portion of the root-inducing (Ri) plasmid to the host cell. The transferred DNA (T-DNA) is integrated into the plant cell genome. After integration the plant produces an abundance of growth hormones and opines which are beneficial for growth of *R. rhizogenes* (Gafni and Levy, 2005). The incidences of these diseases are entirely natural and no specific cause for their infestation in the nursery can be identified. Both diseases are soil-borne diseases, so the presence of these bacteria in the soil, previous year's crop may be a cause of their infestation because the bacterium survives in the soil as discussed earlier. Furthermore, the infestation rate is also entirely natural, as none of the cultivars are more or less susceptible or resistant to crown gall and hairy root and the percentage of infestation is most probably dependent on the grafting wounds, frost injury cracks and the presence of bacterium in the soil of that particular cultivar bed.

4.17 PER CENT SURVIVAL

The data pertaining to the per cent survival of different apple cultivars grafted on seedling rootstock are presented in Table 4.17.

It is pertinent from the data (Table 4.17) that the maximum survival rate (94.33 %) was recorded in T_{16} (Gale Gala grafted on seedling rootstock). It was significantly higher than all the other treatments. It was followed by T_{17} (Gala Mast grafted on seedling rootstock), T_{10} (Chelan Spur grafted on seedling rootstock) and T_2 (Vance Delicious grafted on seedling rootstock) with per cent survival of 91.67 per cent, 90.67 per cent and 90.00 per cent respectively.

Table 4.17 Per cent survival of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Survival (%)
T_1	Royal Delicious grafted on seedling rootstock	89.00 (9.47)
T_2	Vance Delicious grafted on seedling rootstock	90.00 (9.54)
T_3	Super Chief grafted on seedling rootstock	88.33 (9.45)
T_4	Anna grafted on seedling rootstock	89.00 (9.49)
T_5	Jeromine grafted on seedling rootstock	89.67 (9.52)
T_6	Red Velox grafted on seedling rootstock	89.33 (9.50)
T_7	Scarlet Spur II grafted on seedling rootstock	89.00 (9.49)
T_8	Red Chief grafted on seedling rootstock	87.00 (9.38)
T_9	Schelet Spur grafted on seedling rootstock	89.33 (9.50)
T_{10}	Chelan Spur grafted on seedling rootstock	90.67 (9.57)
T_{11}	Early Red One grafted on seedling rootstock	87.00 (9.38)
T_{12}	King Roat grafted on seedling rootstock	88.00 (9.43)
T_{13}	Vista Bella grafted on seedling rootstock	88.67 (9.47)
T_{14}	Red Cap grafted on seedling rootstock	88.00 (9.43)
T_{15}	Redlum Gala grafted on seedling rootstock	88.67 (9.47)
T_{16}	Gale Gala grafted on seedling rootstock	94.33 (9.76)
T_{17}	Gala Mast grafted on seedling rootstock	91.67 (9.63)
T_{18}	Granny Smith grafted on seedling rootstock	88.00 (9.43)
	$CD_{0.05}$	0.09

*Figures in parenthesis are square root transformed values

Minimum survival rate was recorded in T_8 (Red Chief grafted on seedling rootstock) and T_{11} (Early Red One grafted on seedling rootstock) both having survival rate of 87.00 per cent.

The difference in survival rate of the different cultivars might be attributed due to the factors like proper graft union, sprouting of seedling, movement of sap, healing and

failure of graft union which results in drying and ultimately death to the grafted plant. Grafting failure due to incompatibility or improper cuts on stock and scion at graft union may be another factor accounting for survival of grafts. Also due to presence of unfavourable environmental conditions during grafting, results in the weak or dead plants.

Genotypes with graft incompatibility, although all other factors be suitable, a common complete tissue cannot be formed between the grafted plant parts and these two parts cannot survive for a long time (Ermel *et al.*, 1997). Hudina *et al*. (2014) investigated the graft compatibility/incompatibility status of some standard pear cultivars grafted on various rootstocks and found that the survival ratio varied between 25 per cent and 100 per cent. They found that the pear cultivars 'Williams', 'Conference' and 'Abate Fetel' had the lowest survival ratios and that this was due to biochemical factors. It has been emphasised that graft incompatibility is a complex event that can be caused by physiological, anatomical, or biochemical factors and that the survival ratio is lower in scion/stock combinations with high graft incompatibility (Errea, 1998; Pina and Errea, 2005).

4.18 PER CENT HEALTHY PLANTS

The data pertaining to the per cent healthy plants of different apple cultivars grafted on seedling rootstock are presented in Table 4.18.

It is evident from the data (Table 4.18) that the maximum healthy plants (88.33 %), were observed in T_{16} (Gale Gala grafted on seedling rootstock) and was significantly higher than other treatments. It was followed by T_{17} (Gala Mast grafted on seedling rootstock), T_2 (Vance Delicious grafted on seedling rootstock) and T_{15} (Redlum Gala grafted on seedling rootstock) with per cent healthy plants 83.33 per cent, 82.67 per cent and 82.33 per cent, respectively.

Minimum healthy plants (76.00 %), were recorded in T_{12} (King Roat grafted on seedling rootstock) followed by T_8 (Red Chief grafted on seedling rootstock) i.e. 77.67 per cent and both T_3 (Super Chief grafted on seedling rootstock), T_{11} (Early Red One

Crown gall infected plant of King Roat cultivar

Hairy root infected plant of Scarlet Spur II cultivar

Saleable plants of Gale Gala cultivar

Undersize plants of Schelet Spur cultivar

Plate 5. Diseased and healthy plants of different apple cultivars

grafted on seedling rootstock) having 78.67 per cent. The plants survived and selected after discarding diseased plants are termed as the healthy plants which are classified on the basis of height, thickness of scion and sound root system.

Table 4.18 Per cent healthy plants of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Healthy Plants (%)
T_1	Royal Delicious grafted on seedling rootstock	81.33 (9.07)
T_2	Vance Delicious grafted on seedling rootstock	82.67 (9.15)
T_3	Super Chief grafted on seedling rootstock	78.67 (8.93)
T_4	Anna grafted on seedling rootstock	81.00 (9.06)
T_5	Jeromine grafted on seedling rootstock	81.00 (9.06)
T_6	Red Velox grafted on seedling rootstock	81.00 (9.06)
T_7	Scarlet Spur II grafted on seedling rootstock	79.67 (8.98)
T_8	Red Chief grafted on seedling rootstock	77.67 (8.87)
T_9	Schelet Spur grafted on seedling rootstock	81.33 (9.04)
T_{10}	Chelan Spur grafted on seedling rootstock	81.67 (9.09)
T_{11}	Early Red One grafted on seedling rootstock	78.67 (8.93)
T_{12}	King Roat grafted on seedling rootstock	76.00 (8.78)
T_{13}	Vista Bella grafted on seedling rootstock	80.00 (9.00)
T_{14}	Red Cap grafted on seedling rootstock	81.33 (9.07)
T_{15}	Redlum Gala grafted on seedling rootstock	82.33 (9.13)
T_{16}	Gale Gala grafted on seedling rootstock	88.33 (9.45)
T_{17}	Gala Mast grafted on seedling rootstock	83.67 (9.20)
T_{18}	Granny Smith grafted on seedling rootstock	77.67 (8.87)
	$CD_{0.05}$	0.09

*Figures in parenthesis are square root transformed values

4.19 PER CENT SALEABLE PLANTS

The data pertaining to the per cent saleable plants of different apple cultivars grafted on seedling rootstock are presented in Table 4.19.

The perusal of data (Table 4.19) reveals that the maximum saleable plants (78.00 %) were observed in T_{16} (Gale Gala grafted on seedling rootstock), which was statistically at par with T_5 (Jeromine grafted on seedling rootstock) having per cent saleable plants of 76.67 per cent.

Minimum saleable plants (66.33 %), were observed in T_{12} (King Roat grafted on seedling rootstock) followed by T_{18} (Granny Smith grafted on seedling rootstock) and T_{11} (Early Red One grafted on seedling rootstock) i.e. 69.33 per cent and 70.00 per cent respectively.

Table 4.19 Per cent saleable plants of different apple cultivars grafted on seedling rootstock

Treatment Code	Treatments	Saleable Plants (%)
T_1	Royal Delicious grafted on seedling rootstock	74.67 (59.76)
T_2	Vance Delicious grafted on seedling rootstock	74.00 (59.32)
T_3	Super Chief grafted on seedling rootstock	71.33 (57.61)
T_4	Anna grafted on seedling rootstock	75.00 (59.98)
T_5	Jeromine grafted on seedling rootstock	76.67 (61.09)
T_6	Red Velox grafted on seedling rootstock	75.67 (60.42)
T_7	Scarlet Spur II grafted on seedling rootstock	73.00 (58.67)
T_8	Red Chief grafted on seedling rootstock	69.67 (56.56)
T_9	Schelet Spur grafted on seedling rootstock	69.33 (56.35)
T_{10}	Chelan Spur grafted on seedling rootstock	70.67 (57.19)
T_{11}	Early Red One grafted on seedling rootstock	70.00 (56.77)
T_{12}	King Roat grafted on seedling rootstock	66.33 (54.51)
T_{13}	Vista Bella grafted on seedling rootstock	72.00 (58.03)
T_{14}	Red Cap grafted on seedling rootstock	73.67 (59.10)
T_{15}	Redlum Gala grafted on seedling rootstock	76.00 (60.65)
T_{16}	Gale Gala grafted on seedling rootstock	78.00 (62.01)
T_{17}	Gala Mast grafted on seedling rootstock	74.00 (59.32)
T_{18}	Granny Smith grafted on seedling rootstock	69.33 (56.36)
	$CD_{0.05}$	1.09

*Figures in parenthesis are angular root transformed values

The plants with a height of more than 90 cm, having pencil thickness diameter or more, bearing well developed roots and free from insect pests and disease infestations were considered to be saleable plants. The undersized healthy plants were not categorized as saleable plants as they don't met conditions required for saleable plants. The cultivars of Gala series had induced larger vegetative growth variables than others which aid them to exhibit high healthy and saleable per cent than other cultivars. Karamursel and Kalyoncu (2011) had already discussed maximum vegetative growth in Gala series cultivars that had met all the standards for saleable plants, resulting in highest number of saleable plants than other apple cultivars at nursery stage in their performed experiment.

Chapter-5

SUMMARY AND CONCLUSION

The present investigations entitled "**Performance of different apple cultivars grafted on seedling rootstock under nursery condition**" were carried out at the Experimental Farm of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP during 2020-21. The experiment was laid out in Randomized Complete Block Design with 18 treatment combinations of apple cultivars on seedling rootstock.

The result thus obtained and conclusion drawn from the present study is summarized as under:

5.1 Among the various treatments, maximum percent sprouting of seedling (100 %) was recorded in T_{13} (Vista Bella grafted on seedling rootstock). Whereas, minimum percent sprouting of seedling (97.67 %) was recorded in T_{12} (King Roat grafted on seedling rootstock).

5.2 Maximum graft success (95.98 %) was recorded in T_{16} (Gale Gala grafted on seedling rootstock). On the other hand, minimum graft success (90.21 %) in T_{11} (Early Red One grafted on seedling rootstock).

5.3 The maximum height (182.67 cm) was recorded in T_{15} (Redlum Gala grafted on seedling rootstock). Whereas, minimum plant height (130.50 cm) was reordered in T_9 (Schelet Spur grafted on seedling rootstock).

5.4 Treatment T_{10} (Chelan Spur grafted on seedling rootstock) exhibited the maximum stock diameter (10.85 mm) among various other treatments. However, minimum stock diameter (9.47 mm) was recorded in T_{13} (Vista Bella grafted on seedling rootstock).

5.5 The maximum scion diameter (10.45 mm) was recorded in T_{10} (Chelan Spur grafted on seedling rootstock), while the minimum scion diameter (9.04 mm) was recorded in T_{13} (Vista Bella grafted on seedling rootstock).

5.6 The number of leaves per plant (44.33) was found maximum in T_1 (Royal Delicious grafted on seedling rootstock). However, the minimum number of leaves per plant (34.33) was recorded in T_{13} (Vista Bella grafted on seedling rootstock).

5.7 The maximum leaf area (56.23 cm^2) among all other treatments was recorded in T_{13} (Vista Bella grafted on seedling rootstock), while T_8 (Red Chief grafted on seedling rootstock) recorded minimum leaf area with (24.84 cm^2).

5.8 The maximum chlorophyll content (2.78 mg/g) was recorded in T_{14} (Red Cap grafted on seedling rootstock). On the other hand, minimum chlorophyll content (2.11 mg/g) was recorded in T_{15} (Redlum Gala grafted on seedling rootstock).

5.9 The internodal length (3.57 cm) was recorded maximum among all other treatments in T_{13} (Vista Bella grafted on seedling rootstock), whereas minimum internodal length (2.70 cm) was recorded in T_9 (Schelet Spur grafted on seedling rootstock).

5.10 The maximum root length (26.50 cm) was observed in T_{14} (Red Cap grafted on seedling rootstock). However, minimum root length (19.17 cm) was observed in T_8 (Red Chief grafted on seedling rootstock).

5.11 Among all the other treatments, maximum fresh weight of root (56.17 g) was recorded in T_5 (Jeromine grafted on seedling rootstock). The minimum fresh weight of root (30.17 g) was recorded in T_3 (Super Chief grafted on seedling rootstock).

5.12 Maximum dry weight of root (35.17 g) was recorded in T_{14} (Red Cap grafted on seedling rootstock), whereas minimum dry weight of root (18.33 g) was recorded in T_3 (Super Chief grafted on seedling rootstock).

5.13 The fresh weight of shoot was recorded maximum (70.50 g) in T_{15} (Redlum Gala grafted on seedling rootstock) among all the other treatments. However, the minimum fresh weight of shoot (39.67 g) was recorded in T_8 (Red Chief grafted on seedling rootstock).

5.14 The maximum dry weight of shoot (38.50 g) was recorded in T_5 (Jeromine grafted on seedling rootstock). On the other hand minimum dry weight of shoot (22.00 g) was recorded in T_3 (Super Chief grafted on seedling rootstock).

5.15 The maximum biomass (73.33 g) was observed in T_5 (Jeromine grafted on seedling rootstock) among all other treatments. However, minimum biomass (40.33 g) was observed in T_3 (Super Chief grafted on seedling rootstock).

5.16 Maximum disease incidence of crown gall (9.33 %) was observed in T_{12} (King Roat grafted on seedling rootstock). On the other hand, minimum crown gall incidence (3.33 %) was observed in T_{15} (Redlum Gala grafted on seedling rootstock). However, maximum disease incidence of hairy root (4.67 %) was recorded in T_7 (Scarlet Spur II grafted on seedling rootstock). Whereas, minimum hairy root incidence was recorded in T_{16} (Gale Gala grafted on seedling rootstock), T_{11} (Early Red One grafted on

seedling rootstock), T_{13} (Vista Bella grafted on seedling rootstock) and T_{18} (Granny Smith grafted on seedling rootstock) all having hairy root incidence of 2.00 per cent.

5.17 Maximum survival rate (94.33 %) was recorded in T_{16} (Gale Gala grafted on seedling rootstock) among all other treatments. Whereas, minimum survival rate was recorded in T_8 (Red Chief grafted on seedling rootstock) and T_{11} (Early Red One grafted on seedling rootstock) both having survival rate of 87.00 per cent.

5.18 The maximum healthy plants (88.33 %), were recorded in T_{16} (Gale Gala grafted on seedling rootstock). On the other hand minimum percent healthy plants (76.00 %), were observed in T_{12} (King Roat grafted on seedling rootstock).

5.19 The maximum saleable plants (78.00 %) were observed in T_{16} (Gale Gala grafted on seedling rootstock). However, minimum percent plants (66.33 %), was observed in T_{12} (King Roat grafted on seedling rootstock).

CONCLUSION

On the basis of present investigations, it can be concluded that among the different cultivars under nursery condition, Gala series of apple has induced maximum vegetative growth variables. Redlum Gala exhibited maximum plant height (182. 67 cm) and fresh weight of shoot (70.50 g). Gale Gala cultivar of apple has recorded the maximum graft success (95.98 %), survival per cent (98.95 %), healthy (88.33 %) and saleable plants (78.00 %). Spur cultivar like Chelan Spur had recorded compact growth with maximum scion (10.45 mm) and stock diameter (10.85 mm) among all other cultivar groups. Vista Bella recorded the maximum leaf area (56.23 cm^2) and internodal length (3.57 cm). Maximum root length (26.50 cm), dry weight of root (35.17 g) and leaf chlorophyll content (2.78 mg/g) was recorded in Red Cap cultivar. Whereas, maximum fresh weight of root (56.17 g), dry weight of shoot (38.50 g) and biomass was recorded in Jeromine cultivar of apple. These types of studies may be a tool for the nurserymen regarding survival and quality planting material production. It emphasises that it is not possible to get cent per cent planting material for sale, even the same root system, there is variation in morphological features of plants based on its genetic makeup.

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APPENDIX-I

Monthly meteorological data during crop growth period from January 2020 to December 2020

Month	Temperature (˚C)		RH (%)	Rainfall (mm)
	Minimum	Maximum		
January	2.5	15.7	66	168.3
February	4.1	20.3	63	38.5
March	7.2	21.2	53	171.8
April	10.7	26.8	40	47.7
May	14.4	29.7	40	74.8
June	17.4	30.8	56	58.7
July	19.9	30.2	84	278.1
August	20.7	29.2	86	148.6
September	17.6	30.6	79	6.0
October	11.0	29.8	64	0
November	5.5	23.7	60	37.7
December	2.5	21.9	62	23.8

APPENDIX-II

Performance of different apple cultivars grafted on seedling rootstock under nursery condition

ANOVA for per cent sprouting of seedling

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.005			
Treatment	17	0.062	0.004	2.994	0.00317
Error	34	0.042	0.001		
Total	53	0.109			

ANOVA for per cent graft success

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.020			
Treatment	17	0.418	0.025	8.622	0.00000
Error	34	0.097	0.003		
Total	53	0.535			

ANOVA for plant height

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	2.583			
Treatment	17	12,139.542	714.091	26.518	0.00000
Error	34	915.583	26.929		
Total	53	13,057.708			

ANOVA for stock diameter

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.062			
Treatment	17	9.609	0.565	25.564	0.00000
Error	34	0.752	0.022		
Total	53	10.423			

ANOVA for scion diameter

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.010			
Treatment	17	9.968	0.586	105.793	0.00000
Error	34	0.188	0.006		
Total	53	10.167			

ANOVA for number of leaves/plant

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	49.778			
Treatment	17	347.500	20.441	3.370	0.00125
Error	34	206.222	6.065		
Total	53	603.500			

ANOVA for leaf area

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	2.139			
Treatment	17	2,315.901	136.229	138.218	-0.00000
Error	34	33.511	0.986		
Total	53	2,351.550			

ANOVA for chlorophyll content

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.041			
Treatment	17	1.531	0.090	16.180	0.00000
Error	34	0.189	0.006		
Total	53	1.761			

ANOVA for internodal length

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.040			
Treatment	17	2.777	0.163	3.567	0.00078
Error	34	1.557	0.046		
Total	53	4.375			

ANOVA for root length

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	10.613			
Treatment	17	163.943	9.644	4.109	0.00022
Error	34	79.793	2.347		
Total	53	254.349			

ANOVA for fresh weight of root

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	10.176			
Treatment	17	3,195.856	187.992	23.243	0.00000
Error	34	274.991	8.088		
Total	53	3,481.023			

ANOVA for dry weight of root

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	16.287			
Treatment	17	1,282.856	75.462	9.822	0.00000
Error	34	261.213	7.683		
Total	53	1,560.356			

ANOVA for fresh weight of shoot

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	6.398			
Treatment	17	5,214.412	306.730	35.887	0.00000
Error	34	290.602	8.547		
Total	53	5,511.412			

ANOVA for dry weight of shoot

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	4.145			
Treatment	17	1,374.085	80.829	14.629	0.00000
Error	34	187.862	5.525		
Total	53	1,566.092			

ANOVA for biomass of nursery plants

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	32.487			
Treatment	17	4,672.482	274.852	17.004	0.00000
Error	34	549.586	16.164		
Total	53	5,254.554			

ANOVA for disease incidence of crown gall

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.086			
Treatment	17	4.371	0.257	9.471	0.00000
Error	34	0.923	0.027		
Total	53	5.380			

ANOVA for disease incidence of hairy root

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.247			
Treatment	17	1.886	0.111	2.016	0.04014
Error	34	1.871	0.055		
Total	53	4.005			

ANOVA for per cent survival

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.020			
Treatment	17	0.418	0.025	8.622	0.00000
Error	34	0.097	0.003		
Total	53	0.535			

ANOVA for per cent healthy plants

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.001			
Treatment	17	1.144	0.067	21.819	0.00000
Error	34	0.105	0.003		
Total	53	1.250			

ANOVA for per cent saleable plants

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.440			
Treatment	17	202.137	11.890	27.855	0.00000
Error	34	14.514	0.427		
Total	53	217.091			

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Title of Thesis	**Performance of different apple cultivars grafted on seedling rootstock under nursery condition**
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Major Field	Seed Science and Technology
Minor Field(s)	Fruit Science
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ABSTRACT

The present investigations entitled “Performance of different apple cultivars grafted on seedling rootstock under nursery condition” were carried out at the Experimental Farm of Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry Nauni, Solan HP during 2020-21. The experiment was laid out in Randomised Complete Block Design. Eighteen different apple cultivars were grafted on seedling rootstock under nursery condition and were raised for a season long and various growth parameters like plant height, stock and scion diameter, leaf area, chlorophyll content, root length, biomass, healthy and saleable plants etc. were observed and recorded. Therefore, all eighteen treatments were replicated thrice. Gale Gala cultivar of apple had recorded maximum graft success (95.98 %), survival per cent (98.95 %) and healthy (88.33 %) & saleable plants (78.00 %). Chelan Spur had recorded maximum scion (10.45 mm) and stock diameter (10.85 mm) whereas minimum scion (9.04 mm) and stock diameter (9.47 mm) was recorded in Vista Bella. However Vista Bella also recorded maximum internodal length (3.57 cm) and leaf area (56.23 cm^2). It was observed that Jeromine had maximum biomass (73.33 g) and minimum biomass (40.33 g) was recorded in Super Chief. Red Cap cultivar of apple was found to have maximum root length (26.50 cm) and maximum chlorophyll content (2.78 mg/g). Maximum attack of Crown gall (9.33 %) was recorded in King Roat and minimum (3.33 %) in Redlum Gala. From the experiment conducted it was observed that Redlum Gala had induced larger vegetative growth variables than other cultivars of apple whereas Red Chief had induced the least.

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